ISSN: 2584-0495 **Vol. 2, Issue 3, pp. 692-699**

IJMIT International Journal of Microsystems and IoT

International Journal of Microsystems and IoT

ISSN :(Online) Journal homepage: https://www.ijmit.org

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Cite as: Shukla, A. K., Anjum, N., & Nath, V. (2024). Design and Analysis of All Optical 2 To 4 Line Decoder using 2D Photonic Crystal. International Journal of Microsystems and IoT, 2(3), 692-699. https://doi.org/10.5281/zenodo.11162311

DOI: https://doi.org/10.5281/zenodo.11162311

International Journal of Microsystems and IoT
Vol. 2, Issue 3, pp. 692-699; DOI: https://doi.org/10.5281/zenodo.11162311

Design and Analysis of All Optical 2 To 4 Line Decoder using 2D Photonic Crystal

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ABSTRACT
Optoelectronics and the devices made by this technology are expected to be reliable, faster as they work on the principle of interference phenomenon and waveguides. The crystal lattice which is used is photonic crystal which has specialty based on periodic structure and the interference phenomenon. PHC structures can be one dimensional, two dimensional or three dimensional. Typically, optoelectronics is still ongoing and are used for research purposes. In this work, a 2-to-4-line all-optical logic decoder has been proposed employing two-dimensional photonic crystal (PhC) structure. The decoder works based on the principle of optical interference theory inside PhC waveguides. High- logic states have been produced in conditions of zero input using an optical bias. According to modelling results, the maximum power that can be achieved for an on-state output is about 87%. Maximum contrast ratio is achieved around −10 and insertion loss about −8.8 dB for proposed decoder.

KEYWORDS
Optoelectronics; Crystal lattice; Photonic crystal (PhC); Decoder.

1. INTRODUCTION

In integrated circuits, the density of electronic transistors has increased exponentially in the past 50 years. However, the integration density and operating speed of electronic transistors are presently approaching saturation very quickly. Technologists have recently embraced photonics technology to combat this saturation.

Photonics has recently made a substantial contribution to applications in communication, biomedicine, computer networking, aeronautics, and other fields.

Macro porous materials called photonic crystals have a variety of intriguing characteristics, particularly optical. Photonic crystals can be categorized as one- dimensional (1D), two- dimensional (2D), and three- dimensional (3D) depending on changes in the refractive index and period in space. Discussions of recent developments in photonic crystals have focusedon bandgap/defect engineering. Over the next tenyears, it is anticipated that nano processing technology will advance significantly, and that the development of increasingly dependable and accurate devices will continue. Regarding 2D photonic crystal slabs, significant improvements in Si-based systems and advancementsin integration with electronic circuits are predicted. Combined optical and electrical circuits with capabilities like optical switching, tuning, and delay capability may be expected to make further advancements. It is anticipated that optical components will make up most of these circuits, and that optical/electronic chips will be created.

Without a doubt, the size and power requirements of such devices will be tens to hundreds of times lower than they are now. It is also possible to anticipate advancements in a wide range of applications, such as single-photon light sources, supersensitive sensors, next-generation miniaturized multiwavelength light sources based on the incorporation of active functionality, and supersensitive sensors.

One of the most promising technologies to date is theall-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 lightpropagation in it is governed by its special phenomenon, the photonic bandgap.

It has long been recognized that photonic crystal (PC) structures are the ideal medium for directing and controlling optical waves. Scalability, photonic band gap (PBG), low loss, and cross-connected waveguidesare the primary benefits of PC-based structures for developing optical devices. 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. Thegoal is to reduce their operational power and miniaturize them.

In comparison to traditional waveguide devices, PhC-based optical devices provide several advantages,including power consumption and compactness. Witha 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.

No electromagnetic waves are allowed to propagate inside this frequency range, regardless of the wave polarization or wave vector. For regulating the opticalbeam 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 specificdirection. 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.

Using the optical interference principle, a two- dimensional PhC structure is used to create the Boolean logic decoder. To mimic the characteristics of the device, the finite difference time domain (FDTD) approach [6] has been used. The simulationsinvestigate if the gadget can function at a high bit rate.

Other notable characteristics of this design include its incredibly small footprint, the lack of thresholdpower need, quick response times, operating at ITU- standard optical wavelengths, and ease of use. As a result, it is anticipated that the suggested decoder willprove to be a viable option for upcoming photonic integrated circuits.

2. PREVIOUS WORK

PhCs are man-made structures that are composed of two or more dielectric materials with various refractive indices. The refractive index varies periodically in two dimensions in two dimensional PhCs (2DPhCs) [7]. In addition to having perfectphotonic band gaps (PBG), these PhCs also havesimpler manufacture and design processes than three-dimensional PhCs (3DPhCs). That is why we prefer 2D photonic crystals over 3D photonic crystals. 2DPhCs have demonstrated to offer considerable promise for creating optical devices appropriate for all optical communications.

Researchers have created various PhC-based optical components over the last few decades, including the optical router [8], demultiplexer [9,10], decoder [11],
polarizer [12, 13], coupler [14, 15], logic gates [15– 16], drop filter [17], and others. The all-optical Boolean logic decoder is a significant and difficult device among them. An optical switch, which can regulate output signal by its input and bias signals, is the key component of all-optical decoders.

Recent work has described a few all-optical decodersthat combine non-linearity in the PhC platform. S. Foteinopoulou et al utilized the wave vector diagram formalism to carefully explore a set of refractive phenomena that may occur at the interface of a two- dimensional photonic crystal. Both instances of birefringence and instances of a single propagating beam (moving in either a positive or negative direction) were noted [18]. According to the results, there need not be more than one refracted beam for there to be more than one reflected beam in the medium of incidence. We describe our findings interms of the source of the beam that is propagating andthe type of propagation (left-handed or not). Fourunique situations that result in a negatively refracted beam were found. The definition of phase velocity in a periodic medium is reexamined considering these discoveries, and its physical interpretation is addressed. Recent work has described a few all-opticaldecoders that combine non-linearity in the PhC platform. In the electro-optic sector, Teimoori et al [19].'s demonstration of an optical decoder switch is one example. The device can only function at a maximum data rate of 10 Gbps and a contrast ratio of 7.9 dB, which is insufficient for future generation all-optical PICs, according to their paper. On the other hand, Serajmohammadi et al. [20] have published a 1-to-2-line optical decoder switch based on a nonlinear Kerr effect and a photonic crystal ring resonator, which needs a lot of power to operate. The integrationdensity of PICs is, however, constrained by these undesirable requirements, which include high operating power, long interaction lengths, and large nonlinear coefficients of the matter, and others, despite the existence of alternative approaches [21] fordesigning all-optical decoders in the non-T linear/electro optic domain.

An optical decoder is a switch that has multiple input and output channels for optical circuitry. The optical decoder's incoming logic ports allow for management of the output state. With the help of multi-mode interference and an electro-optical device as their framework, Chen et al. [22] suggested a 2- to 4- decoder switch. electro-optical device as their framework, Chen et al. [22] suggested a 2- to 4- decoder switch.

3. METHODOLOGY

1. *Device design*

The design that has been suggested has four output ports, one bias port, and two optical logic inputs to present an entirely optical 2:4 decoder switch. The switching output of the proposed decoder is depicted in Table 1. The proposed framework is created by Photonic crystal ring structure, and the bias signal is controlled by thesetwo logic input ports to go towards which output port. A PhCRR structure is the fundamental structure that is used to create the suggested optical decoder. A square grid of silicon glass rods of wafer dimensions 25X15 with a refractiveindex of 3.1 in air is used to create the PhCRR. The radius taken of the silicon rods is equal to 0.3a, where a = 825 nm is the lattice constant of the structure.

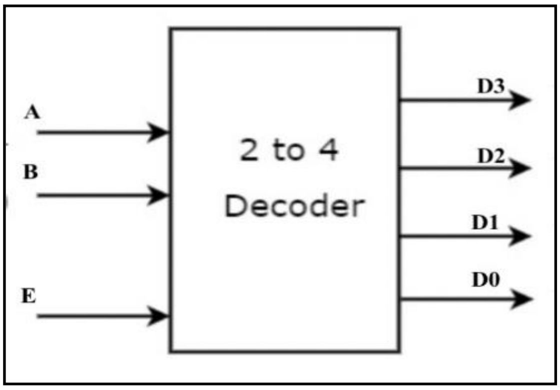

Fig. 1 Schematic Diagram of 2 to 4 decoder

Table 1 Truth Table of 2:4 decoder

A	B	D3	D2	D1	D0	OUTPUT
0	0	0	0	0	1	O1
0	1	0	0	1	0	O2
1	0	0	1	0	0	O3
1	1	1	0	0	0	O4

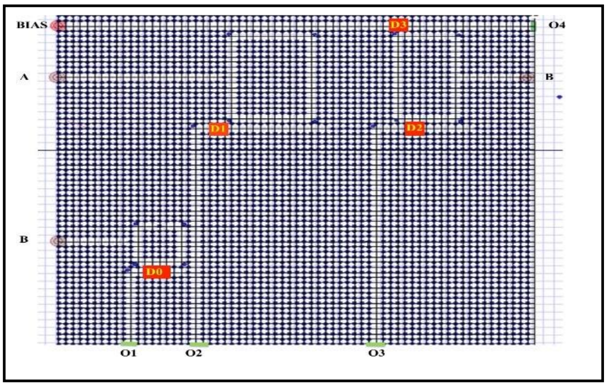

Fig. 2 Proposed 2 to 4 decoder.

The schematic of a combinational 2 to 4 decodercircuit is shown in figure 1 along with its truth Table depicted in Table 1. The central portion of the PhC ring is a square latticed octagon-shaped construction. The central structure's radius and lattice constant are 123 and 465 nm, respectively. The Centre section's radius and lattice constant are distinct from those of the basic structure as shown in figure 2.

The resonant wavelength of this PhCRR is λ=150 nm.It has been demonstrated that the refractive index of the structure affects the resonant wave- length of PhCRRs, and that a small change in the refractive index will cause the structure's wavelength to change.

4. RESULTS AND DISCUSSIONS

The properties of the designed 2 to 4 optical decoder have been explained through PWE bandgap simulation and finite difference time domain-FDTD method, which are thorough and effective techniques when it comes to optical devices which are very smallin size. The proposed 2 to 4 decoder device is operatedin X and Z plane as it is simulated with a 2D photoniccrystal with a Gaussian Modulated Continuous Wave in input. The simulation of the proposed device is analyzed in Transverse electric TE mode and the bandgap of the photonic is shown in fig 3. The band gap has a hexagonal K-vector path with a width which came out to be approximately 0.126, which is large enough to control the passing of the light waveguide.

To show input as low or with the low intensity input power the resonant effect of the crystal ring causesphotonic crystal to work linearly and it eventually results in decrement of the waveguide and subsequentlyfor the working of the device for inputs given as high with greater intensity of power supplied on the input ports the power becomes 1 kW/ μm^2 and for the high power the refractive index increases resulting in changeof the wavelength of the crystal ring and it won’t have any effect on the input waveguide. Decoders are input- controlled toggle switches, so it would be feasible to implement one employing a photonic crystal ring PhCRR whose light field strength is increased by decoder input. Implementation of the bias signal is suchthat if both the inputs A and B are low it would help in simulation with its input state as high.

The functionality of the 2 to 4 decoders designed is evaluated through the normalized power intensities at their outputs. Figure 4 to 7 shows the output of the simulation for the given four cases of input.

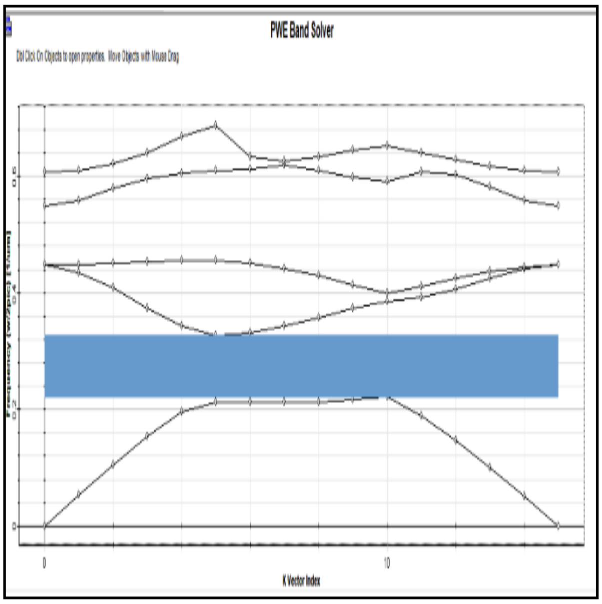

Fig. 3 PBG structure of all-optical decoder for Transverse Electric mode.

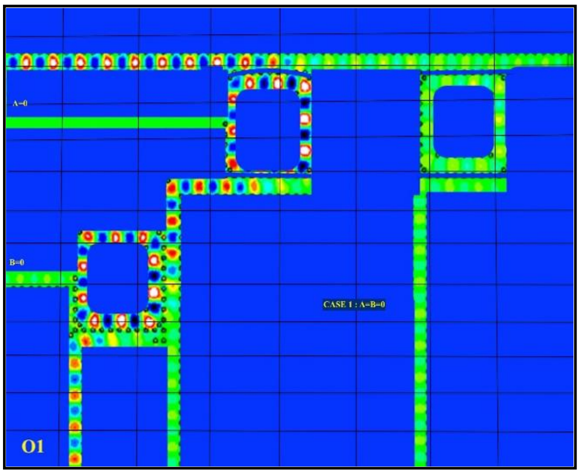

Fig. 4 Output state of device for A=B=0

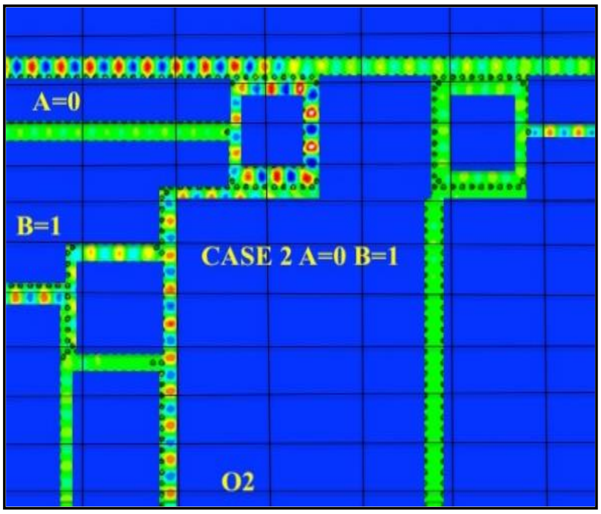

Fig. 5 Output state of the device for A=0, B=1

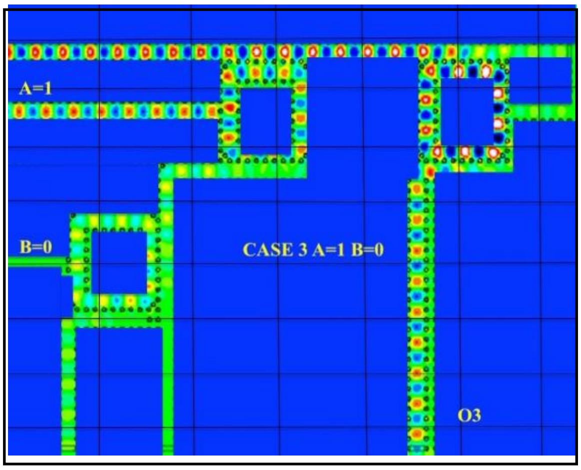

Fig. 6 Output state of the device for A=1, B=0

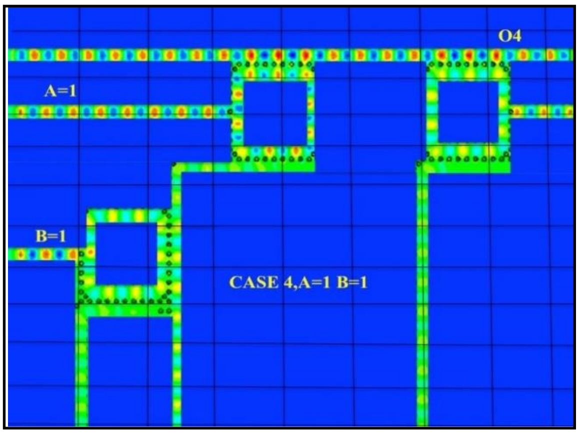

Fig.7 Output state of the device for A=0, B=1

CASE1: A=0, B=0

When both input logic are off the waveguide which is running along with the bias signal will be conveyed through the output port 1 as depicted in figure 4.

CASE 2: A=0, B=1

When one of the logics is low and the other is high i.e. A=0(off), B=1(on) the waveguide is flowed andconveyed through the output port 2 as depicted in figure5.

CASE 3: A=1, B=0

When the point source at input port A is high A=1(on) while on the other side B is low, B=0 (off) then the output is depicted at port 3 as depicted in figure 6.

CASE 4: A=1, B=1

Finally, when both the input is high i.e. A=1 and B=1 the waveguide will show the output at output port 4 as depicted in figure 7.

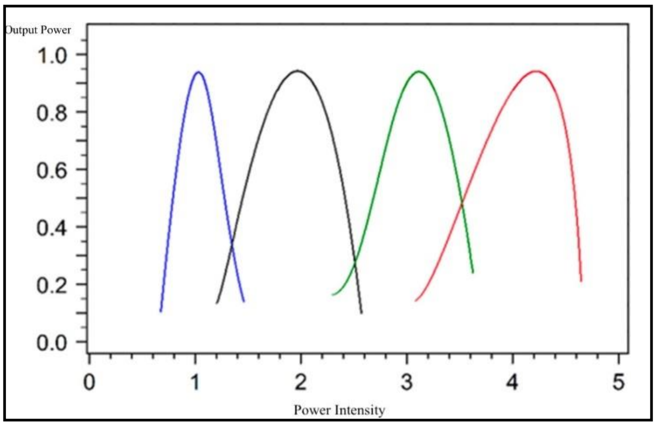

Fig. 8 The output normalized power vs power intensity. Maximum powerintensity observed is 10mW/um^2.

The working of Decoder for different input operation has been verified and observed by varying crystal's refractive index (RI) from 3.1 to 3.4. Figure 8 shows the variation of the output power and power intensity observed during the decoder operation, it has been concluded that maximum flowing of the light amongstthe waveguides is 10mW/µm^2. For the potential states, the normalized powers are provided in addition to the designated logics at ports O0, O1, O2, and O3. The figure shows that the matching outputs for each stage have been significantly expanded, and the decoder's precision is sufficient. The output power levels for each condition have been investigated to assess the performance of the suggested structure more accurately. The findings are shown in Table 2.

Table 2 The absolute power intensities observed for theproposed decoder.

A	B	Absolute Output power at port O1	Absolute Output power at port O2	Absolute Output power at port O3	Absolute Output power at port O4
0	0	87	3	3	2
0	1	3	151	3	2
1	0	3	3	155	3
1	1	3	4	4	239

The findings of the study indicates that the O1 displays 87% of outputs for an input state of case 1 in which both the inputs are low i.e. A=0 and B=0. According to the description of contrast ratio as 10log (P_{low} /P_{high}) [22], the highest contrast ratio of port O1 is attained at a level of approximately -10.7 for each output port. The insertion loss for O1 is approximately 5.5 dB if the insertion loss [23] is defined as equation (1).

$$\frac{10log\times(P_{in}-P_{out})}{P_{in}} \qquad (1)$$

Subsequently, for case 2 in which input 1 is low and input 2 is high i.e. A=0 and B=1 Output port 2 O2 shows maximum power intensity amongst other ports which is 151 and contrast ratio for this case is found to be -10.9 whereas insertion loss is about -8.8dB. On behalf of the third case when input 2 is low and input port 1 is high i.e. A=1 and B=0 output port intensity at port 3 is highest which is 155 and finally for the last case where both the input ports are high A=1 and B=1 the output power intensity obtained is 239. Because the on/off ratio is drastically reduced in these conditions, the insertion loss and contrast ratio are greater [24-25].

A fair comparison to the prior work cannot be made because the previously published works did not disclose the percentage of output power and the on/off ratio. However, this design has greater contrast ratio and reduced insertion loss when compared to the findings of Ref. [22]. Additionally, the findings clearly demonstrate the impressive efficiency a logic decoder is capable of. In contrast to all earlier works, the necessary optical intensity in this piece is lower than the one [26]. It can be said that the primary benefits of the planned structure are its compactness, incredibly quick reaction time, low power consumption, and substantial logic 0 to 1 interval.

Moreover, Table 3 shows the calculated contrast ratio and insertion loss for the proposed 2:4 decoder

Table 3 All optical decoder switching stages for various configurations of logic input lines.

A	B	Output	Contrast Ratio	Insertion Loss
0	0	O1	-10.79	-5.5
0	1	O2	-10.94	-8.8
1	0	O3	-7.7	-5.5
1	1	O4	-3.4	-2.2

5. CONCLUSION

A 2:4 decoder was implemented using opti FDTD. The performance features of an all-optical 2:4 decoder basedon pho- tonic crystal structures were investigated by numerical models such as PWE band gap and the finite difference time domain FDTD. The layout of the device is based on photonic crystal ring resonator it has been implemented using 2D photonic crystal. A square grid of silicon glass rods of wafer dimensions 25X15 with arefractive index of 3.1 in air is used to create the PhCRR. Two input port and one bias signal along with four photonic crystal rings were implemented. One benefit is that, in contrast to earlier works, the structure's size wasreduced to 90 um^2. Additionally, it was estimated that the gaps for logics 0 and 1 differed by about 87%.
According to the findings, it is possible to draw the conclusion that the suggested encoder can be used in optical integrated circuits.

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