DESIGN OF ALL-OPTICAL 8*3 ENCODER USING HEXAGONAL SHAPED PHOTONIC CRYSTAL RING RESONATOR

J. K. JAYABARATHAN[a*] , G. SUBHALAKSHMI[b], S. ROBINSON[b]
[a]*Department of Computer Science Engineering*
[b]*Department of Electronics and Communication Engineering*
Mount Zion College of Engineering and Technology, Pudukkottai, Tamilnadu, India 622507

A two Dimensional Photonic Crystal (2DPC) based 8*3encoder is designed on a triangular lattice. An 8*3encoder is constructed by implementing the hexagonal shaped ring resonator, resonant cavities and waveguides in this proposed design. The Photonic Band Gap (PBG) of the proposed encoder is determined using Plane Wave Expansion (PWE) method and their performance was evaluated using Finite Difference Time Domain (FDTD) method. The minimum input power for logic 0 is $0.01P_{in}$ and maximum input power for logic 1 is $0.7P_{in}$ where input power is denoted as $P_{in.}$ The switching rate and time delay of the proposed encoder is determined as 3THz and 0.33ps, respectively. The simulation output has the highest power level above 80% is considered as logic1 and lowest power level of logic 0 is considered as below 20%.The proposed encoder is operated in the wavelength of 1550 nm. The overall size of 8*3 encoder is 36.4μm x 46μm. The proposed structure has low intensity inputs and fast response. Hence, it is applicable for high speed Optical integrated circuits.

(Received July 21, 2018; Accepted September 20, 2018)

Keywords: Photonic crystal, encoder, Resonator, FDTD, triangular lattice

1. Introduction

Optical circuits and optical devices play a major role for designing all high speed optical networks, optical signal processing and optical communication systems. It can achieve high speed, more bandwidth, high data transfer rate and immunity to noise while compared to electronic devices. Speed limitation occurs in the electronics due to electro optic conversion and it is overcomes by using optical devices. Hence, many researchers focus on designing the optical devices such as logic gates [1-3], encoder [4], decoder [5-7] filters [8], multiplexer [9] and demultiplexer [10] are the several examples of optical devices which are operated in an optical domain.

Currently, Photonic Crystal (PC) is the best choice for creating the optical devices. Since, it has the exclusive properties such as compactness, high speed, and low power consumption and Photonic Band Gap (PBG) [11]. In certain frequency region, the optical wave does not enter into the PC and it is known as PBG. The properties of PBG structure is determined by the factors such as refractive index contrast, the fraction of high and low index material of lattice and lattice element arrangements [12]. The defects are made in the PC structure in order to break the periodicity property and PBG. Hence the light localize in to the PBG region, which tends to design a PC based optical devices [13].

Optical encoder is a combinational logic device and its play crucial role in optical communication systems for data processing and analog to digital conversion. By utilizing the logic '0' and logic '1', it converts the 2^N inputs in to N-bit binary codes. It has 2^N inputs and 2 outputs in which single input is applied at a time [14].

*Corresponding author: jaysonmzcet@gmail.com

Many optical encoders have been designed based on PC. Iman Ouahab and Rafah Naoum proposed a 4x2 encoder switch. It is made by the combination of nonlinear resonator and kerr effect. The size of the device is 18.5μm x 13μm [15]. Yin-Pin Yang et al. proposed an PC based encoder using ring resonator .The encoder operated in the 1.31 μm, 1.49 μm, and 1.55 μm and it is used in the all-optical logic multitasking circuits in optical wafers [16]. An optical 4x2 encoder using non-linear PCRR was proposed by Siamak Gholamnejad and Mahdi Zavvari. The low intensity input and quick response are the merits of the design [17]. Shahla khosravi and Mahdizadeh were proposed an optical 2*4 all - optical decoder is designed using nonlinear kerr effects in a PCRR. The ON/OFF ratio of reported decoder is at least 2.22.The maximum crosstalk is -10dB and insertion loss is -8.8dB is attained from the decoder [18]. Farhad Mehdizadeh et al. proposed an optical encoder which is constructed by using the buffer and OR gate. The encoder has an delay time and the switching time of 200fs and 5 THz [19]. Tamer A. Moniem proposed presented an optical encoder based on the PCRR NOR gates .The switching speed of this encoder is 500 GHz and it is suitable for optical networks and optical signal processing [20]. Mahdi Hassangholizadeh et al. proposed a reversible encoder using of nonlinear Kerr effect with elliptical resonator. A reversible encoder has low loss of data in optical signal processing [21]. An optical encoder based on the combination of beam splitter and mirror along with self-collimated effect is proposed by Hamed Alipour-banaei et al. The response speed of the proposed encoder is 1400 fs [22].

The 8*3 encoder was designed using nonlinear PCRR by Amir salimzadeh and Hamed Alipour –Banaei. The maximum time delay of the reported encoder is 2 ps [23]. Farhad Mehdizadeh proposed the 2*4 decoder using nonlinear PCRR and kerr effect. The 2*4 decoder has the maximum switching speed of 10GHzand total footprint is 581 μm^2. It requires less optical intensity for input ports is 50W/μ m^2 [24]. The implementation of waveguide-coupled ring resonators in PC was reported to investigate the effect of ring size and crystal parameters on the resonant wavelength PCRR. It achieves high transmission efficiency, stability and high quality factor compare with other mechanism of designing the optical devices [25]. Though, there are several attempt made to design encoder which massively follows nonlinear optics. Hence, the reported encoder suffers the fundamental limitations namely, power consumption and limited operating wavelength range. Further, the performance of the device is sensitive to phase of the input signal. In order to overcome the aforementioned issues, in this paper all optical 8*3 encoder designed using a hexagonal based ring resonator in 2DPC.

In this work, an optical 8*3 encoder designed using a hexagonal based ring resonator in 2DPC. The structure has eight inputs and three outputs which is made by using three, four input OR gates. The guided mode of propagation and PBG are determined using the PWE method. The proposed PC structure has four input waveguides and two output waveguides which are coupled to hexagonal shaped resonator. The transmission behaviour of the proposed encoder is analyzed using 2D FDTD method. It works in the third optical window and it is fit for all optical integrated circuits.

The rest of the paper is organized as follows: Section 2 describes the design of 8*3optical encoder. Section 3 describes the simulation results and discussion of proposed encoder. Sections 4 conclude the proposed work.

2. Design of 8*3 optical encoder

An 8*3 encoder is designed using triangular lattice of an array of 83x57 which is placed on the X and Z direction. It has eight inputs and three outputs which are built using three, four input OR gate. Fig. 1 represents the block diagram of 8*3encoder and Fig. 2 denoted the symbol of an 8*3 encoder. Its truth table describes the behavior of proposed optical encoder which is shown in Table 1.The propagation of optical waves inside the PC and its corresponding PBG is calculated using PWE method. The PBG structure consists of TE mode which ranges from 0.31a/λ to o.48a/λ is 1330nm to 2064nm and it is derived from the Fig. 3.

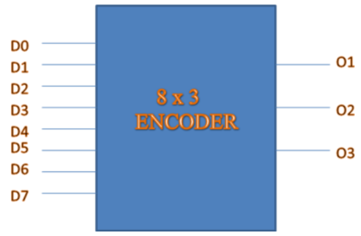


*Fig. 1. Block diagram of optical 8*3 encoder.*

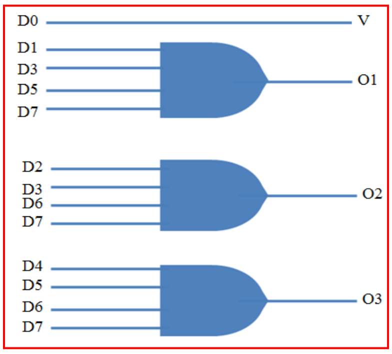


*Fig. 2. Symbol of 8*3 optical encoder.*

Table 1. Truth table of proposed encoder.

INPUT								OUTPUT		
D0	D1	D2	D3	D4	D5	D6	D7	O1	O2	O3
1	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1
0	0	1	0	0	0	0	0	0	1	0
0	0	0	1	0	0	0	0	0	1	1
0	0	0	0	1	0	0	0	1	0	0
0	0	0	0	0	1	0	0	1	0	1
0	0	0	0	0	0	1	0	1	1	0
0	0	0	0	0	0	0	1	1	1	1

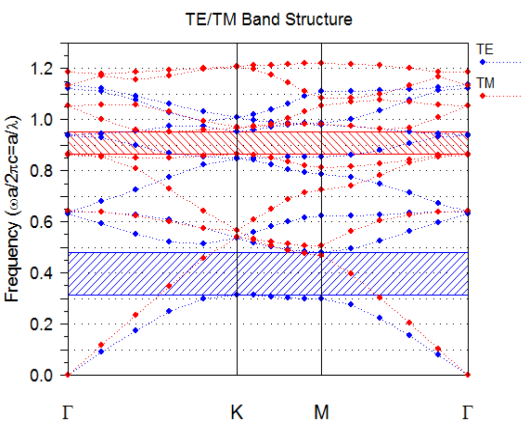


Fig. 3. Band diagram of proposed 4x2 encoder.

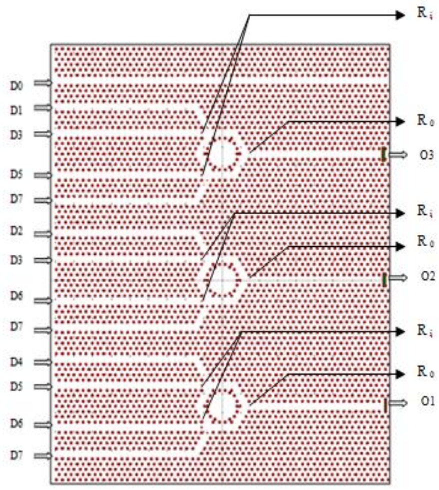


*Fig. 4. Schematic structure of proposed 8*3 encoder.*

The structure of 8*3 optical encoder is represented in the Fig. 4. The 8*3 encoder is constructed by a triangular lattice which has an array of 83x57.The mechanism such as line defects, cavities and hexagonal shaped ring resonator are introduced in this structure. An 8*3 encoder consists of eight inputs and three outputs. The eight inputs are made by creating thirteen input waveguides along with 3 resonant rings which is present in between the waveguide. The size of the rod reduced at the junction of each ring shaped resonator present on the left side is to 45nm which is denoted as R_i and right side of the rod radius at the junction is1nm and it is denoted as $R_{0.}$ The resonant cavities are generated inside the resonant rings in order to reduce the switching threshold. The input waveguides of proposed encoder are D0, D1, D2, D3, D4, D5, D6, D7and output waveguides are O1, O2, and O3 respectively.

3. Simulation results and discussion

The eight different working stages of proposed 8*3 encoder is simulated and evaluated its functional performance. The field distribution of proposed optical encoder is depicted in the Figs. 5(a)-5(h). The central wavelength of device is 1550nm and it is given as the input bias for the proposed encoder. Figs. 6(a)-6(h) Shows the output performance of the 8*3 encoder and briefly discussed about its functional performance.

Case 1: When D0 is ON, an optical wave does not enter into any of three resonant rings hence D0 is not coupled to the corresponding resonant rings and so all the output ports are OFF. The normalized output power at O1, O2 and O3 is 3%, 10% and 11% which is shown in the Fig. 6(a)

Case 2: When D1 is ON, optical waves pass through the resonant ring 1 and the waves dropped in to O3.Since O1 and O2 will be OFF and O3 is ON. Fig. 6(b) shows the output power level of O1, O2 and O3 is 5%, 10% and 80%.

Case 3: When D2 is ON, then the optical waves enter in to the resonant ring 2 and reaches the O2 goes to ON, O1 and O3 goes to OFF. The normalized transmission power at O1, O2 and O3 be 12%, 72% and 9% and it is shown in Fig. 6(c).

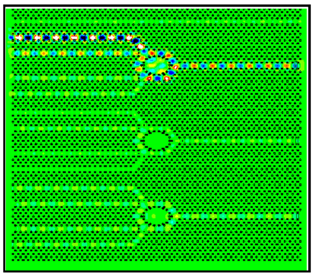
Case 4: The optical waves propagate in to resonant ring 2 and ring 3 due to resonant effect, when D3is ON. Then O2 and O3 will be ON and O1 will be OFF. Fig. 6(d) represents the output response at which O1 is 10%, O2 is 90% and O3 is 85%.

Case 5: When D4 is ON, the optical waves only enter into the resonant ring 3 and it reaches O1and it goes to ON and remaining outputs are OFF. Fig. 6(e) shows the transient response is O1, O2 and O3 which are 90%, 5% and 5%.

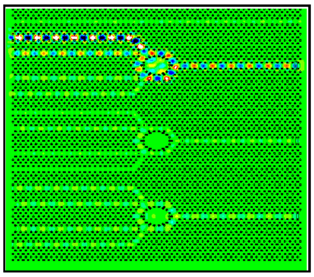
Case 6: When D5 is ON, O1 and O3 are ON due to the signal reaches the output ports O1 and O3 through the resonant rings 1 and ring 3 but not in O2 and it goes to OFF. O1, O2 and O3 has the output power level shown in the Fig. 6(f) are 85%, 5% and 100%.

Case 7: When D6 is ON, The optical signal will dropped in to the resonant ring 2 and ring 3. Hence O1 and O2 is ON and O3 is OFF. The transmission behaviour of output power level at O1, O2 and O3 are 85%, 100% and 5% which is depicted in the Fig. 6(g).

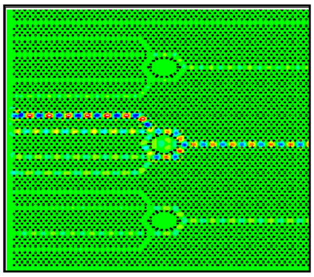
Case 8: When D7 is ON, while the input D7 is coupled to all the resonant rings, hence the optical waves enter into all the three outputs such as O1, O2 and O3 goes to ON. The power level at the O1, O2 and O3 are 80%, 85% and 80%.This is shown in the Fig. 6(h).



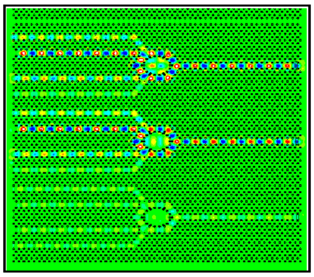
(a)D0=1,D2=D3=D4=D5=D6= =D7=0, O1=0, O2=0, O3=0



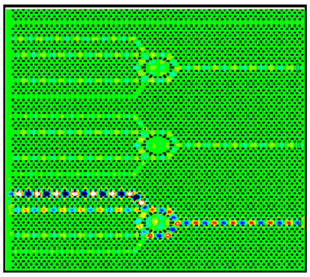
(b)D1=1, D0=D2=D3=D4=D5=D6= = D7=0, O1=0, O2=0, O3=1



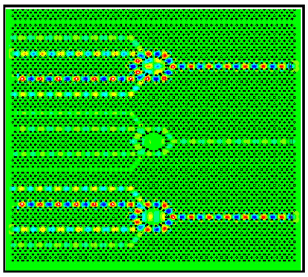
(c)D2=1,D0=D1=D3=D4=D5=D6= =D7=0, O1=0, O2=1, O3=0



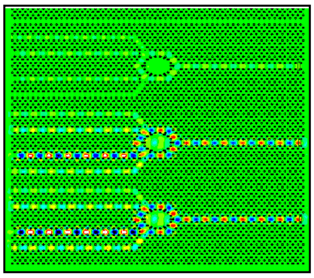
d) D3=1,D0=D1=D2=D4=D5=D6= = D7=0, O1=0, O2=1, O3=1



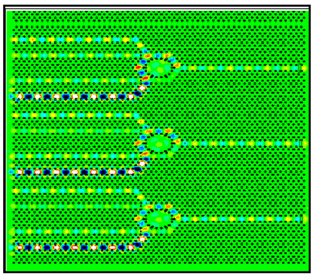
(e)D4=1,D0=D1=D2=D3=D5=D6= = D7=0, O1=1, O2=0, O3=0



(f)D5=1,D0=D1=D2=D3=D4=D5=D6= =D7=0, O1=1, O2=0,O3=1

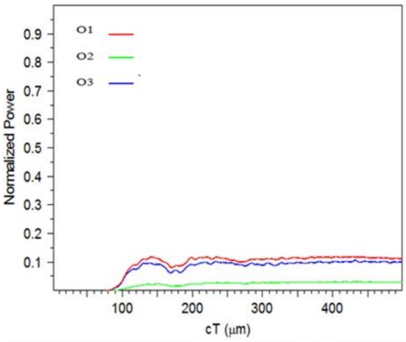


(g) D6=1, D0=D1=D2=D3=D4=D5= =D7=0, O1=1 ,O2=1,O3=0

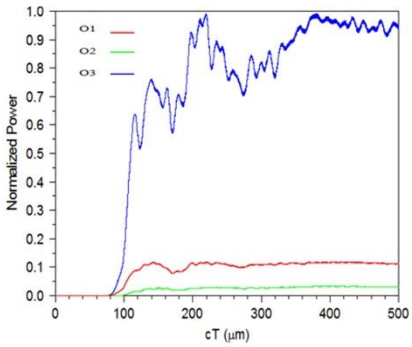


(h) D7=1, D0=D1=D2=D3=D4=D5= = D6=0, O1=1, O2=1, O3=1

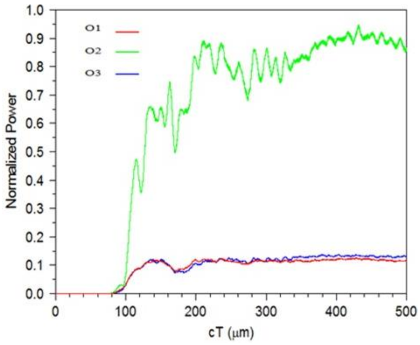
Fig. 5. Optical field distribution of proposed encoder at eight cases (a) to (h).



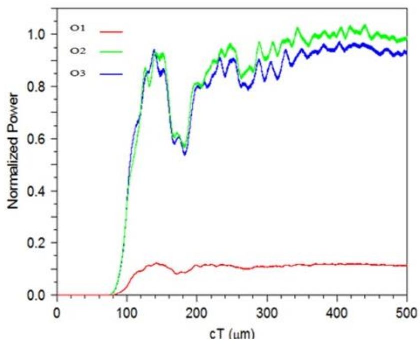
(a) D0=1, D1=D2=D3=D4=D5=D6=D7=0, O1=0 ,O2=0,O 3=0



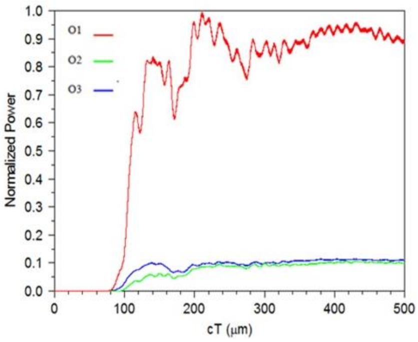
(b) D1=1, D0=D2=D3=D4=D5=D6=D7=0, O1=0, O2=0, O3=1



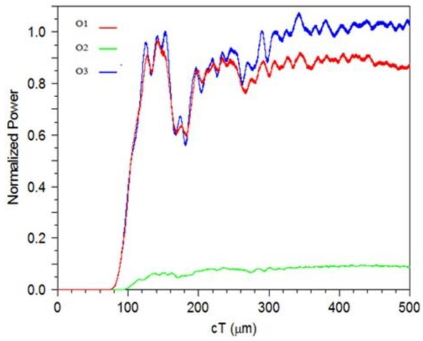
(c) D2=1, D0=D2=D3=D4=D5=D6=D7=0, O1=0, O2=1, O3=0



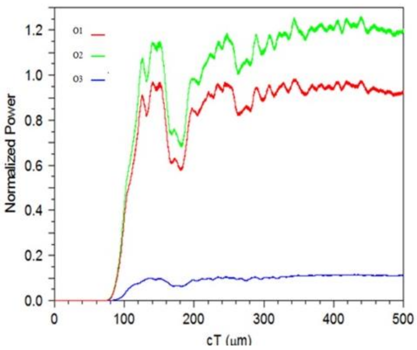
(d) D3=1, D0=D1=D2=D4=D5=D6=D7=0, O1=0, O2=1, O3=1



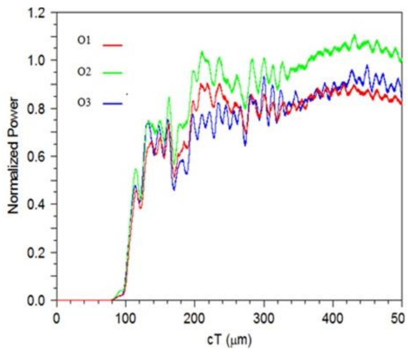
(e) D4=1, D0=D1=D2=D3=D5=D6=D7=0, O1=1,O2=0,O3=0



(f) D6=1, D0=D1=D2=D3=D4=D5=D7=0, O1=1 , O2=0,O3=1



(g) D6=1, D0=D1=D2=D3=D4=D5=D7=0, O1=1, O2=1, O3=0



h) D7=1, D0=D1=D2=D3=D4=D5=D6=0, O1=1, O2=1, O3=1

Fig. 6. Output performance of proposed encoder at eight cases (a) to (h).

Table 3. Output performance of the proposed encoder.

INPUT								OUTPUT		
D0	D1	D2	D3	D4	D5	D6	D7	O1	O2	O3
1	0	0	0	0	0	0	0	3	10	11
0	1	0	0	0	0	0	0	5	10	80
0	0	1	0	0	0	0	0	12	72	9
0	0	0	1	0	0	0	0	10	90	85
0	0	0	0	1	0	0	0	90	5	5
0	0	0	0	0	1	0	0	85	5	100
0	0	0	0	0	0	1	0	85	100	5
0	0	0	0	0	0	0	1	80	85	80

4. Conclusions

A hexagonal shaped ring resonator is combined along with waveguides and cavities for designing the 8*3 encoder. The parameter of encoder such as switching rate and time delay is evaluated by using 2D-FDTD method.

The maximum time delay and switching rate of the proposed encoder is 0.33ps and 3THz, respectively. The proposed structure can encode the eight different combinations of inputs and produce eight 3-bit binary code based on the corresponding inputs. Hence, it is suitable for high speed optical integrated circuits and devices due to its fast response and compact size.

References

[1] Younis, Areed, Obayya, IEEE Photonics Technologies Letters **26**(19), 1900 (2014).
[2] Enaul Haq Shaik, Nakkeeran Rangaswamy, Photonic Network Communications **34**(1), 140 (2017).
[3] Enaul Haq Shaik, Nakkeeran Rangaswamy, Journal of computational Electronics **17**(1), 337 (2018).
[4] Chongfu Zhang, Kun Qiu, Optics and Laser in Engineering **46**(8), 582 (2000).
[5] Somaye Serajmohammadi, Hamed Alipour-Banei, Farhad Mehdizadeh, Optical and Quantum Electronics **47**(5), 1109 (2015).
[6] Tina Daghooghi, Mohammad Sorooshi, Karim Ansari-Asli, Photonic Network Communications **35**(3), 335 (2017).
[7] S. Robinson, R. Nakkeeran, Optical and Quantum Electronics **43**(6-10), 69 (2013).
[8] Gianluca Manzacca, DanielePaciotti, Alesandro Marchese, Micheala Svaluto Moreolo, Gabrilla Cincotti, Photonics and Nanostructures-Fundamentals and Applications **5**(4), 164 (2007).
[9] Reza Talebzadeh, Mohammad Soroosh, Yousef S. Kavin, Farhad Mehdizadeh, Photonic Network Communications **34**(2), 248 (2017).
[10] Ekmel Ozbay, Irfan Bula, Photonics and Nanostructure- Fundamentals and Applications, **2**(2), 87 (2004).
[11] E. Yablonovitch, Journal of the Optical Society of America B, **10**(2), 283 (1993).
[12] Thomas F. Krauss, Richard M. DeLaRue, Stuart, Letters to Nature **383**, 699 (1996).
[13] J. D. Joannopoulos, Pierre R.Villeneuve, Shanhui Fan, Nature **386**, 143 (1997).
[14] Farhad Mehdizadeh, Mohammad Soroosh, Hamed Alipour-Banaei, IET Optoelectronics,

11(1), 29 (2017).
[15] Iman Ouahab, RafahNaoum, Optik-International Journal of Light and Electron Optics **127**(19), 7835 (2016).
[16] Yi-Pin Yang, Kuen-Chernglin, I-Chenyang, Kun-Yi Lee, Wei-Yu Lee, Yao-Tsung Tsai Optik-International Journal for Light and Electron Optics **142**(5), 354 (2017).
[17] Siamak Gholamnejad, Mahdi Zavvari, Optical and Quantum Electronics **49**, 302 (2017).
[18] Shahla Khosravi, Mahdizavvari, Photonic Network Communications **35**(1), 122 (2018).
[19] Tamer A. Moniem, Journal of Modern Optics **6**(8), 735 (2016).
[20] Mahdi Hassangholizadeh-Kashtiban, Reza Sabbaghi Nadooshan, Hamed Alipour-Banaei, Optik-International Journal for Light and Electron Optics **126**(20), 2368 (2015).
[21] Hamed Alipour-Banaei, Mehdi Ghorbanzadeh Rabati, ParisaAbdollahzedeh-Badelbou, Farhad Mehdizadeh, Physica E: Low-dimensioal Systems and Nanostructures **75**, 77(2016).
[22] Amir Salimzadeh, Hamed Alipour-Banaei, Optics Communications **410**, 793 (2018).
[23] Farhad Mehdizadeh, Hamed Alipour-Banaei, Somaye Serajmohammadi, Optik-International Journal for Light and Electron Optics **156**, 701 (2018).
[24] V. Dinesh Kumar, T. Srinivas, A. Selvarajan, Photonics and Nanostructures-Fundamentals and Applications **2**(3), 199 (2005).