# A novel proposal for all optical amplitude shift keying demodulator using photonic crystal based nonlinear ring resonators

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In this paper a new structure was proposed for designing an all optical amplitude shift keying demodulator. The proposed structure was designed using nonlinear ring resonators inside photonic crystal platform. The nonlinear ring resonators were created by adding doped glass rods inside the ring. When the optical intensity of the input signal is 1, 7, 14 and 21 W/mm2 the proposed structure can generate 00, 01, 10 and 11 codes at the output ports. The structure has maximum delay time of 3 ps.

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*Keywords:* Photonic crystal, ASK demodulator, Nonlinear ring resonator, Kerr effect

## 1. Introduction

Currently photonic crystals (PhCs) [1,2] are one the promising structures that can be used as the fundamental structures for designing optical devices [3–5]. PhCs can be created using periodic arrangement of two or more dielectric materials with different refractive indices. This periodic refractive index variation inside these structures results in photonic band gaps [6–8], which the key to control optical waves inside these structures [9]. Therefore PhCs can be used for designing all optical devices [10–14].

Adding Kerr effect to the PhC based structures is a common way for implementing optical threshold switching [15–17]. Threshold switching is very important for designing optical logic devices like optical gates [18–24], decoders [25–29], encoders [30–35], adders [36–39], multiplexers [40], comparators [16,41,42], subtractors [43,44] etc. An optical threshold switching mechanism can be implemented by using nonlinear ring resonators [45,46] or nonlinear cavities [47,48] that are created by adding nonlinear materials inside a ring resonator [12,49,50] or resonant cavity [51].

Optical demodulators are required for realizing modulation techniques in optical communication systems and networks. Amplitude shift keying (ASK) is one of the digital modulation techniques in which optical digital codes can be sent by choosing different amplitudes for the optical carrier signal. The optical ASK demodulators required at the receiver end of the optical link to create the digital code based on the amplitude of the received carrier signal. Karimzadeh and Andalib [52] had proposed the only PhC based optical demodulator. Their proposed structure is an optical binary phase shift keying demodulator which works based on constructive or destructive interference of optical waves.

In this paper we are going to proposed a novel structure for all optical ASK demodulator using nonlinear PhC ring resonators (PhCRRs). The proposed structure should be capable of generating a 2-bit code based on the four different amplitude of the optical signal received at the input port.

Finite difference time domain method with the help of RSOFT photonics CAD will be used for designing and simulating the proposed structure. In this method the output spectra and optical field patterns at the different points of the structure will be calculated by solving the Maxwell equations. Choosing appropriate step sizes for position and time is very important in obtaining accurate results.

## 2. Nonlinear PhCRR

As mentioned the proposed structure for realizing the optical demodulator will be designed using nonlinear PhCRR. The easiest way to create a nonlinear PhCRR is to add some nonlinear rods around the core section of the resonant ring [40]. A 25*25 array of dielectric rods in air background was used to create the basic platform for the nonlinear ring resonator. For the basic platform the refractive index, radius and lattice constant of the rods are 3.46, 126 nm and 631 nm respectively. The nonlinear ring resonator was sandwiched between to waveguides. The blue colored rods located around the core section are the nonlinear rods whose linear refractive index and Kerr coefficient are 1.4 and $10^{-14}$ $m^2/W$ respectively (Fig. 1).

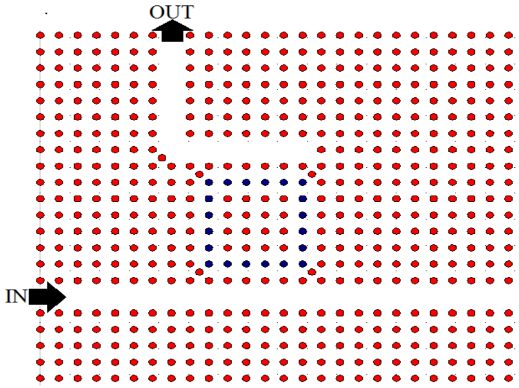


*Fig. 1. The nonlinear PhCRR (color online)*

The radius of the nonlinear rods are very important for controlling the switching threshold of the proposed nonlinear resonator. For designing the proposed structure we need at least 3 nonlinear resonators with different switching thresholds. Fig. 2, shows the switching threshold versus R1, where R1 is the radius of nonlinear rods. It shows that when R1 is 126, 115 and 106 nm the switching threshold of the nonlinear ring will be 7, 14 and 21 W/μm$^2$ respectively. Fig. 3 shows the output diagram of the nonlinear ring resonator for three different values of r1. This figure also proves that the switching threshold values of the nonlinear resonator are 7, 14 and 21 W/μm$^2$ when the radius of nonlinear rods are 126, 115 and 106 nm respectively.

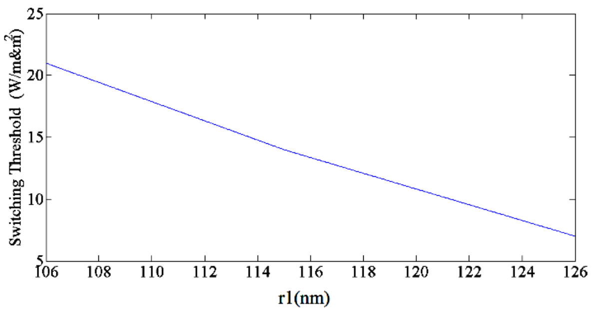


*Fig. 2. The variation of the switching threshold of the nonlinear PhCRR versus r1*

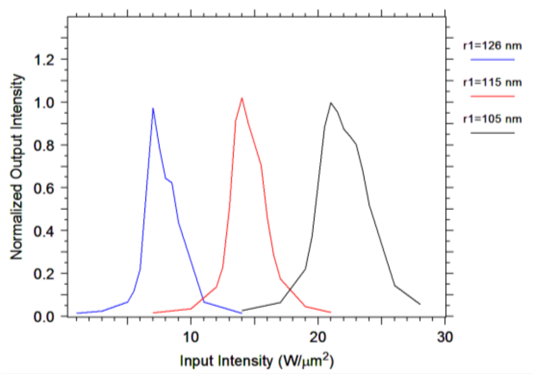


*Fig. 3. The output diagram of the nonlinear PhCRR for different values of r1 (color online)*

### 3. Optical ASK demodulator

For designing the final structure a 51*51 array of dielectric rods were used as the basic platform. All the structural parameters are as the same as the previous section. The proposed structure consists of three main parts: an input waveguide, four nonlinear ring resonators and the output ports. The input waveguide where created by removing a complete row of dielectric rods from the center of the basic platform. Then four nonlinear ring resonators were located above and beneath the input waveguide. These nonlinear ring resonators were labeled as R1, R2, R3 and R4. The radius of nonlinear rods for R1 and R2 are 126 and 115 nm respectively. But R3 and R4 have the same values for the radius of nonlinear rods which is about 106 nm. According to the information provided in Figs. 2 and 3, R1 and R2 should drop the optical waves when the input intensity is 7 and 14 W/μm$^2$ respectively. Also R3 and R4 can drop the optical waves simultaneously when the optical intensity is 21 W/μm$^2$. Then corresponding to any of the resonators we created a drop waveguide. These waveguides are labeled W2, W3, W4 and W5. W2 and W3 join together and create the W6 output waveguide. Similarly W4 and W5 join together to create the W7 output waveguide. In the proposed structure I is the input and O0 and O1 are the output ports of the structure (Fig. 4).

The simulation result for the proposed structure when the wavelength of the input signals is 1550 nm for four different values of optical intensities are shown in figure 5. When the optical intensity is 1 W/mm2 none of the nonlinear resonators can drop the optical waves into their corresponding drop waveguides. Therefore the optical waves cannot reach the output ports and exit the structure from the end side of the input waveguide. In this case both output ports are OFF and the output code is 00.

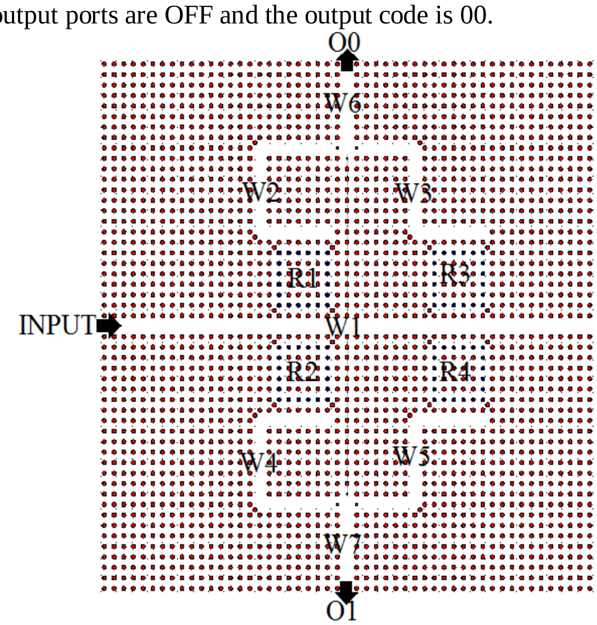


*Fig. 4. The proposed optical ASK demodulator (color online)*

When the optical intensity of the input signal is 7 W/μm$^2$, R1 drops the optical waves into W2. These optical waves can reach O0 port through W2 and W6, however no optical waves can reach O1. Therefore in this case O0 is ON but O1 is OFF and the generated code will be 01. When the optical intensity of the input signal is 14 W/mm2, R2 drops the optical waves into W4. These optical waves can reach O1 port through W4 and W7, however no optical waves can reach O0. Therefore in this case O0 is OFF but O1 is ON and the generated code will be 10.

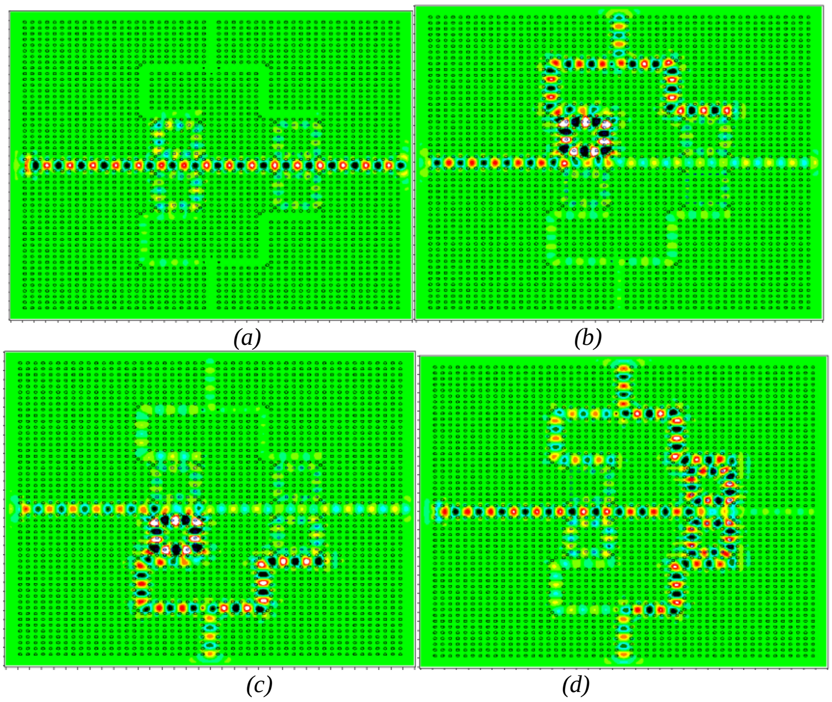


*Fig. 5. The optical behavior of the proposed ASK demodulator when the input intensity is (a) 1 W/μm$^2$, (b) 7 W/μm$^2$, (c) 14 W/μm$^2$ and (d) 21 W/μm$^2$ (color online)*

Finally when the input signal has optical intensity as much as 21 W/μm$^2$, R3 and R4 simultaneously drop the optical waves into W3 and W5 respectively. These optical waves can reach O0 and O1 ports. Therefore in this case both O0 and O1 will be ON and the generated code will be 11.

As shown in Fig. 5, the proposed structure can create four 2-bit binary codes for the different values of the input signal optical intensity. Therefore one can conclude that the proposed structure is suitable to be used as an all optical ASK demodulator. Besides the time response diagram of the proposed structure for different amplitudes of the input signal are shown in Fig. 6.

As shown when the input intensity is 1 W/mm2, the amount of normalized intensity at both O0 and O1 are less than 5%. For the second case in which the optical intensity of the input signal is 7 W/μm$^2$, the amount of normalized optical intensity at O0 and O1 are 90% and less than 5% respectively. The time delay for the O1 port is about 3 ps. When the input signal has optical intensity of 14 W/μm$^2$, the amount of normalized optical intensity at O0 and O1 are 5% and 91% respectively. The time delay for the O1 port is about 2 ps. Finally when the optical intensity of the input signal is 21 W/μm$^2$, the amount of normalized optical intensity at O0 and O1 are 45% and 44% respectively. The time delay for both of them is 2.5 ps.

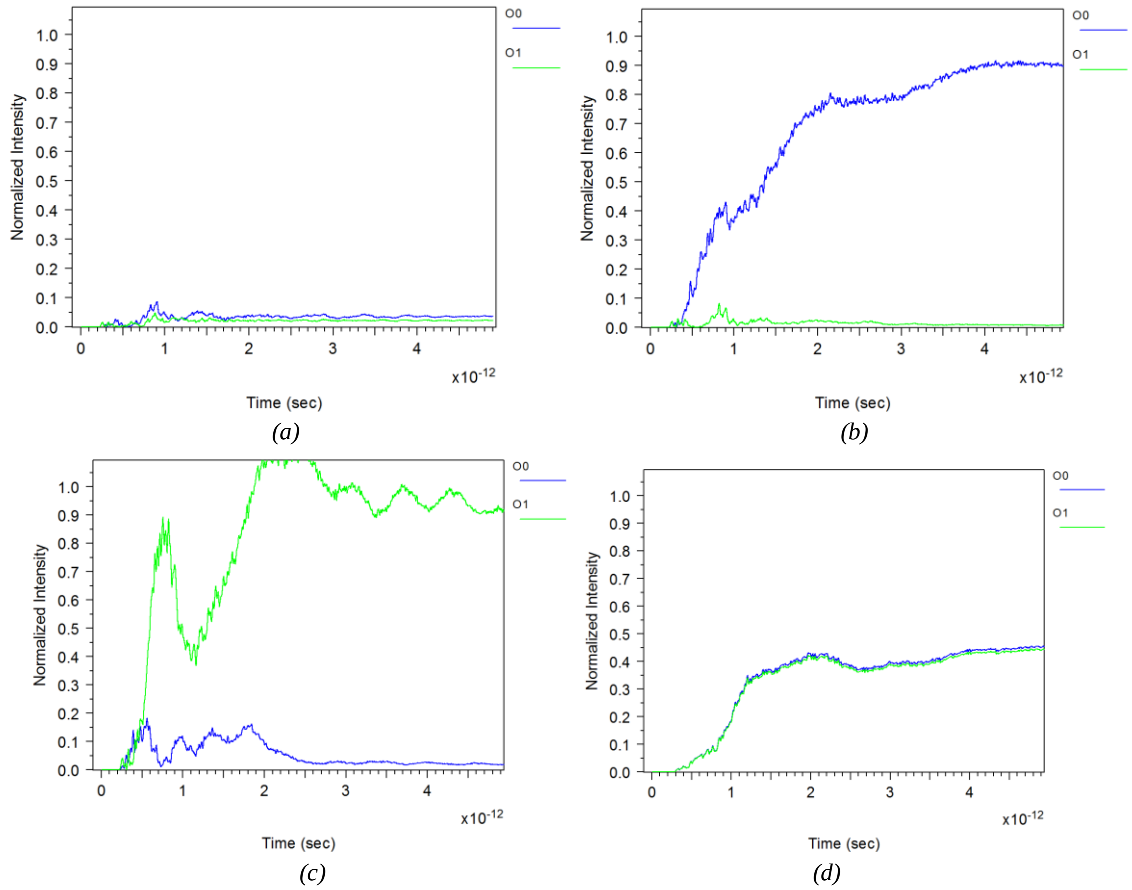


*Fig. 6. The output diagram of the proposed ASK demodulator when the input intensity is (a) 1 W/$\mu$m$^2$, (b) 7 W/$\mu$m$^2$, (c) 14 W/$\mu$m$^2$ and (d) 21 W/$\mu$m$^2$ (color online)*

## 4. Conclusion

Four nonlinear PhCRRs were used for designing an all optical ASK demodulator. The resonators were designed such that they have different switching thresholds. This was done using the radius of nonlinear rods. The finals structure can generate 00, 01, 10 and 11 code when the optical intensity of the input signal is 1, 7, 14 and 21 W/mm2. The maximum delay time of the structure is 3 ps.

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