A novel proposal for all optical amplitude shift keying demodulator using photonic crystal based nonlinear resonant cavities

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In this paper a new structure was designed for realizing an all optical amplitude shift keying demodulator. Firstly a nonlinear optical demultiplexer was designed using four nonlinear resonant cavities, which were created by adding doped glass rods inside the cavity. Then the final structure was created by properly connecting the end sides of the output waveguides of the nonlinear demultiplexer. When the optical intensity of the input signal is 1, 2, 3 and 4 W/μm^2 the proposed structure can generate 00, 01, 10 and 11 codes at the output ports. The structure has maximum delay time of 11 ps.

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Keywords: Photonic Crystal, ASK demodulator, Nonlinear resonant cavity, Kerr effect

1. Introduction

Considering current trends in communication industry, which has convinced most of the researchers that conventional electronic based systems and networks cannot cope the ever increasing bandwidth and processing speed requirements [1]. Therefore a faster solution with high bandwidth is required to be replaced with electronics. It has been shown that currently the best choice is using optical waves and photons instead of electrons and electronics [1]. It has been proven that optical waves and photons can be used for carrying data like electrons but with more speeds and bandwidths.

Photonic crystals (PhCs) [2,3] are one of the promising candidates that can be used for controlling optical waves and photons. A typical PhC can be realized by periodic arrangement of dielectric rods or layers in one, two or three dimensions [4,5]. The main result of periodicity of refractive index in PhCs is photonic band gap (PBG) [6,7]. PBG make them capable of controlling the propagation of optical waves and photons [8]. By imposing suitable defects inside the periodic structure one can create optical waveguides [8], resonant cavities [9–12] or ring resonators [13–19]. It has been shown that a large variety of optical devices can be created simply by properly combining optical waveguides and resonators [20–24].

In digital communications the data and information are delivered in from of digital codes. Amplitude shift keying (ASK) is a digital modulation technique in which optical digital codes can be sent by using different amplitudes for the optical carrier signal. When the codes are sent by means of different amplitudes and optical ASK demodulator is required to translate these amplitudes into digital codes. Recently an all optical PhC-based phase shift keying demodulator was proposed by Karimzadeh and Andalib [25]. The proposed structure is capable of generating 1-bit codes based on the initial phase of the input optical signal. The working principle of the proposed structure is based on constructive and destructive interference of optical beams.

Both analog to digital converters and amplitude shift keying demodulators generate digital binary codes. The Difference is at the type of their input signals. For the analog to digital converters the input signal is an analog continues signal, but for ASK demodulators the input signal is a digital discrete signal.

In this paper we are going to design and propose a 2-bit all optical ASK demodulator using nonlinear resonant cavities inside 2D PhCs. Nonlinear resonators that can be created by adding Ker type materials inside the cavities [26,27] or rings [28] are very popular for designing optical digital devices like logic gates [29–32], decoders [33–36], adders [37–40], comparators [41–43], multiplexers [44] and etc.

2. Nonlinear optical demultiplexer

A nonlinear optical demultiplexer is required to separate different optical amplitudes from each other. For a 2-bit optical ASK demodulator four different levels of optical amplitudes should be separated, this can done using a 3-channel nonlinear optical demultiplexer. The required nonlinear optical demultiplexer was designed using a 31*31 2D PhC consisted of Silicon rods surrounded by air. The radius of the rods and the lattice constant of the structure are 102 nm and 508 nm respectively. Nonlinear cavities are used as the wavelength selecting section of the structure. These nonlinear rods are consisted of two nonlinear rods. The nonlinear rods are made of doped glass, whose linear refractive index and Kerr coefficient are 1.4 and 10^{-14} m^2/W respectively [45].

For designing the required demultiplexer we used four nonlinear cavities. The radius of nonlinear rods for C1, C2, C3 and C4 cavities are 80, 75, 70 nm and 70 nm respectively. As shown C3 and C4 are the same, therefore their resonant modes are exactly the same. The proposed nonlinear optical demultiplexer is shown at Fig. 1. The output spectra of the proposed nonlinear optical demultiplexer for different values of input optical intensities are shown at Fig. 2. In these diagrams one can see three curves instead of four, because the resonant mode of C3 and C4 are the same, therefore their curves have complete overlap with each other.

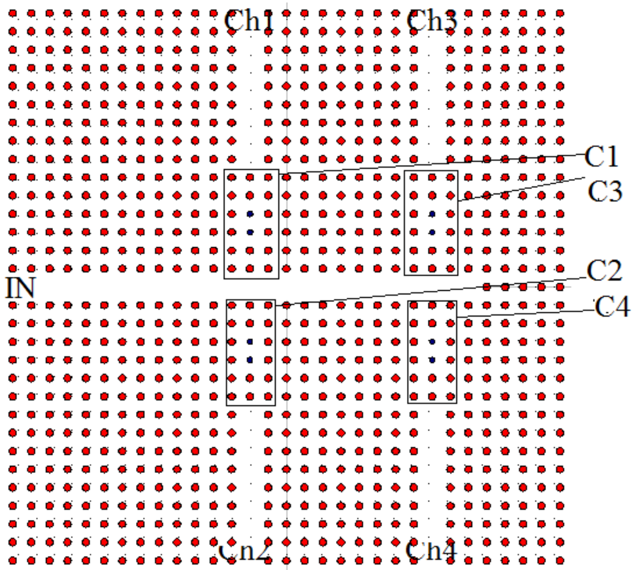


Fig. 1. The nonlinear demultiplexer (color online)

As shown at Fig. 2a, when the optical intensity of the input signal is 1 W/μm^2, the resonant mode of C1, C2 and C3/C4 cavities are at 1547 nm, 1544 nm and 1541 nm respectively. It means none of the resonant cavities can drop the optical waves with central wavelength of 1550 nm (Fig. 3a). When the optical intensity the input signal is 2 W/μm^2, the resonant mode of C1, C2 and C3/C4 cavities are at 1550 nm, 1547 nm and 1544 nm respectively (Fig. 2b). Therefore in this case C1 can drop the optical waves with central wavelength of 1550 nm, because its resonant mode coincides with the central wavelength of the input signals (Fig. 3b). When the optical intensity the input signal is 3 W/μm^2, the resonant mode of C1, C2 and C3/C4 cavities are at 1553 nm, 1550 nm and 1547 nm respectively (Fig. 2c). Therefore in this case C2 can drop the optical waves with central wavelength of 1550 nm, because its resonant mode coincides with the central wavelength of the input signals (Fig. 3c). Finally when the optical intensity the input signal is 4 W/μm^2, the resonant mode of C1, C2 and C3/C4 cavities are at 1556 nm, 1553 nm and 1550 nm respectively (Fig. 2d). Therefore in this case C3 and C4 can drop the optical waves with central wavelength of 1550 nm, because their resonant mode coincides with the central wavelength of the input signals (Fig. 3d). The normalized transmission efficiency of C3 and C4 are about 50% because the input power was divided into two parts.

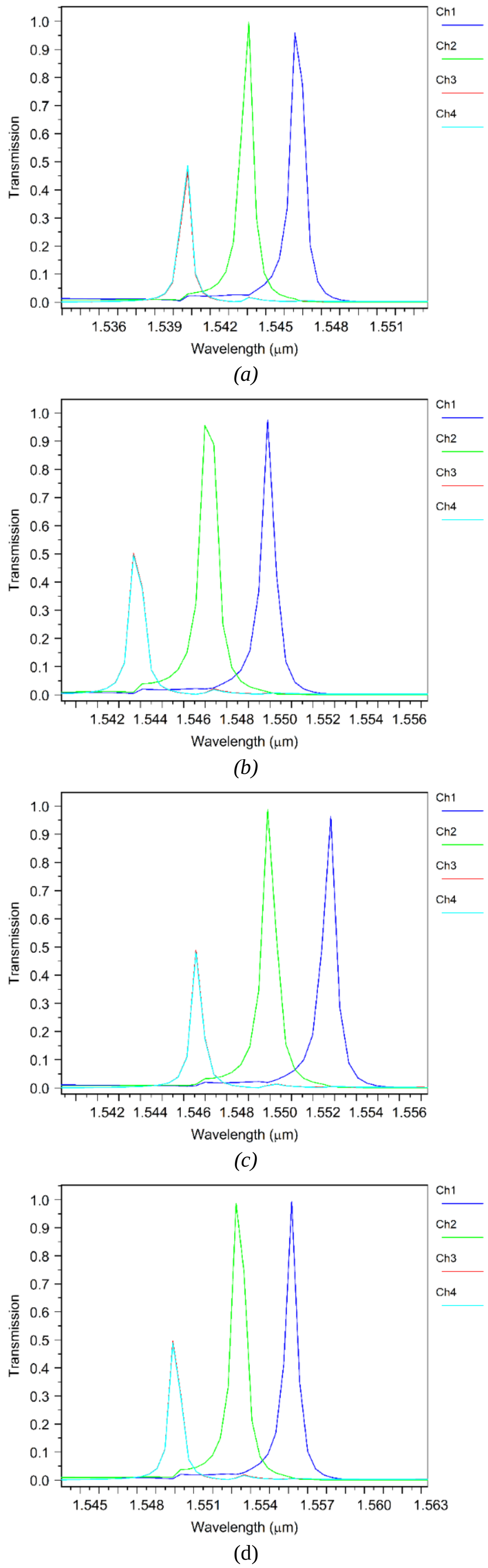
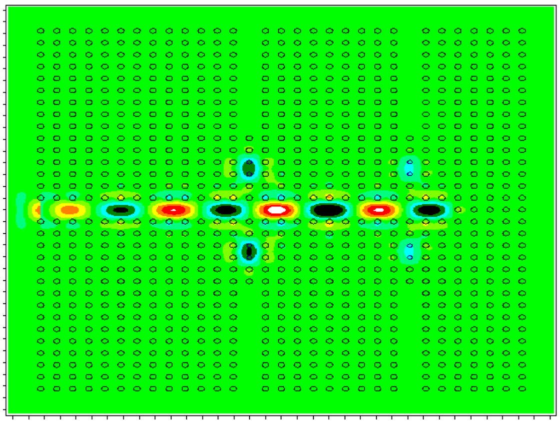
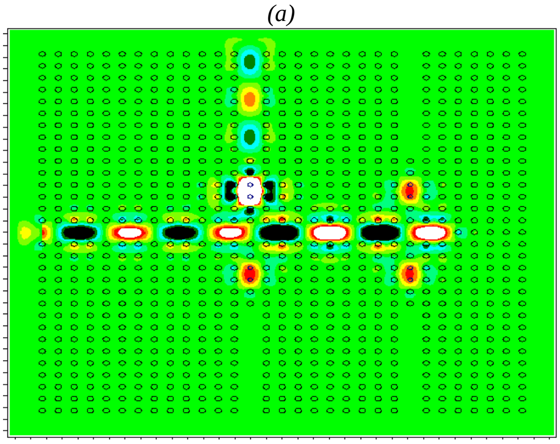


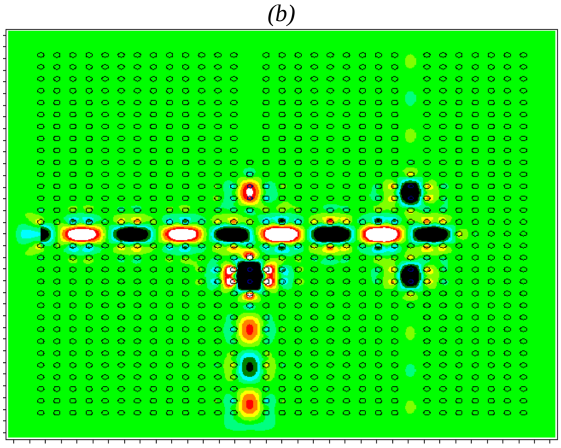
Fig. 2. The output spectra of the nonlinear demultiplexer for different optical intensities (color online)



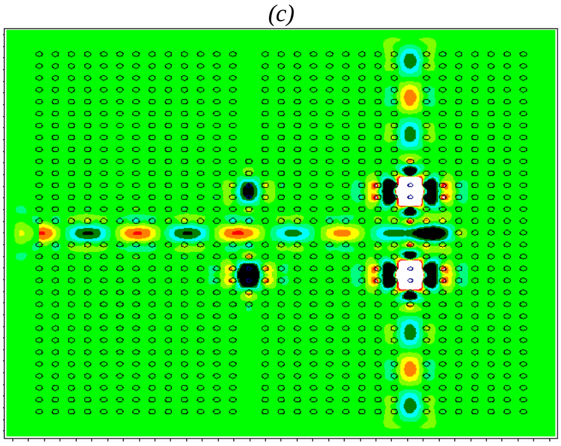
(a)



(b)



(c)



(d)

Fig. 3. The optical behavior of the nonlinear demultiplexer for different optical intensities (color online)

3. All optical ASK demodulator

After designing and obtaining proper functionality of the nonlinear optical demultiplexer as the first and the main stage of the demodulator, we designed and implemented the final structure for the optical ASK demodulator. The finals structure was realized inside the 2D PhC structure composed of 51 rows and 31 columns of Silicon rods with square lattice. All the structural parameters are the same as the nonlinear optical demultiplexer. As we know a typical 2-bit demodulator has 2 output ports. The most significant bit (MSB) output should be ON when the optical intensity of the input signal is 3 or 4 W/μm^2. And the least significant bit (LSB) bit should be ON when the optical intensity of the input signal is 2 or 4. In order to implement such a functionality we connected the end sides of C1 and C3 output waveguides to the LSB output port, labeled as O1 and similarly connected the end sides of C2 and C4 output waveguides to the MSB output port, labeled as O2. The final structure is shown at Fig. 4.

The proposed structure was simulated for four different values of optical intensities using optical signals with central wavelengths of 1550 nm. The distribution of optical fields and the time response diagrams of the final structure were obtained using finite difference time domain methods. As discussed in the previous section when the optical intensity of the input signal is 1 W/μm^2, none of the resonant cavities can drop the optical waves because their resonant modes don't match with the central wavelength of the input signal. Therefore as shown in Fig. 5 no optical waves can reach the output ports and both of them will remain OFF and the amount of normalized power at both of the output ports is less than 1%.

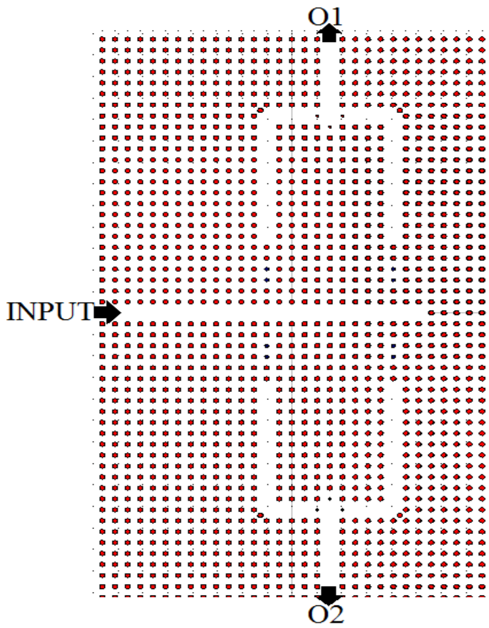
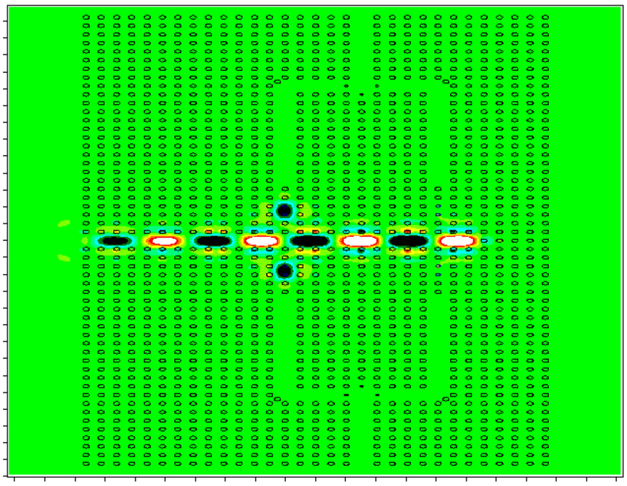
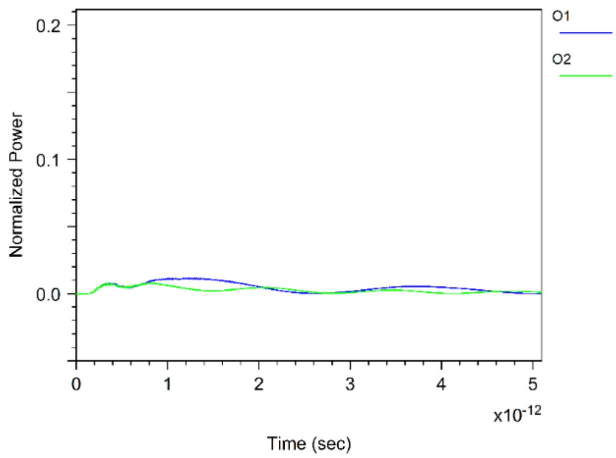


Fig. 4. The optical ASK demodulator (color online)

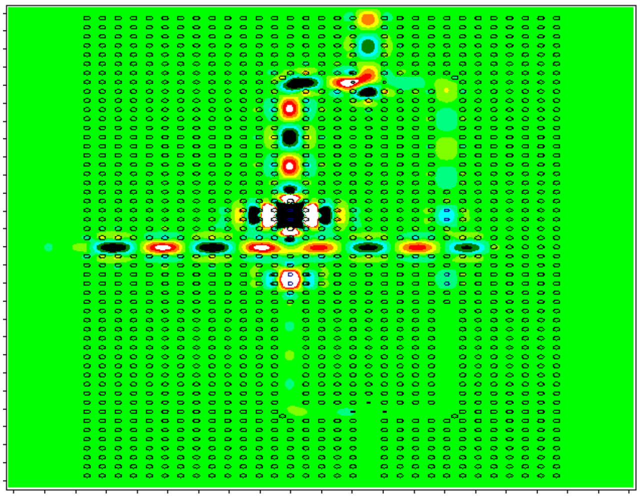


(a)

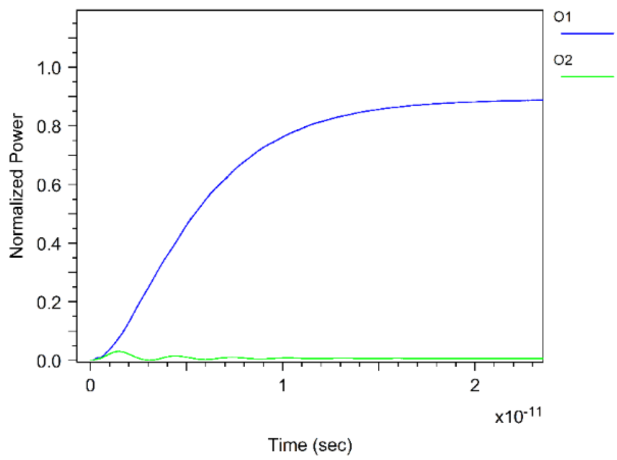


(b)

Fig. 5. (a) The optical behavior and (b) the time response of the ASK demodulator when the input intensity is 1 W/μm^2 (color online)



(a)

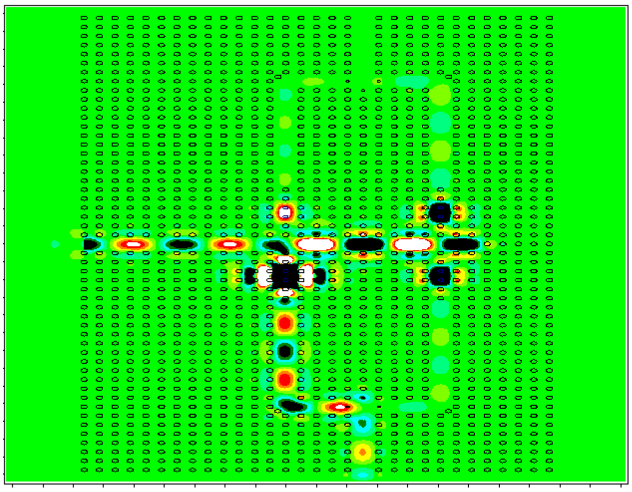


(b)

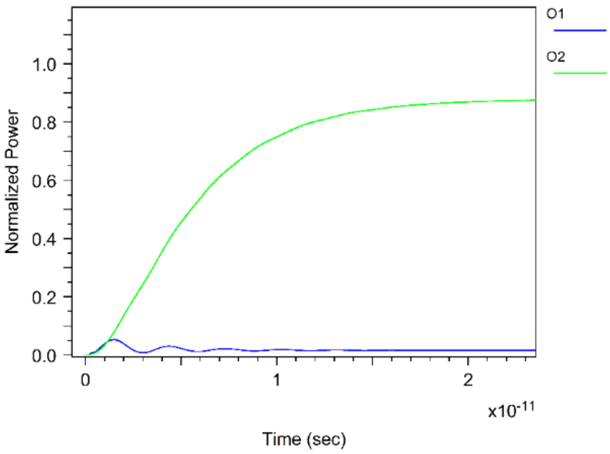
Fig. 6. (a) The optical behavior and (b) the time response of the ASK demodulator when the input intensity is 2 W/μm^2 (color online)

In the second case when the optical intensity of the input signal is 2 W/μm^2, due to increase in the refractive index of nonlinear rods the resonant mode of the cavities shift toward higher wavelengths, so the resonant wavelength of C1 matches with 1550 nm and it can drop the optical waves and guide them toward O1. As a result as shown in Fig. 6 in this case O1 is ON and O2 is OFF. The amount of normalized power at O1 and O2 are 90% and 0% respectively. The rise time for O1 is about 11 ps.

In the third case when the optical intensity of the input signal is 3 W/μm^2, due to increase in the refractive index of nonlinear rods the resonant mode of the cavities shift toward higher wavelengths, so the resonant wavelength of C2 matches with 1550 nm and it can drop the optical waves and guide them toward O2. As a result as shown at Fig. 7 in this case O1 is OFF and O2 is ON. The amount of normalized power at O1 and O2 are 0% and 90% respectively. The rise time for O2 is about 11 ps.



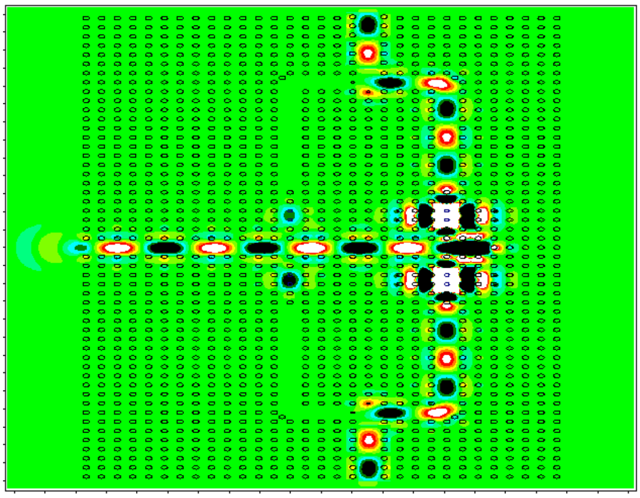
(a)



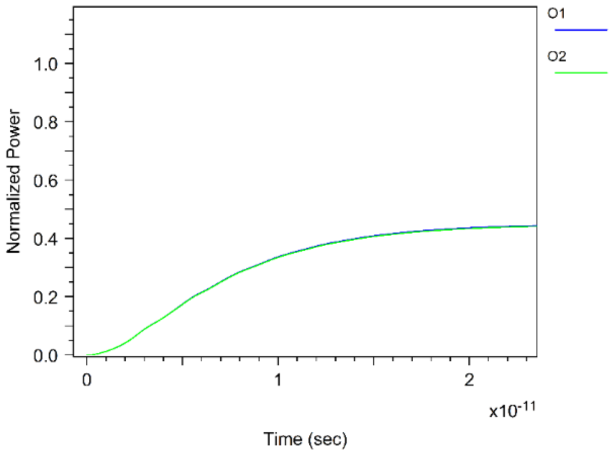
(b)

Fig. 7. (a) The optical behavior and (b) the time response of the ASK demodulator when the input intensity is 3 W/μm² (color online)

In the last case when the optical intensity of the input signal is 4 W/μm², due to increase in the refractive index of nonlinear rods the resonant mode of the cavities shift toward higher wavelengths, so the resonant wavelength of C3 and C4 match with 1550 nm and they can drop the optical waves and guide them toward O1 andO2. As a result as shown in figure 8 in this case both O1 and O2 are ON. The amount of normalized power at O1 and O2 are 45% and 45% respectively. The rise time for O1 and O2 is about 11 ps.



(a)



(b)

Fig. 8. (a) The optical behavior and (b) the time response of the ASK demodulator when the input intensity is 4 W/μm² (color online)

As the simulation results show the proposed structure can convert four 2-bit codes based on the optical intensity of the input signal. The maximum rise time of the proposed structure is about 5 ps. The minimum normalized power for logic 1 and the maximum normalized power for logic 0 are 45% and 2% respectively. Therefore the contrast ratio of the proposed structure will be 13.5 dB.

4. Conclusion

A nonlinear optical demultuplexer was designed as the first stage of the optical demodulator. The nonlinear demultuplexer was designed using 4 nonlinear cavities, according to the simulation results when the optical intensity of the input signal is 1 W/μm², none of the cavities can drop the optical waves. For the optical intensity being 2 W/μm² and 3 W/μm², C1 and C2 can drop the optical waves and finally both C3 and C4 can drop the signals with the optical intensity being 4 W/μm². The final structure is capable of creating four 2-bit codes based on the amplitude of the input signal. According to the simulation results for the final structure the maximum rise time is about 11 ps.

References

[1] H. J. R. Dutton, Understanding Optical Communications, Prentice Hall PTR, 1998.
[2] S. John, Phys. Rev. Lett. **58**, 2486 (1987).
[3] E. Yablonovitch, Phys. Rev. Lett. **58**, 2059 (1987).
[4] K. Sakoda, Optical Properties of Photonic Crystals, Springer Science & Business Media, 2004.
[5] J. D. Joannopoulos, S. G. Johnson, J. N. Winn, R. D. Meade, Photonic Crystals: Molding the Flow of Light, Second Edition, Princeton University Press, 2011.
[6] D. Liu, Y. Gao, A. Tong, and S. Hu, Phys. Lett. A **379**, 214 (2015).
[7] F. Mehdizadeh and H. Alipour-Banaei, J. Opt. Commun. **34**, 61 (2013).
[8] M. Noori, M. Soroosh, Opt. Int. J. Light Electron. Opt. **126**, 4775 (2015).
[9] F. Mehdizadeh, H. Alipour-Banaei, S. Serajmohammadi, J. Mod. Opt. **64**, 1233 (2017).
[10] F. Mehdizadeh, M. Soroosh, H. Alipour-Banaei, E. Farshidi, Opt. Quantum Electron. **49**, 38 (2017).
[11] A. Dideban, H. Habibiyan, H. Ghafoorifard, Phys. E Low-Dimensional Syst. Nanostructures **87**, 77 (2017).
[12] A. Rostami, F. Nazari, H. A. Banaei, A. Bahrami, Photonics Nanostructures - Fundam. Appl. **8**, 14 (2010).
[13] F. Mehdizadeh, M. Soroosh, H. Alipour-Banaei, E. Farshidi, IEEE Photonics J. **9**, 1 (2017).
[14] H. Alipour-Banaei, F. Mehdizadeh, Photonic Netw. Commun. **33**, 152 (2017).
[15] M. Youcef Mahmoud, G. Bassou, A. Taalbi, Opt. Int. J. Light Electron. Opt. **124**, 2864 (2013).
[16] M. Youcef Mahmoud, G. Bassou, A. Taalbi, Z. M. Chekroun, Opt. Commun. **285**, 368 (2012).
[17] A. Taalbi, G. Bassou, M. Youcef Mahmoud, Opt. - Int. J. Light Electron Opt. **124**, 824 (2013).
[18] A. Tavousi, M. A. Mansouri-Birjandi, Superlattices Microstruct. **114**, 23 (2018).
[19] A. Tavousi, M. A. Mansouri-Birjandi, Photonic Netw. Commun. **32**, 160 (2016).
[20] R. Talebzadeh, M. Soroosh, Y. S. Kavian, F. Mehdizadeh, Photonic Netw. Commun. **34**, 248 (2017).
[21] S. Serajmohammadi, H. Alipour-Banaei, F. Mehdizadeh, Appl. Opt. **57**, 1617 (2018).
[22] M. Ghadrdan, M. A. Mansouri-Birjandi, Opt. Quantum Electron. **45**, 1027 (2013).
[23] T. A. Moniem, J. Mod. Opt. **62**, 1643 (2015).
[24] S. Rezaee, M. Zavvari, H. Alipour-Banaei, Opt. Int. J. Light Electron. Opt. **126**, 2535 (2015).
[25] M. Karimzadeh, A. Andalib, J. Opt. Commun. **89**, 4 (2018).
[26] D. Jafari, T. Nurmohammadi, M. J. Asadi, K. Abbasian, Opt. Laser Technol. **101**, 138 (2018).
[27] M. Neisy, M. Soroosh, K. Ansari-Asl, Photonic Netw. Commun. **35**, 245 (2018).
[28] S. Gholamnejad, M. Zavvari, Opt. Quantum Electron. **49**, 302 (2017).
[29] Y. Miyoshi, K. Ikeda, H. Tobioka, T. Inoue, S. Namiki, K. Kitayama, Opt. Express **16**, 2570 (2008).
[30] J. Bao, J. Xiao, L. Fan, X. Li, Y. Hai, T. Zhang, C. Yang, Opt. Commun. **329**, 109 (2014).
[31] Tamer A. Moniem, Quantum Electron. **47**, 169 (2017).
[32] F. Mehdizadeh, M. Soroosh, Indian J. Pure Appl. Phys. **54**, 35 (2016).
[33] F. Mehdizadeh, H. Alipour-Banaei, S. Serajmohammadi, Opt. Int. J. Light Electron. Opt. **156**, 701 (2018).
[34] T. Daghooghi, M. Soroosh, K. Ansari-Asl, Appl. Opt. **57**, 2250 (2018).
[35] S. Khosravi, M. Zavvari, Photonic Netw. Commun. **35**, 122 (2018).
[36] S. Salimzadeh, H. Alipour-Banaei, J. Mod. Opt. **65**, 2017 (2018).
[37] A. Rahmani, F. Mehdizadeh, Opt. Quantum Electron. **50**, 30 (2017).
[38] M. M. Karkhanehchi, F. Parandin, A. Zahedi, Photonic Netw. Commun. 1 (2016).
[39] M. M. Karkhanehchi, F. Parandin, A. Zahedi, Photonic Netw. Commun. **33**, 159 (2017).
[40] A. Andalib, Photonic Netw. Commun. (2018).
[41] S. Serajmohammadi, H. Alipour-Banaei, F. Mehdizadeh, Photonics Nanostructures - Fundam. Appl. **34**, 19 (2019).
[42] A. Surendar, M. Asghari, F. Mehdizadeh, Photonic Netw. Commun. **38**, 244 (2019).
[43] V. Fakouri-Farid, A. Andalib, Optik **172**, 241 (2018).
[44] T. Zhao, M. Asghari, F. Mehdizadeh, J. Electron. Mater. **48**, 2482 (2019).
[45] F. Mehdizadeh, M. Soroosh, H. Alipour-Banaei, E. Farshidi, Appl. Opt. **56**, 1799 (2017).

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