

# A novel proposal for ultra-fast all optical half subtractor based on nonlinear ring resonators

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## Research Article

**Keywords:** photonic crystals, nonlinear ring resonators, half subtractor, Kerr effect

**Posted Date:** March 31st, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-359156/v1>

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# Abstract

Optical half subtractors are required for designing any optical computation system. Operation speed and the on/off contrast ratios are very important characteristics for any optical logic device. A novel structure composed of three nonlinear ring resonators and some optical waveguides are used for designing for the proposed half subtractor with improved operation speed and on/off contrast ratio. The simulation results show that the rise time for this structure is 1.5 ps. Also the on/off contrast ratios for B and D are 13.7 dB and 14.5 dB respectively.

## 1. Introduction

The periodic distribution of refractive index inside photonic crystals (PhCs) is the origin for a unique optical property of these artificial structures which is called photonic band gap (PBG) (Liu et al. 2015). Due to PBG, these structures can confine the propagation of optical waves inside PhC-based waveguides (Mirjalili and Mirjalili 2016). A typical optical waveguide can be created by removing a complete row of dielectric rods or air holes.

Besides optical waveguides, one can create optical resonators inside PhCs. PhC-based optical resonators are categorized into two main groups namely resonant cavities (Gupta and Janyani 2014) and ring resonators (Tavousi et al. 2017). These resonators are wavelength selective mechanism which have been used for designing different kinds of optical filters and demultiplexer.

Nonlinear resonators can be realized by using Kerr type materials inside the cavities or ring resonators (Mehdizadeh et al. 2017a). Nonlinear resonators play crucial roles for designing wide range of optical devices like optical digital structures (Abbasi et al. 2012; Zamanian-Dehkordi et al. 2018), which function based on threshold switching that can be implemented using nonlinear resonators.

Optical adders (Jalali-Azizpoor et al. 2018; Jalali and Andalib 2019), subtractors (Moradi 2019) and comparators (Serajmohammadi et al. 2019) are required for creating an all optical computation system. Recently different research teams had proposed different works about designing PhC-based optical subtractors. Moradi (Moradi 2019) employed 3 nonlinear ring resonators for designing an all optical PhC-based half subtractor. Askarian et al (Askarian et al. 2019a) combined beam interference and threshold switching for designing another structure for all optical half subtractor. They also proposed another structure which was designed purely based on optical beam interference mechanism (Askarian et al. 2019b).

In this paper we are going to propose a novel structure suitable for optical half subtractor. The main goal is to improve the operation speed and on/off contrast ratio of the proposed structure. The presented structure will be designed using 3 nonlinear ring resonators.

## 2. Design Procedure

A two dimensional rod type PhC structure composed of 34 rows and 64 columns was used as the fundamental structure for designing the proposed structure. The dielectric rods are made of Silicon whose refractive index is 3.46. Also the radius of these rods and the lattice constant of the fundamental structure are 119 nm and 595 nm respectively. For such a structure there will be a PBG region which can cover the wavelengths between 1400-2000 nm.

Optical threshold switching is the working mechanism of the proposed structure. For implementing optical threshold switching nonlinear resonators are needed. In this work we used nonlinear ring resonators presented in [1]. This nonlinear ring resonators has circular core composed of linear rods similar to fundamental structure. Then some nonlinear rods were arranged around the linear core. These nonlinear rods are made of doped glass for which the linear refractive index and Kerr coefficient are 1.4 and  $10^{-14} \text{ m}^2/\text{W}$  respectively (Mehdizadeh et al. 2017b). For this nonlinear ring resonator the resonant mode and the switching threshold are 1550 nm and  $1 \text{ W}/\text{mm}^2$ .

For designing the propose structure first of all four optical waveguides were created by removing 66, 49, 35 and 13 rods in horizontal direction respectively. These waveguides were labeled as W1, W2, W3 and W4 respectively. Then three nonlinear rods were located near these waveguides such W1, W2 and W3 are the bus waveguides for R1, R2 and R3. W5 and W6 were created as the drop waveguides for R1 and R2 respectively, which were joined together to create the output waveguide labeled as W7. Finally W8 was created as the drop waveguide for R3 which works as the other output waveguide of the proposed structure. The front sides of W1 and W3 were connected to X. Also the front sides of W2 and W4 were connected to Y. The end sides of W7 and W8 were connected to D and B respectively. Where X and Y are the input ports. Also D and B are the output ports of the proposed structure as shown at figure 1.

### 3. Simulation And Results

The final step after designing the propose structure is to test its functionality. This can be done by simulating the proposed structure and obtaining its optical behavior. For this purpose Gaussian optical waves with wavelength and optical intensity of 1550 nm and  $1 \text{ W}/\text{mm}^2$  were used respectively. The simulation results are as follows:

It is obvious that when both input ports are OFF (i.e.  $X=Y=0$ ), there is no optical waves inside the structure therefore both output ports will be OFF. When X is OFF and Y is ON (i.e.  $X=0, Y=1$ ), the optical waves coming from Y enter W2 and W4. As mentioned W2 is the bus waveguide for R2, and R2 can drop these waves into W6 and guide them toward W7 and D. But R3 cannot drop the optical waves from W4 because W4 is not the bus waveguide for R3. As a result in this case B is OFF and D is ON (figure 2a). When X is ON and Y is OFF (i.e.  $X=1, Y=0$ ), the optical waves coming from X enter W1 and W3 which are the bus waveguides for R1 and R3. Therefore both R1 and R2 can drop these optical waves into W5 and W8 and guide them toward the output ports. As a result in this case both output ports are ON (figure 2b). When both X and Y are ON ( $X=Y=1$ ), in this case there are two sets of optical waves near each resonant ring. High amount of optical intensity near the resonant rings shifts their resonant mode so none of these rings

can drop the optical waves and no optical waves can reach the output ports. As a result both output ports are OFF. These results prove that the proposed structure can work as an optical half subtractor.

We also calculated the output diagrams of the propose structure. As shown at figure 3a, when X is OFF and Y is ON the amount of normalized intensity at B and D ports are 2% and 84% respectively. Also the rise time for D is about 1.5 ps. Figure 3b shows that when X is ON and Y is OFF the amount of normalized intensity at B and D ports are 94% and 88% respectively. Also the rise times for B and D are about 1ps and 1.5 ps respectively. And finally when both X and Y are ON the amount of normalized intensity at B and D are 4% and 3% respectively (figure 3c). The on/off contrast ratio for B and D are 13.7 dB and 14.5 dB respectively.

## 4. Conclusion

Three nonlinear ring resonators combined with some optical waveguides were used for designing an all optical half subtractor based on PhCs. The working mechanism of the proposed structure is based on nonlinear threshold switching. For this structure the maximum rise time is 1.5 ps. Also the on/off contrast ratio for B and D are 13.7 dB and 14.5 dB respectively.

## Declarations

All the authors declare that none of us have no conflict of interests.

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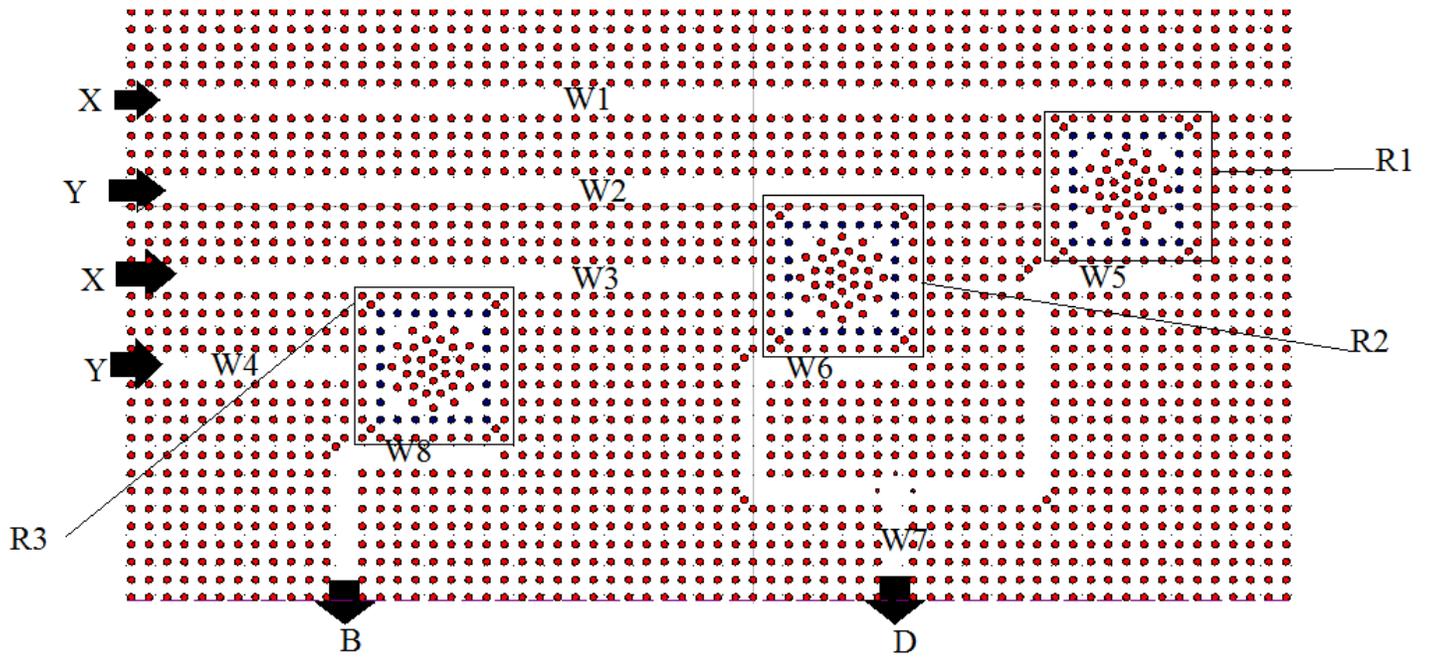
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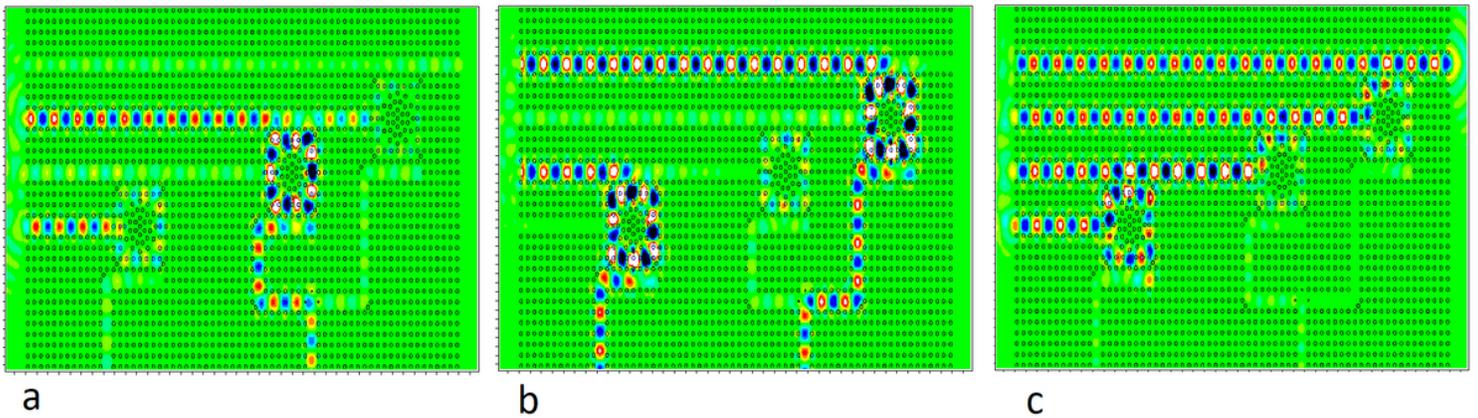
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## Figures



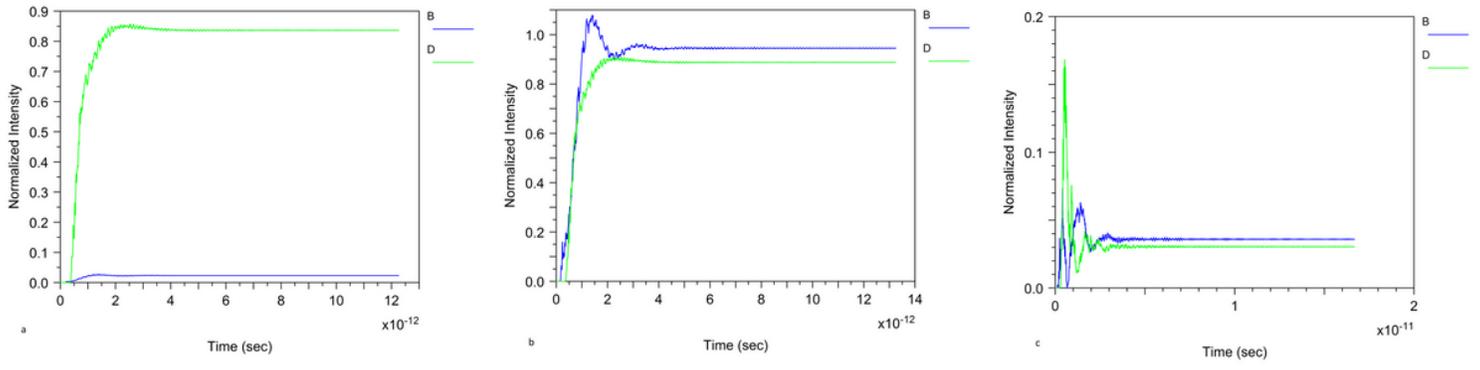
**Figure 1**

all optical half subtractor.



**Figure 2**

The optical behavior of the proposed structure.



**Figure 3**

the output diagrams of the proposed structure.