Proposal for all optical comparator using nonlinear PhC-based cavities

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Research Article

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Abstract

In this paper an all optical comparator was designed and simulated. The proposed structure works using nonlinear threshold switching that was implemented by application of nonlinear resonant cavities. X and Y are the input ports of the proposed structure using different combination of these input ports one can control that which bias port can be connected to its corresponding output port. O1 is ON when X is ON and Y is OFF, O2 is ON when Y is ON and X is OFF, and O3 is ON when both X and Y have similar states.

1. Introduction

Increasing bit rate and reducing the time response delay is one of the most important goals defined for system designers and researcher. It has been shown that using optical waves and photons instead of electrons can help us to reach that goal. Therefore recently most researchers dedicated their attempts toward designing the building blocks required for creating optical systems.

For implementing the next generation all optical data processing systems and networks one needs different kinds of logic gates (Goudarzi et al. 2016; Mohebbi et al. 2015; Salmanpour et al. 2015; Shaik and Rangaswamy 2016), and other optical digital circuits (Daghooghi et al. 2019; Haddadan and Soroosh 2018; Zhao et al. 2019). All of the required devices can be designed and realized using photonic crystals (PhCs). Recently, some works have been proposed for designing all optical digital comparators. The first PhC based optical comparator was proposed by Fakouri-Farid et al (Fakouri-Farid and Andalib 2018), using four nonlinear ring resonators. The delay time for this structure is 6 ps. Another PhC based comparator was proposed by Serajmohammadi et al (Serajmohammadi et al. 2019), for which the delay time is 6 ps, too. Surendar et al (Surendar et al. 2019), proposed an optical comparator in which the rise and fall times are 2 and 1.5 ps respectively. Zhu et al presented an optical PhC based comparator and obtained delay times equal to 4 ps.

In this paper a novel structure will be proposed for designing all optical comparator. For this purpose we will use a special optical switch realized using nonlinear resonant cavities. The main goal of the proposed structure is to reduce the rise time.

2. Design Procedure

Optical switches are required for designing any typical logic circuit that works based on threshold switching. For designing the proposed structure a special kind of optical switch is used that was proposed by Hassangholizadeh-Kashtiban et al (Hassangholizadeh-Kashtiban et al. 2020b; Hassangholizadeh-Kashtiban et al. 2020a; Hassangholizadeh-Kashtiban et al. 2019). This special switch is composed of a nonlinear resonant cavity located at the center of two cross connected waveguides. The bandwidth of the cavity in horizontal direction is very less than vertical direction. Therefore it is in horizontal direction its resonant mode is very sensitive upon the variation of refractive index, however in vertical direction refractive index sensitivity is very weak. The central defect of the cavity is made of
doped glass which has a very high Kerr coefficient equal to $10^{-14} \text{m}^2/\text{W}$ (Mehdizadeh et al. 2017; Youssefi et al. 2012). Therefore the optical behavior of the cavity at horizontal direction is very sensitive upon the variation of optical intensity. In other words one can use vertical waveguide to control whether the cavity can drop the optical waves at horizontal direction or not.

The schematic diagram of the proposed comparator is shown at figure 1. Four horizontal and two vertical waveguides are created inside the 2D PhC. Eight nonlinear switches were located at the cross connection points of the horizontal and vertical waveguides. Two groups of optical switches are used; $S_1$, $S_4$, $S_5$ and $S_6$ are the normally open (NO) switches, it means when the vertical port is OFF, these switches cannot pass the optical waves at horizontal directions, otherwise they can pass them at horizontal direction. However $S_2$, $S_3$, $S_7$ and $S_8$ are the normally close (NC) switches, it means when the vertical port is OFF, these switches can pass the optical waves at horizontal directions, otherwise they cannot pass them at horizontal direction. At the proposed structure $B_1$, $B_2$, $B_3$ and $B_4$ are the bias ports, $X$ and $Y$ are the input ports, and $O_1$, $O_2$ and $O_3$ are the output ports (figure 2).

3. Simulation And Results

The working wavelength and the threshold switching of optical switches are 1550 nm and 0.15 W/mm$^2$. Optical Gaussian sources with central wavelength and intensity of 1550 nm and 0.1 W/mm$^2$ were used for launching the proposed structure. Different working states of the proposed optical comparator are discussed at the followings. For all working states all the bias ports are ON.

1st case: both $X$ and $Y$ are OFF, $S_1$ and $S_5$ prevent the propagation of optical waves through $W_1$ and $W_3$ respectively. The optical waves coming from $X$ can pass through $S_3$ and travel toward $S_4$, which does not pass them toward the output port. Both $S_7$ and $S_8$ can pass the optical waves coming from bias port and guide them toward $O_3$. Therefore when $X$ and $Y$ are OFF, only $O_3$ can be ON and the other ports will be OFF (figure 3a). The amount of normalized intensities at the $O_1$, $O_2$ and $O_3$ are 1%, 6% and 93% respectively. The rise time for $O_3$ is 1 ps (figure 3b).

2nd case: $X$ is OFF and $Y$ is ON, similar to the 1st case $S_1$ and $S_5$ prevent the propagation of optical waves through $W_1$ and $W_3$ respectively. The optical waves coming from $X$ can pass through $S_3$ and travel toward $S_4$, which can pass them toward the output port. $S_7$ can pass the optical waves coming from bias port toward $S_8$, but $S_8$ cannot pass them toward the output port. Therefore when $X$ is OFF and $Y$ is ON, only $O_2$ can be ON and the other ports will be OFF (figure 4a). The amount of normalized intensities at the $O_1$, $O_2$ and $O_3$ are 4%, 87% and 9% respectively. The rise time for $O_2$ is 3 ps (figure 4b).

3rd case: $X$ is ON and $Y$ is OFF, the optical waves coming from bias can pass through $S_1$ and $S_2$ and reach $O_1$. But $S_3$ and $S_7$ prevent the propagation of optical waves along $W_2$ and $W_4$ respectively. $S_5$ can pass the optical waves coming from $B_3$ and guide them toward $S_6$, which cannot pass them toward the output port. Therefore when $X$ is ON and $Y$ is OFF, only $O_1$ can be ON and the other ports will be OFF
(figure 5a). The amount of normalized intensities at the O1, O2 and O3 are 88%, 4% and 8% respectively. The rise time for O1 is 3 ps (Figure 5a).

4th case: X and Y are ON; S3 and S7 prevent the propagation of optical waves through W2 and W4 respectively. The optical waves coming from can pass through S1 and travel toward S2, which does not pass them toward the output port. Both S5 and S6 can pass the optical waves coming from bias port and guide them toward O3. Therefore when X and Y are ON, only O3 can be ON and the other ports will be OFF (figure 6a). The amount of normalized intensities at the O1, O2 and O3 are 6%, 4% and 90% respectively. The rise time for O3 is 2 ps (figure 6b).

The simulation results confirmed the correct functionality of the proposed all optical comparator. For the proposed comparator the maximum rise time is about 3 ps and the ON/OFF contrast ratio is about 9.8 dB. This structure has better rise time compared with previous works. The other advantage of this comparator is that the amount normalized intensity for logic 1 for all the output ports are very close to each other and variation is low unlike some previously proposed structures.

4. Conclusion

NO and NC optical switches were designed using nonlinear resonant cavities. Then four NO and Four NC switches were located at the cross connecting points of four horizontal and two vertical waveguides to design an all optical comparator. X and Y are the input ports of the proposed structure using different combination of these input ports one can control that which bias port can be connected to its corresponding output port. O1 is ON when X is ON and Y is OFF, O2 is ON when Y is ON and X is OFF, and O3 is ON when both X and Y have similar states.

Declarations

The author declare that he has no conflict of interests.

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Figures
Figure 1

The schematic diagram of the proposed optical comparator.
Figure 2

The final sketch of the proposed optical comparator.
Figure 3

(a) The optical behavior and (b) time response diagram of the optical comparator when both X and Y are OFF.
Figure 4

(a) The optical behavior and (b) time response diagram of the optical comparator when X is ON and Y is OFF.
Figure 5

(a) The optical behavior and (b) time response diagram of the optical comparator when X is OFF and Y is ON.
(a) The optical behavior and (b) time response diagram of the optical comparator when both X and Y are ON.

Figure 6