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All optical 1 to 2 decoder based on photonic crystal ring resonator

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Abstract: In this paper we combined an optical mixer via photonic crystal ring resonator to propose an all optical 1 to 2 decoder. The main idea used in this paper is based on controlling the optical behavior of the resonant ring via optical power intensity. We know that resonant wavelength of the photonic crystal ring resonator is very sensitive upon the refractive index of dielectric rods, on the other had the refractive index of dielectric materials depend on the optical power intensity. Therefore we can change the resonant wavelength of the resonator by increasing the optical power intensity up to adequate amount. The final structure has two output ports whose working states can be controlled by one input port. When I is OFF, the O_1 port will turn ON and O_2 is OFF, when I is ON, O_1 turns OFF and O_2 turns ON. The proposed structure works completely in optical domain without any electronics.

Key words: Photonic crystal, optical decoder, photonic band gap, Kerr effect.

1. INTRODUCTION

Photonic crystal ring resonators (PhCRRs) are fundamental structures employed for realizing different kinds of all optical devices. A typical PhCRR consists of a resonant ring sandwiched between two parallel waveguides, namely BUS and DROP waveguides [1]. Some works have also reported T-shaped configurations for BUS and DROP waveguides, in which BUS and DROP waveguides will be perpendicular to each other [2]. PhCRR is a wavelength-selective structure,

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which can drop optical waves from BUS to DROP waveguide in a certain wavelength called resonant mode or resonant wavelength [3].
The resonant wavelength of PhCRRs depend on the structural parameters of the ring core such as lattice constant, radius and refractive index of dielectric rods [4–7]. These properties make PhCRRs suitable mechanisms for designing all optical devices such as optical filters [8–10], demultiplexers [11–14], switches and logic gates [15–17].
In order to cope the ever increasing demand for high speed, high bit rate and wide band width communication links, we need to immigrate from current microwave networks toward optical communication networks and systems. For gaining the full advantages of all optical networks and systems we need all optical devices.
Optical decoder is an optical switch with multiple input and multiple output ports, by which one can control 2^N output ports via N input ports. Optical decoder also can be used for converting binary codes into decimal numbers. All optical decoder plays a crucial role in realizing all optical circuits and logic systems used for all optical data processing and all optical communication networks. A 2 to 4 optical decoder has been proposed by Chen et al [18] based on electro optical multimode interference. By combining nonlinear Kerr effect with PhCRRs, two all optical decoders have been proposed [19, 20]. Another PhC based decoder has been proposed by Taem [21], which has been realized by combing a T waveguide and set of Y and T splitters. All the above mentioned structures have important drawbacks which can limit their applications in all optical circuits and systems. As an example the structure proposed in Ref [18], the working mechanism is based on electro-optical interference therefore its function depends in electrical signals which is not acceptable in all optical circuits. The main drawback of the structures proposed in Ref [19,20] is their very high amount of optical power back reflected toward the input ports which originates from their design. In these structures more than 60% of input signal from logic input ports would be reflected toward the input ports which is not acceptable but in this work this back reflection was reduced down to 10%.
In this paper we are going to propose a 1 to 2 all optical decoder. The proposed structure was realized by combining an optical mixer with a PhCRR. In which the switching task is done by employing the nonlinear Kerr effect and refractive index dependency of the PhCRR resonant mode. At the end we can say that reducing the back reflected power toward input ports, representing time delay and crosstalk values are the novelty of the proposed structure.
The rest of the paper is organized as follows: in section 2 we will discuss the design procedure in section 3 we will propose the simulation results and finally in section 4 we concluded from our work.

2. DESIGN PROCEDURE

For designing the proposed structure we employed a square array of dielectric rods immersed in air. The square matrix has 50 and 30 rods in X and Z directions respectively. The material used for dielectric rods is chalcogenide glass whose linear refractive index is 3.1, also its nonlinear Kerr coefficient is $n_2=9*10^{-17}$ m^2/W. The radius of dielectric rods is r=0.215*a, where a is the lattice constant of the fundamental PhC structure.

Before proceeding the deign procedure of the proposed structure we should inspect, whether the fundamental structure has suitable photonic band gap (PBG) according to our goals. For this purpose using plain wave expansion (PWE) method [22] and with the aid of Bandsolve toolbox of RSoft photonic CAD software, the band structure diagram of the fundamental PhC structure was obtained like figure 1. As shown in figure 1 the fundamental structure has 1 PBG region at TM mode, which is at $0.30< a/\lambda< 0.42$ normalized frequency region. By choosing the lattice constant to be a=630 nm the PBG region will be at 1500 nm $<\lambda<$ 2100 nm, which completely covers the third optical communication window in TM mode.

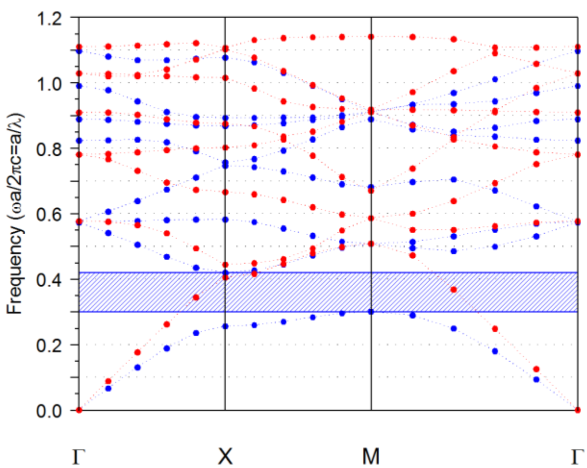


Fig. 1. The band structure diagram of the fundamental photonic crystal structure.

The proposed decoder was realized by combining a PhCRR with an optical mixer. The optical mixer is a sub-structure which can mix optical beams coming from its different input ports. It consists of two input branches, which should have identical lengths, in order to avoid phase difference between the arrived optical beams at the mixing point. At the mixing point, we placed 3 point defects – blue colored rods in figure 2 -. These defects guide the maximum

portion of optical beams toward output branch of the optical mixer. The optical mixer is shown in figure 2.
The second sub-structure of the proposed decoder is the resonant ring, which works as an optical power level comparator. The resonant ring was designed such that it has a resonant mode at λ=1550 nm. It means that at λ=1550 nm the resonant ring will drop the optical waves from BUS into DROP waveguide.

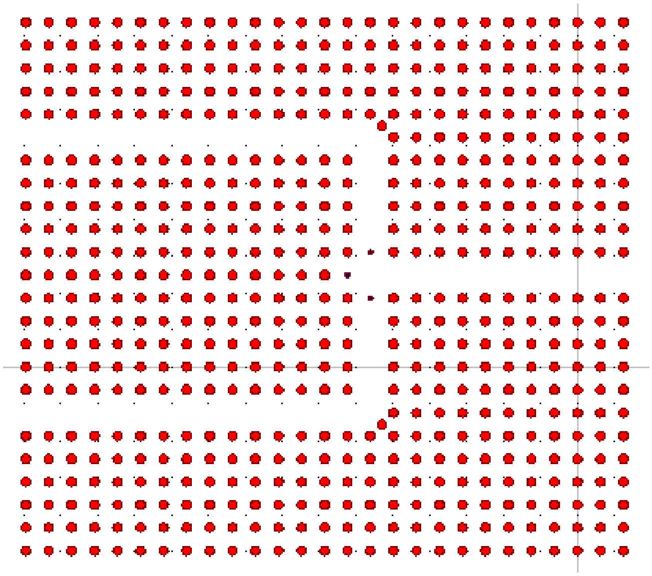


Fig. 2. The optical mixer sub-structure.

It has been shown that the resonant wavelength of the resonant ring depends on the refractive index of the dielectric rods [11, 14]. On the other hand according to the Kerr effect, the refractive index of the dielectric rods depend on the power intensity of the optical waves. As a result increasing the power intensity of the input optical waves will shift the resonant mode of the resonator toward higher wavelengths and causes a mismatch between the input optical beam wavelength and the resonant mode of the resonator. Therefore the resonator could not drop the optical beam into DROP waveguide. The amount of optical power intensity which causes such a wavelength mismatch is called switching threshold that is about 2 KWμm^{-2} for the proposed ring resonator.

The final sketch of the proposed decoder is shown in figure 3. As one can see the proposed decoder has two input ports namely BIAS and I. The BIAS port is for the bias light and port I acts as the control input port of the structure. Also the decoder has two output ports as O_1 and O_2.

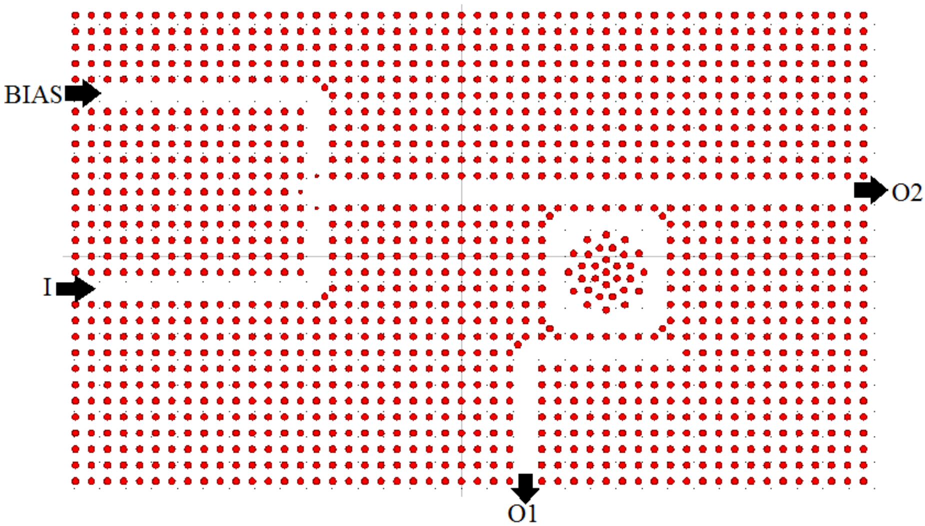


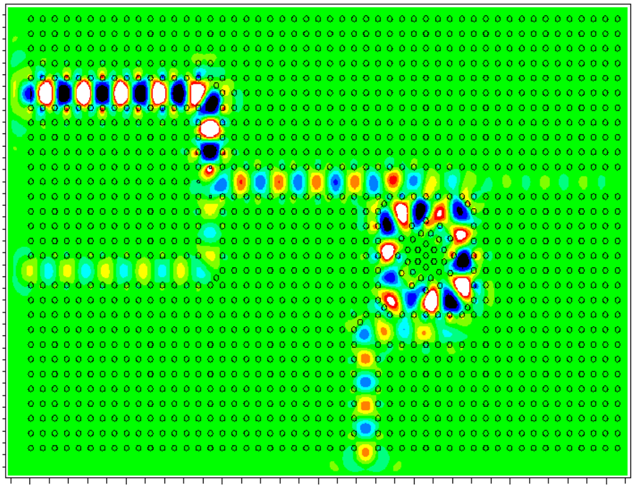
Fig. 3. The final sketch of the proposed optical decoder.

3. Simulation and Results

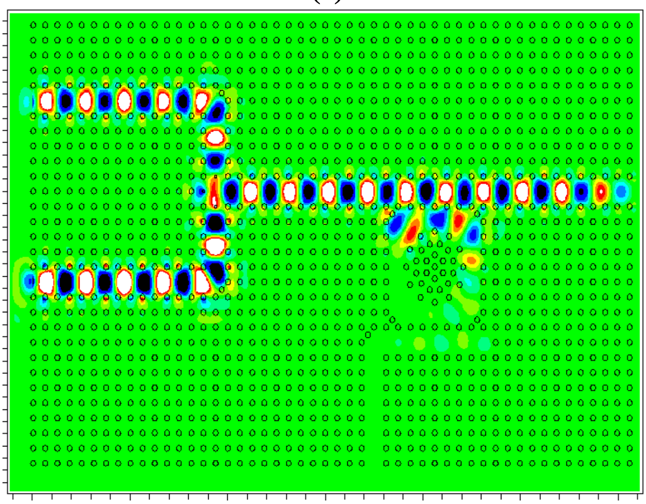
After finalizing the design procedure of the propose decoder we are going to test and study its performance and optical behavior. For this purpose we used finite difference time domain (FDTD) method [23] with the aid of Fullwave toolbox of Rsoft photonic CAD. As we mentioned earlier the proposed structure has two output ports which can be controlled via port I. Therefore the proposed structure has two operational states, in both states the BIAS port should be on, otherwise the working state of the structure will not be valid. We assume that the power intensity and central wavelength of BIAS and I inputs are equal to 1 kWμm^{-2} and 1550 nm respectively. At the following we will discuss the simulation results for the different states of the control inputs.

In the first state port I is OFF and only port BIAS is ON. In this case the optical beam coming from the BIAS port travels toward the resonant ring. The optical power intensity near the resonant ring is less than switching threshold, so the resonant mode of the resonator coincides with the central wavelength of the optical waves and resonator will couple optical beam from the BUS into DROP waveguide. As a result optical beam will reach the O_1 port and turn it ON but the O_2 port will be OFF. Therefore one can summarize that when I is OFF, O_1 is ON and O_2 is OFF.

In the second state I and BIAS both are ON. Both optical beams reach together at the mixing point and due to the identical length of the mixer branches both are in phase, therefore the power intensity will be increased. In this case the optical power intensity near the resonant ring will reach the switching threshold and causes wavelength mismatch between the resonator and optical beams. Consequently the resonator would not drop the optical waves into DROP waveguide and the optical beams would travel toward port O_2 and turn it ON. Therefore one can summarize that when I is ON, O_1 is OFF and O_2 is ON. These states are depicted in figure 4 and summarized in table 1, where 0 and 1 are the representatives for OFF and ON states, respectively.



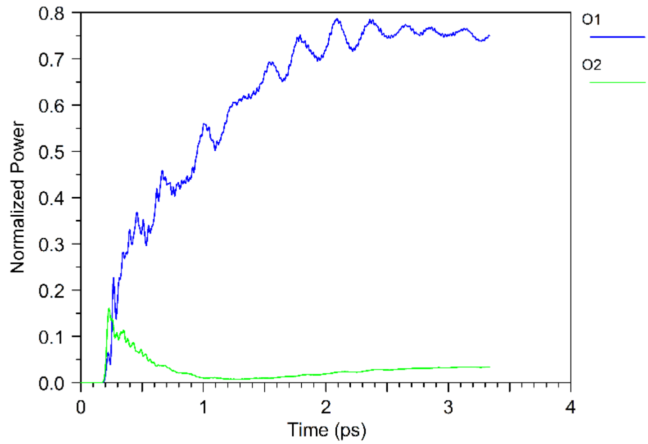
(a)



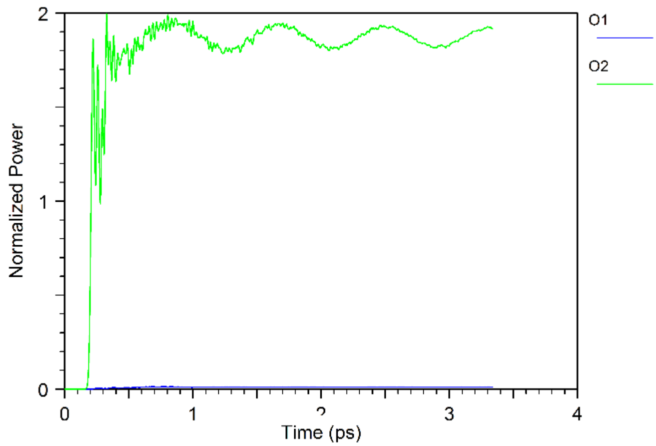
(b)

Fig. 4. Different working sates of the optical decoder (a) I is OFF and (b) I is ON.

Also the time response diagrams of the proposed structure are shown in figure 5. As shown in figure 5(a), when I is OFF, the amount of normalized optical power at O1 and O2 will be about 0.75 and 0.05 respectively. Also the time delay for O1 to reach its final state is about 3ps. Figure 5(b) shows that when I is ON, the amount of normalized optical power at O1 and O2 will be about 0.02 and 1.85 respectively. Also the time delay for O2 to reach its final state is about 1ps. The crosstalk values for O1 and O2 are respectively -24 dB and -40 dB. Finally the amount of the back reflected power toward port I, when I is OFF is shown in figure 6. As shown in figure 6 the amount of normalized power back reflected toward I is about 0.1.



(a)



(b)

Fig. 5. Time response of the proposed decoder when I is (a) OFF, and (b) ON.

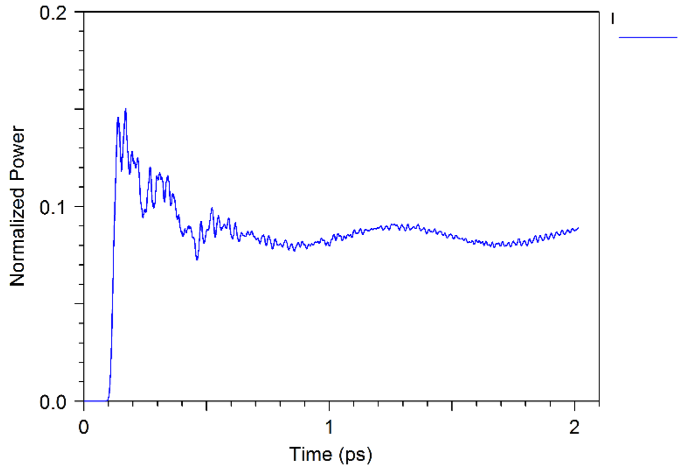


Fig. 6. The amount of back reflected power toward I.

Compared with the structures proposed in Ref [19,20], in this paper by modifying the connection between the resonant ring and input ports we succeeded in reducing the back reflection power down to 10%, which was more than 60% in the previous works proposed in Ref [19,20]. The other difference between this paper and Ref [19,20] is calculating the time delay and crosstalk values. In Ref [19,20] only qualitative results have been presented but in this work we represent the quantitative characteristics of the proposed structure.

Table 1. working states of the decoder switch

I1	O1	O2
0	1	0
1	0	1

4. CONCLUSION

A 1 to 2 all optical decoder has been proposed designed and simulated in this paper. The proposed structure was composed of two main sub-structures. The first sub-structure was an optical mixer employed for combining and mixing the input optical beams. The second sub-structure was a PhCRR which acts as an optical power level comparator. The proposed structure has two output ports, whose working states can be controlled by the input I port. . When I is OFF, the O_1 port will turn ON and O_2 is OFF, when I is ON, O_1 turns OFF and O_2 turns ON. The proposed structure works completely in optical domain without any electronics. The proposed structure can be used in all optical logic circuits and systems suitable for optical processing and optical communication networks.

Also it can be used in optical coding and decoding block of optical systems and in addressing lines of the optical memories.

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