Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

OPTIMIZING COMBINATIONAL DEVICES THROUGH PHOTONIC CRYSTAL ARCHITECTURES: A COMPREHENSIVE LITERATURE REVIEW

T. THAMIZH MANI
Department of Electronics and Communication Engineering, University College of Engineering Panruti, Chennai Kumbakkonam Highway, Panikankuppam, Panruti 607106, India.

Dr. R.J. KAVITHA
Department of Electronics and Communication Engineering, University College of Engineering Panruti, Chennai Kumbakkonam Highway, Panikankuppam, Panruti 607106, India.

Abstract

Photonic crystals represent a viable option for the creation of small and high-speed optical devices because of their special ability to manipulate light. The progress in photonic crystal-based comparators, encoders, and logic gates is examined in this review of the literature. The review addresses the structural parameters, functional parameters, approaches, and applications related to combinational device (comparators, encoders, and logic gates) based on photonic crystals. For improving the functionality of the device, various techniques were reviewed. By compiling research studies and experimental demonstrations to summarize the state-of-the-art at this time, the review offers valuable insights into the advancements and potential of photonic crystals for optical device development.

Keywords: Combinational Devices, Functional Parameters, Photonic Crystal (PhC), Structural Parameters.

INTRODUCTION

For several decade semiconductor technology played vital role in our daily life, while moving towards miniaturization and high speed electronic circuits faces issues in terms of power dissipation and sensitivity to signal synchronization. Above mentioned problems are overcome by a new technology called Photonics. In electronics the information carrier is electrons while in Photonics the information carrier is photons. Photons which is also called as light particles. Photons have many more advantages than electrons in terms of greater speed, larger bandwidth, less energy loss[1].Electronics based devices are larger in size meanwhile size reduction is made possible with Photonic based devices. Size reduction of devices produce diffraction which can be overcome by Photonic Crystal based devices [7]. In semiconductor naturally atoms have periodicity but in photonic crystal (PhC) the periodicity of dielectric media (refractive index) has to be created artificially. The mechanism used to control light propagation in photonic crystal is termed as Photonic Band Gap (PBG) or frequency band gap. In simple words no light is present inside the crystal for a range of frequencies is called PBG. Using PBG many miracles can be produced in the Photonic Crystal based devices. For guiding the light inside the photonic crystal, periodicity of dielectric media has to be disturbed such mechanism is termed as defect [1].For flowing of light signal at particular wavelength in the device is achieved by defect creation in the crystal. There are three types of defects exists in

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

photonic crystal. The radius or refractive index of a single rod in a crystal structure can be changed to create a point defect. Line defect is created by removing a row or column rods of crystal structure. By cutting row or column rods at the edge of the crystal structure, a surface defect is produced. [3].Micro cavity is a point defect based structure, waveguide is a line defect based structure. Micro cavity and waveguide created using photonic crystal forms the basic building blocks in controlling the spontaneous emission of atom. Waveguide guide the light in a direction without any loss, micro cavity provides the angular momentum for photons [1].The PhCs are also called the one, two, and three-dimensional (1D, 2D, and 3D) PhCs. PhCs are structures that show sporadic variations in the dielectric constant in one, two, or all three orthogonal directions.1D PhC offers a homogenous medium in the other two directions but consists of a periodic variation of the refractive index in the light propagation direction. The refractive index fluctuates in two directions but remains constant in the third direction in 2D PhCs. By changing the refractive index in each of the three spatial directions, 3D PhCs may be created.[4].Among these, the refractive index of 2D PhC changes in two perpendicular directions that are useful for designing photonic devices because of their simple design, easy fabrication capability, accurate PBG calculation, effective light confinement, and ease of control over their propagation modes [5].PBG width is directly proportional to PhCs difference in refractive index[6].

The main goal of communication network and system is to improve, optimize the channel capacity, bandwidth, bit rate and transfer speed. Optical communication network consists of waveguides, filters, multiplexer, demultiplexer, logic gates, adders, encoders, decoders etc., [8].For optical communication, optical switching, optical computing, optical signal processing system all optical devices mentioned above are used as building blocks. The primary benefits of optical networks over electronics network are improved bandwidth, transfer rate and immune from noise[9].In optical communication network, the speed of the network is reduced due to the conversion from electrical(E) to optical(O) and optical(O) to electrical(E).The speed of the network is improved by using PhC based device [10].

Multiwave length operation, supplementary input, bias input, number of ring resonator, compactness, delay time, switching speed, contrast ratio are a few things taken into account when evaluating the performance of devices manufactured by PhC. [11].The parameters used to design the device are termed as structural parameters and the parameters used to assess the performance of device are termed as functional parameters. Lattice type, lattice constant, radius, refractive index are some of the structural parameters for PhC devices. Contrast ratio, delay time, operating range, fall time, extinction ratio, rise time, bit rate are some of the functional parameters for PhC devices. PhC based device is said to be a best when it achieves high contrast ratio, low response time, low power consumption [12].One important metric for logic devices is the Contrast Ratio (CR), which may be computed using10log (P_1/P_0), whereP_0 andP_1 represent the normalized output power of logic "0"and logic "1" respectively. An optical device's CR is directly influenced by its operating wavelength, coupling rod radius, corner rod radius, and refractive index values [13].The dispersion diagram is used to investigate

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

the device's functioning frequency zone. To create the dispersion diagram, the Plane Wave Expansion (PWE) method is used. Band structure, which is plotted using the plane wave expansion method, explores the operation frequency range. The working frequency and field propagation are obtained using the finite difference time domain (FDTD) method. [14].The device's reaction time to an input signal, which is correlated with its speed is known as response time [15]. Extinction ratio(ER) of a device is computed as ER=10 log (without output power intensity/with output power intensity) [16].

There are several approaches of managing light propagation inside the structure, including nonlinear materials, self- collimated beams, multimode interference, and defect based interference [2]. The primary characteristics of the self- collimated beam effect are Total Internal Reflection (TIR), simple in design, short simulation time and the absence of diffraction during light propagation. Line Defects in a PhC structure can result in the TIR. The disadvantages of a self- collimated beam include the necessity for a phase shifter, a huge area need, increased building costs, a low contrast ratio, and the fact that light propagates only in horizontal as well as vertical directions [2]. Using the self-collimation effect, NOR, XNOR, AND NAND, and logic functions are performed in a building with a 6 dB ON-OFF contrast ratio and an operational wavelength of 1.5551 µm. Because of its compactness, it is appropriate for photonic integrated circuits and optical computing. [19].The structural parameters in Fig.1determine the Self Collimation.3.46and11.97 are the silicon rod refractive index and permittivity used for creating square lattice-shaped PhC. The structure has two line-defect regions. The normal region of the structure has a rod radius (r) of 105nm. The line defect region has a rod radius (r_d) of 83nm. The radius of the defect rods determines the phase difference and splitting ratio. If r < rd,the phase difference between the reflecting and transmitting signals is -π/2.If r > r_d the phase difference between the reflecting and transmitting signals is π/2.Defect region1 has two inputs, I_1&I_2. Defect Region 2 has one reference input. At defect region 2, interference occurred between the reflected beams of I_1&I_2 and the reference transmitted beam. Based on the phase difference, interference may be constructive or destructive one. A destructive interference signal is taken out at face 2. AND, NOR, NAND, and XNOR are the logic gates created using this structure. This structure achieved a contrast ratio of 4.9dB, 3.1dB, 7.4dB, and 7.2dB for AND, NOR, NAND, and XNOR gates, respectively [19].

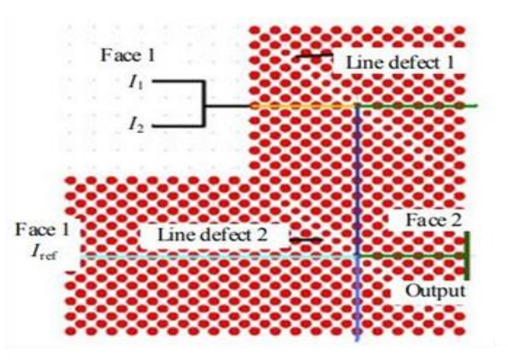

Figure 1: 10µm*10µmself-collimated Logic gates structure [19]

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

Self-imaging is the foundation of Multi-Mode Interference (MMI). The primary characteristics of MMI are able to build single structure for all logic gates, compact in size, low cost for designing the device. Because of its affordability and small size, Multi-Mode Interference (MMI) is a commonly utilized technology in optical communication systems. It does, however, have certain short comings that must be rectified.

The requirement for phase shifters, which may be costly and complex, is one of the main problems. Long simulation periods are also a result of the need for complicated algorithms to obtain better performance. In order for MMI to fully realise its promise in the realm of optical communication, several obstacles must be removed [2].For the C band, all optical NOR and AND logic gates use the BPSK signal with contrast- specific values not less than19 dB and 21 dB respectively [17].The properties of the logic gates are enhanced by the application of the geneticalgorithm(GA).

According to simulation results, the AND logic gate is roughly one-third the size of conventional devices and has an operating bandwidth of at least 6.79 dB[18].Interference-based PhC optical OR, XOR, NOT, AND logic gates achieve high contrast ratios, operate multiple wavelengths, and can be optimized for optical integrated networks without nonlinear materials or amplifiers [20].

Based on optical interference, all optical logic gates, including NOT, AND, OR, XOR, NAND, NOR, and XNOR, have a center operating wavelength of1550nm.[21].5.04µm* 5.04 µm T-shaped waveguide as a NOT gate and Dual T-shaped waveguide with dimensions of 8.04 m* 5.04 m as NAND, NOR, and XNOR gates, having a fast response time less than0.35ps[22].An all-optical, nonlinear material-free, 1 bit PhC waveguide-based magnitude comparator. Based on the idea of beam interference, it employs a T-shaped lattice with silicon dielectric rods set against an air background [7].

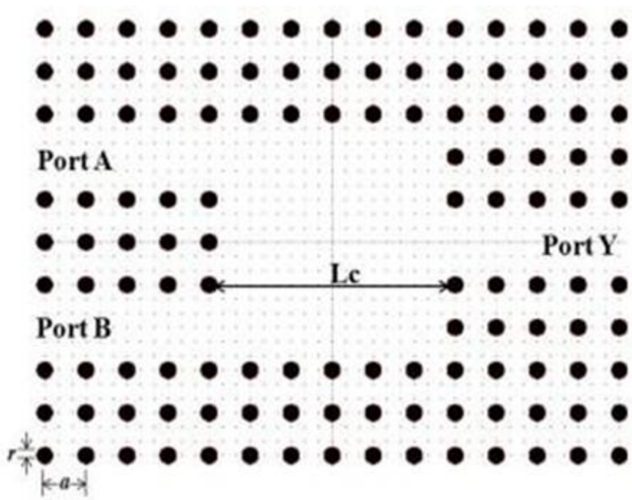

Figure 2: Multi-Mode interference based logic gates structure without absorbing waveguide [33]

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

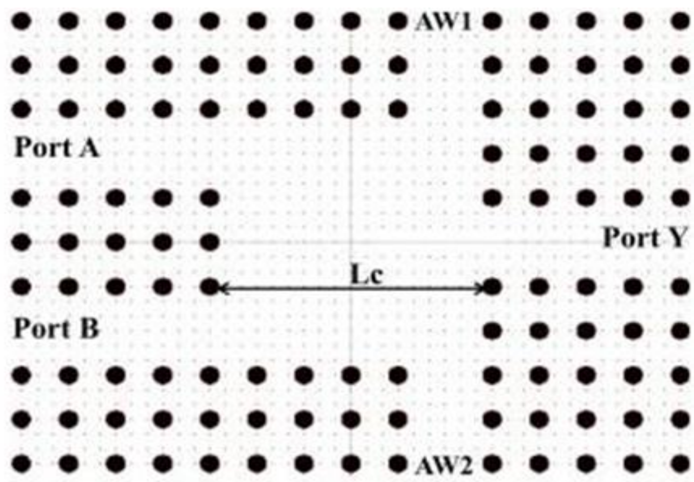

Figure 3: Multi-Mode interference based logic gates structure with absorbing waveguide [33]

In Figs. 2 and 3, Ports A and B are the structure's input ports, and Port Y is the structure's output port. AW represents the absorbing wavelength in Fig. 3. L_c is the coupling length of the structure. This structure fabrication is easy because all the rod radii are 0.2 a, where a is 600nm. But it has a drawback of back reflection for the structure shown in Fig. 2, which can be overcome by introducing an absorbing waveguide as shown in Fig. 3. The structure has a coupling length (Lc) of 6a, which creates multimode interference. Without an absorbing waveguide, the contrast ratio for NAND/OR is 37.40 dB, and for XOR/XNOR, it is 40.41 dB. After introducing an absorbing waveguide in the structure, 11.53% for NAND/OR and 12.46% for XOR/XNOR were achieved [33].

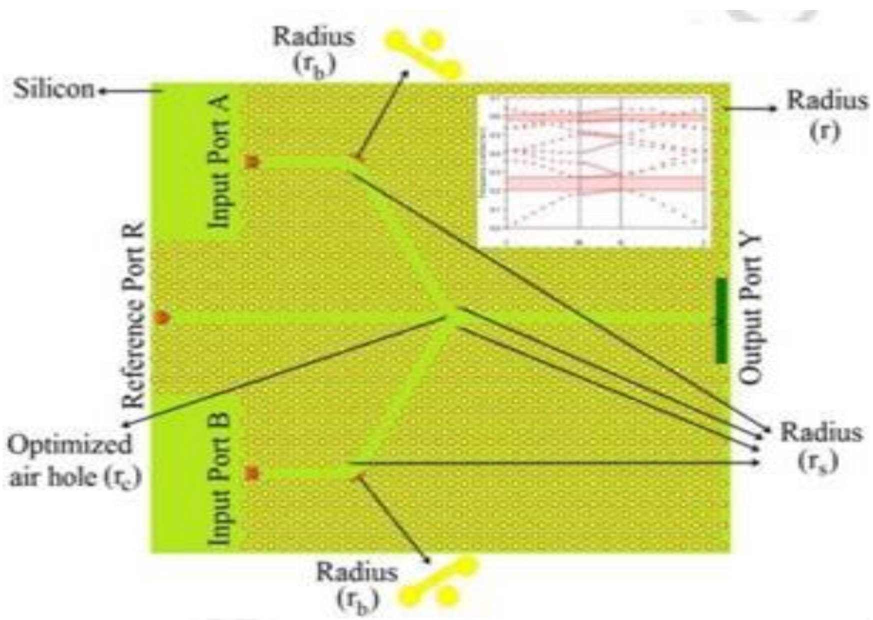

Figure 4: Basic structure for NAND gate [20]

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

The basic structure of the NAND gate is shown in Fig. 4. This structure has two input ports (A and B), one reference port (R), and one output port (Y). The structural parameters for the NAND gate are as follows: triangular lattice of air holes in silicon substrate, a = 0.352 µm, six hole rod radius as r_b=0.15a in the edges of input ports, centre hole radius r_c=0.24a, four edge air hole radius r_s=0.17a as shown in fig. 4. Using this basic structure, all other logic functions such as NOT, XOR, XNOR, AND, OR are created. For NOT, this basic structure is enough, but for all other gates mentioned above, a combination of this basic structure is needed. Three NAND gate combinations are used to produce XOR, XNOR, AND, OR logic functions. In the modified structure, NAND gate1, having two inputs with reference, produces an output of Y1. NAND gate2, having two inputs with a reference, produces an output ofY2. NAND gate 3, having two inputs (Y1 and Y2) with reference, produces a structure's final output (Y). For each logic function, the input, references have to be changed, as shown in Fig. 5 [20].

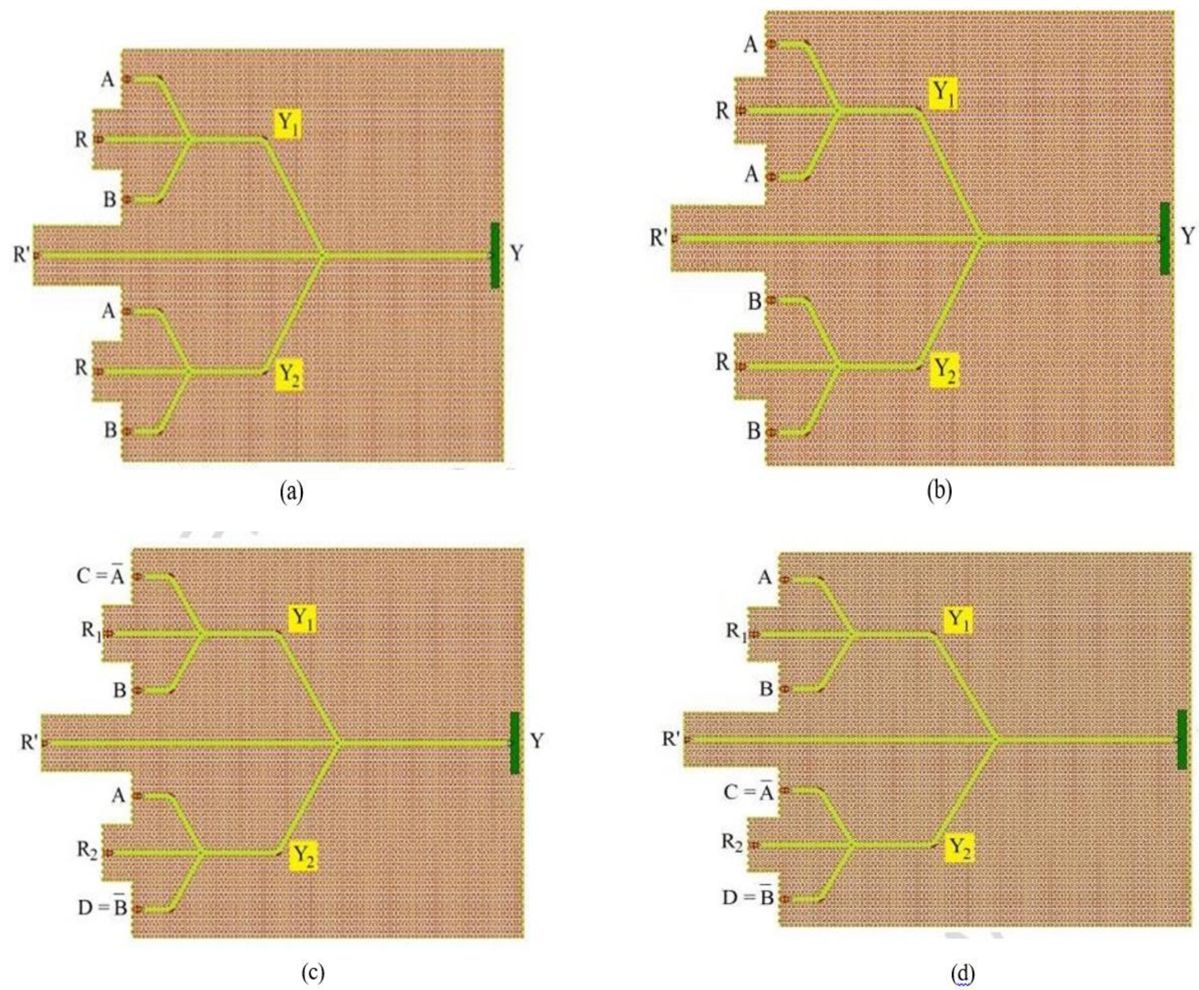

Figure 5: all optical logic functions for (a) AND gate[20] (b)OR gate[20] (c)XOR gate[20] (d)XNOR gate[20]

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

The simplicity and high contrast ratio of interference-based defects features make them a suitable choice for phase shifter- free devices.

These characteristics make them an affordable and effective solution for a range of applications as they do away with the requirement for intricate phase shifting devices. In Phc devices, defect based on interference can lead to serious problems.

The need that the input signals reach the device in phase which might be challenging to accomplish is one of its main drawbacks. Furthermore, the lack of a systematic design framework makes troubleshooting and fixing potential flaws difficult [2].X-shaped one-bit comparator having two inputs as A and B and two outputs as F1 and F2, as shown in Fig. 6.

This structure uses the line and point defect technique for its creation. This structure uses a hexagonal lattice made of GaAs rods. The value of the lattice constant is 600nm, with a defect-free rod radius of r=0.18a,four rods radius of r=0.7r,and one rod radius of r=0.8 r. Generally, a one-bit comparator has two inputs and three outputs as A=B, A>B, and A<B, but this structure has only two outputs as F1 and F2, which has to produce the conventional results.

Fig. 7 (a) produces the compartor output as F1=F2, which means A=B; Fig. 7 (b) produces the compartor output as F1<F2, which means A<B. Fig. 7(c) produces the comparator output asF1>F2, which means A>B. Fig. 7(d) shows the output response of this comparator.

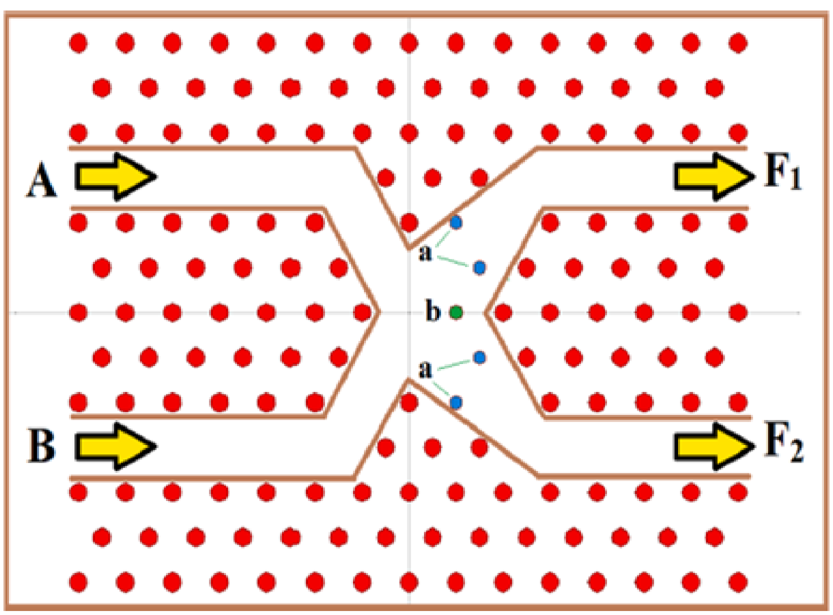

Figure 6: X-shaped 1bit comparator [6]

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

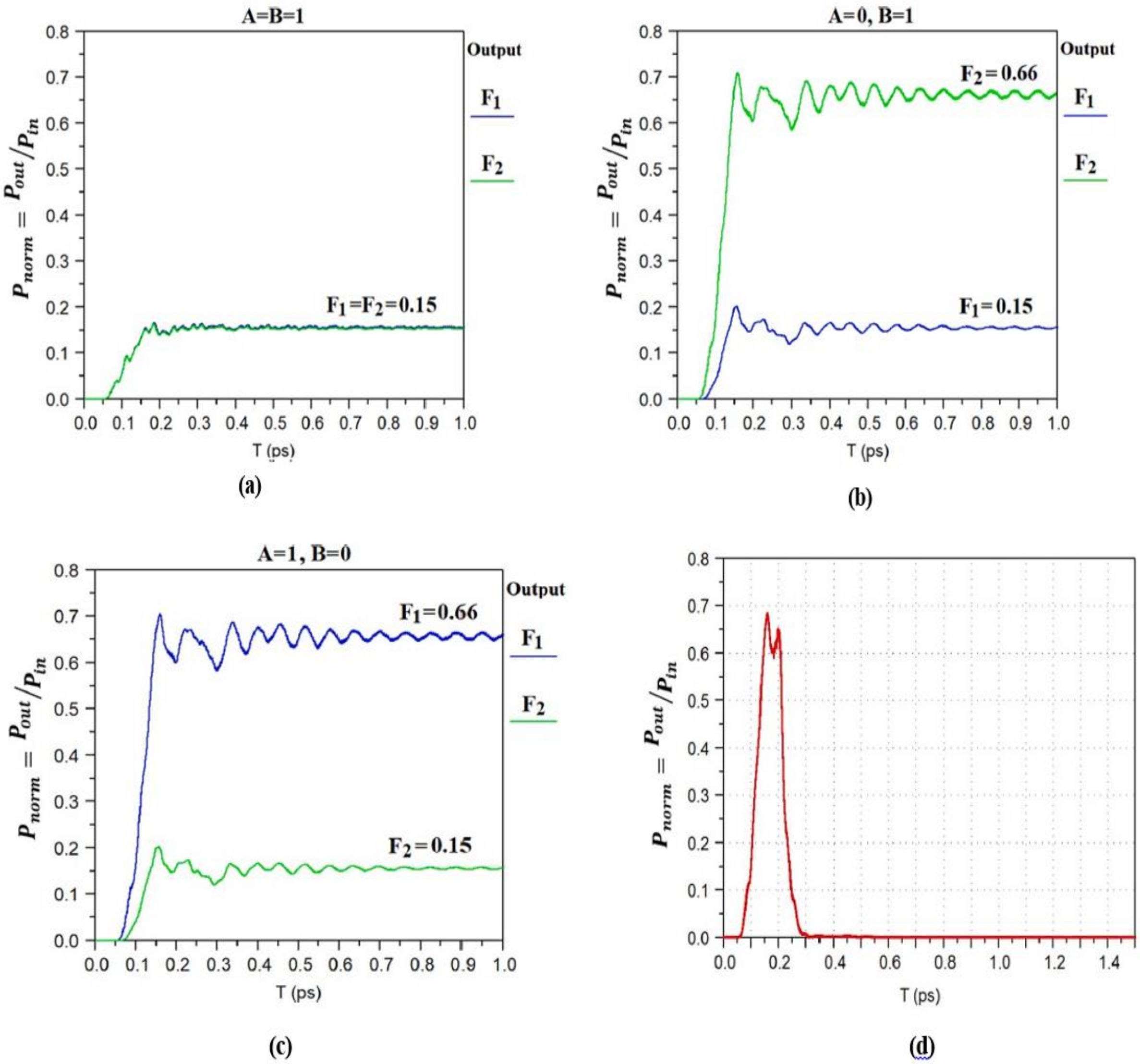

Figure 7: (a) Normalized output power for A=B=1[6] (b) Normalized output power for A=0,B=1[6] (c) Normalized output power for A=1, B=0[6] (d)output response [6]

From Fig. 7(d), this comparator achieves a delay time of0.07 ps, which means the operation takes place in a faster manner. The overall time needed for output to reach zero is 0.3 ps. The bit rate of this comparator is 3.33 Tbps [6].Fig. 8 structure consists of silicon dielectric rods having a radiusof0.17 a, where the lattice constant is a = 598 nm. The four-reflecting rod radius is chosenas0.4ato get maximum power at the output. When the input signal A=B=0andthereference signal with a phase of 180º are applied to the structure, destructive interference occurs in the T-shaped region, producing high intensityat the A=B output port. When the input signals A = 1, B = 0, and a reference signal with a phase of 180º is applied to the structure, constructive interference occurs in the T-shaped region, producing high intensity at the A>B output port. When the input signals A=0,B=1, and a

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

reference signal with a phase of 180ºis applied to the structure, constructive interference occurs in the T-shaped region, producing high intensity at the A<B output port. When the input signal A=B=1 and the reference signal with a phase of 0ºis applied to the structure, both constructive and destructive interference occur in the T-shaped region, producing high intensity at the A=B output port. This structure can find application in CPU- and microcontroller-based circuits [7].By combining ring cavity, Mach- Zehnder interferometers and single-line defects approaches, create an all-optical OR gate with a bit rate of0.8Tb/sec and a contrast ratio of 7.27 dB. [23]. An ultra compact all-optical photonic crystal AND gate, consisting of two PC ring resonators embedded between three parallel line defects Si nano crystals (Si-ncs) were used as the nonlinear material[24].An encoder design with four input wave guides for 4*2

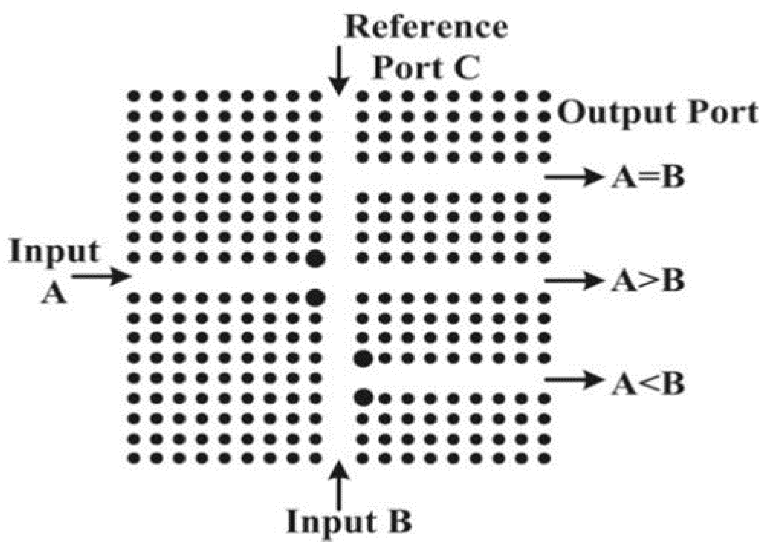

Figure 8: 11.5μm*11.5μm one bit comparator [7]

and twoY-shaped output wave guides for 8*3, and thirteen wave guides for 8 inputs and 3 outputs or 8*3.The encoder provides a high contrast ratio, better response time, low power consumption, and a wide operating bandwidth. [3].

Fig.9 structure is made of L-shaped input X1 and Y-shaped output (A) waveguides, along with a straight waveguide for input X0. The structure's lattice constant value is 580 nm, and the silicon rod radius is 0.11 μm. To improve the performance of this structure, three coupling rods are introduced at the junction of input X1 and output A with a rod radius of 30nm.

One corner rod radius of 40 nm is introduced at the output port A to avoid back reflection in the input port X1. When X0=1, X1=0, this encoder produces output as '0'. When X0=0, X1=1, this encoder produces output as '1' [13].

The primary characteristic of nonlinear materials is their refractive index, which varies with signal strength. Compact in size, non-linear materials are inexpensive because of their intrinsic qualities. Their flexibility and usefulness are increased by the fact that they operate regardless of the phase of the incoming signal.

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

Non-linear materials have various disadvantages even though they are useful in some situations. Their excessive power usage may reduce productivity and raise overhead. These materials response times affect how quickly device can operate, which might lower efficiency. Moreover, their usefulness in wider frequency applications may be limited by the fact that their working frequency is limited to the resonator drop frequency.

Furthermore, these materials usually function in a small frequency range, which might provide difficulties in applications that ask for broad performance. Therefore, while incorporating non-linear materials in different devices, these characteristics should be carefully taken into account [2].An all optical NAND gate based on photonic crystal ring resonators (PCRR), which uses the nonlinear Kerr coefficient to combine the dropping effect of PCRR [25].

A 1-bit comparator made of four resonant rings and nonlinear rods made of doped glass is suitable for high-speed processing with a maximum delay time of 2ps[27].Two1-bit values may be compared thanks to the structure's four non linear resonant rings with optical waveguides. The structure has a maximum delay time of 6ps[29].

A high-speed, 1-bit optical comparator utilising photonic crystals, because nonlinear rods are used in this structure at the junction of two optical waveguides, its footprint is much smaller—just 55 µm2. Integrated optical circuits can benefit from the suggested structure [31]. The structural parameters and functional parameters for combinational devices are summarized, along with their applications,as shown in the table.

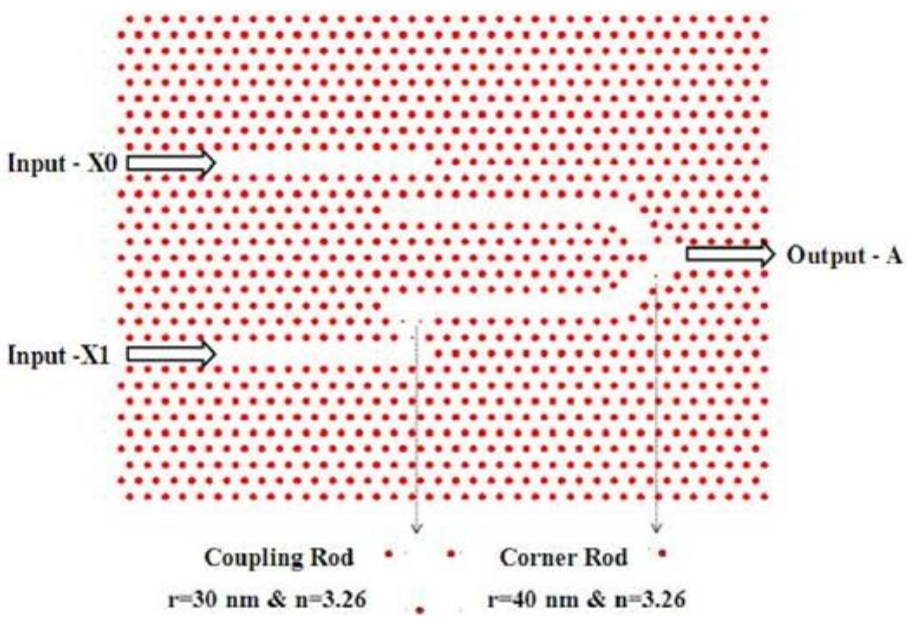

Figure 9: 37*31 silicon rod 2*1encoder [13]

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

Function	**Operating range**	**Latticetype**	**Radiusofrods**	**Lattice constant**	**DeviceDimension**	**ContrastRatio**	**Responsetime**	**Bitrate**	**Approach**	**Applications**	**Ref**
AllopticalAND and NORgates	1530nm to 1565nm	Square Sirods inair	0.18 a	522 nm	21.4µm*23.5µm	>21 dB(AND), 19dB(NOR)	**	**	MultiMode Interference	OpticalSignal Processing	[17]
AllopticalAND and XORgates	1540nm	Triangular Sirods inSio2	0.25a	0.45µm	9.9µm*10.8µm 9.9µm*11.3µm	notlessthan 6.79 dB	**	**	Multi ModeInterferene	Optialpacket switchingsystem	[18]
AND,NAND, XNOR,NOR insamestructure	1.5551nm	Square Sirods inair	105nm	302nm	**	3.1to7.4 dB	**	**	Selfcollimatedbeam	PhotonicIntegratedcircuit(PIC)andoptical computing	[19]
DesigningNOT,AND,OR,XOR,XNOR Using NAND gate	1550nm	Triangularairholes in Sisubstrate	0.3a	0.352µm	32µm*26.4µm	3.74 to 12.48 dB	2.168ps	0.461Tbps	Interference	**	[20]
OR,NOT,ANDNOR,XOR, NAND,XNOR	1550nm	Square Gerods inair	**	0.58µm	eachgateshavingdifferentdimension	5.036dB(NAND)12.155dB (XOR)	**	3.8Tbps(NAND) 7.6Tbps(XNOR)	Interference	**	[21]
NOR&AND insame structure	1550nm	Triangular Sirodinair	0.2 a	580nm	11.6µm*10µm	**	0.65ps	1.54 Tbps	Interference	PIC	[16]
NOT,NOR,XNOR,NAND	1430nmto 2120nm	Square Sirods inair	0.2a	600nm	5.04µm*5.04µm (NOTgate)8.04 µm*5.04µm forothergates	2.91db(NOR, XNOR)4.93dB (NAND)	0.35ps	**	Interference	OnchipPhotonic IC	[22]
ORgate	1287.8nm	Triangular Sirodinair	0.2a	**	12.5µm*16 µm	7.27 dB	**	0.8Tbps	Machzehnder Interferometer	PIC	[23]
AND gate	1550.9nm	SquareGaAsrodsinborosilicate crown	0.2a	455nm	18.2µm*15µm	93.1%dropefficiency	8.2ps	120Gbps	NonlineareffectandRingResonator	**	[24]
AllopticalNANDgate	1550nm	Chalcogenideglassrodinair	0.2a	640nm	18.9µm*18.9µm 37.8µm*18.9µm	**	**	**	Nonlineareffect andRingResonator	**	[25]

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

1bitcomparator	1550nm	Hexagonal GaAsrodsinair	0.18a	600nm	60µm²	**	Delay time is0.07ps	3.33Tbps	Interferencebased linedefects	Highspeedlogic circuit	[6]
1bitcomparator	1330nm to 2222nm	Hexagonal Sirods inair	0.2a	600nm	691µm²	**	Delay time is0.5ps	0.25Tbps	Nonlinear ResonantRing	Opticaldata Processor	[26]
1bitcomparator	1417nm to 2125nm	Square Sirods inair	0.2a	595nm	1585µm²	**	Delay time is1.2ps	<0.2Tbps	Nonlinear ResonantRing	PIC	[27]
1bitcomparator	1550nm	Square Sirods inair	120nm	599nm	2690µm²	**	Delay time is1ps	<0.2Tbps	Nonlinear ResonantRing	Opticaldata Processor	[28]
1bitcomparator	1.55µm	Square Sirods inair	0.17a	600nm	11.5µm*11µm	**	**	**	Leardefects	Centralprocessingunit &Microcontrollingcircuits	[7]
1bitcomparator	1.55µm	Square Sirods inair	0.2a	600nm	149.04µm²	5.2dB	Risetimeis 0.4psandDelaytimeis0.1ps	**	Interferencebasedlinedefects	**	[30]
1bitcomparator	1363nmto 2222nm	Square Sirods inair	120nm	600nm	55µm²	5.26 dB	Delaytimeis 0.31ps	**	Nonlinear	Integratedopticalcircuits	[31]
2:1Encoder	1520nm	Triangular Sirods inair	0.11µm	0.585µm	343µm²	25.82 dB	0.2833ps	3.52Tbps	Linearlineand pointdefects	Photonicintegratedcircuit, optical signalprocessor	[13]
4:2Encoder	1.525µm	Square Sirods inair	0.2a	0.6µm	128.52µm²	7.1138 dB	0.1ps	10Tbps	Linearline defect,RingResonator	Highspeedopticalprocessingdevices	[11]
4:2ReversibleEncoder	1550nm	Hexagonal Sirods inair	247.nm	650nm	**	11.5dB	**	**	Nonlinearring resonator	PIC	[32]
4:2Encoder 8:3Encoder	1550nm	TriangularSirodsinair	0.2a	610nm	415.84µm²for4:2Encoder 705.12 µm²for 8:3Encoder	8.1 dBfor 4:2Encoder9.08dB for 8:3Encoder	0.28ps for4:2Encoder0.132psfor 8:3Encoder	3.5Tbpsfor4:2Encoder 7.5Tbpsfor8:3Encoder	Linearlineand pointdefects	Opticalswitchingintegrated device	[3]

ISSN: 1671-5497
E-Publication: Online Open Access
Vol: 43 Issue: 11-2024
DOI: 10.5281/zenodo.14208836

CONCLUSION

Optical Signal Processing, Optical Packet Switching System, Photonic Integrated Circuit (PIC), Optical Computing, High Speed Logic Circuit, Optical Data Processor are the several applications related to PhC-based combinational devices, such as all optical logic gates, comparators, encoders and so forth. The approaches for designing all optical photonic crystal-based combinational devices are broadly divided into linear and nonlinear. Both types have their own advantages and disadvantages based on the applications. High contrast ratio, small dimension, minimum power consumption, reversible operation are the vital requirements of all optical photonic crystal-based combinational devices. By reviewing the articles, structural parameters are the key factors for obtaining the needed functional parameters of photonic crystal-based combinational circuits. AI-based design, topological photonics, and photonics combining with plasmonics are the latest and upcoming approaches for designing all optical combinational devices.

References

1) Joannopoulos,J.D., Villeneuve,P.R., & Fan, S. (1997,March13). Photonic crystals: putting a new twist on light. *Nature*, *386*(6621), 143–149.https://doi.org/10.1038/386143a0

2) Hussein,H. M.,Ali,T. A., & Rafat,N.H.(2018, October).A review on the techniques for building all-optical photonic crystal logicgates.

3) *Optics &Laser Technology*, *106*,385–397. https://doi.org/10.1016/j.optlastec.2018.04.018.

4) Latha,K.,Arunkumar,R.,Prabha,K.R.,&Robinson,S.(2021,April15).Performance AnalysisofallOptical4*2and8*3EncoderUsing Two Dimensional Photonic Crystals Waveguides. *Silicon*, *14*(7), 3245–3258. https://doi.org/10.1007/s12633-021- 01107-2

5) Butt,M.,Khonina,S.,& Kazanskiy,N.(2021,October).Recent advances in photoniccrystalopticaldevices: A review. *Optics & Laser Technology*, *142*, 107265. https://doi.org/10.1016/j.optlastec.2021.107265

6) Robinson, S.,& Nakkeeran, R.(2013,June12). *Photonic crystal ringresonator-based add drop filters: a review*. Optical Engineering. https://doi.org/10.1117/1.oe.52.6.060901

7) Parandin,F.(2021,December).Ultra-compactterahertzall-optical logic comparator on GaAs photonic crystal platform. *Optics & Laser Technology*, *144*, 107399. https://doi.org/10.1016/j.optlastec.2021.107399

8) Rathi,S.,Swarnakar,S.,& Kumar,S.(2019,October25).Design of One-Bit Magnitude Comparatorusing Photonic Crystals. *Journal of Optical Communications*, *40*(4), 363–367. https://doi.org/10.1515/joc-2017-0084

9) Seif-Dargahi, H.(2018,June15).Ultra-fast all-optical encoder using photonic crystal-based ring resonators. *Photonic Network Communications*, *36*(2), 272–277. https://doi.org/10.1007/s11107-018-0779-3

10) Gholamnejad, S., & Zavvari, M. (2017,August 20).Design and analysis of all-optical4–2binaryencoder based on photonic crystal. *Optical and Quantum Electronics*, *49*(9). https://doi.org/10.1007/s11082-017-1144-y

11) Moniem,T.A.(2015,July6).All optical active high decoder using integrated 2 Dsquare lattice photonic crystals. *Journal of Modern Optics*, *62*(19), 1643–1649. https://doi.org/10.1080/09500340.2015.1061061

12) Mostafa,T.S.,Mohammed,N.A.,&El-Rabaie,E.S.M.(2018,November23).Ultracompact ultrafast-switching-speedall-optical4×2 encoder based on photonic crystal. *Journal of Computational Electronics*, *18*(1), 279–292. https://doi.org/10.1007/s10825-018-1278-6

13) Anagha, E. G.,& Jeyachitra, R. K. (2022, June25).Review on all-optical logicgates: design techniques and classifications –heading toward high-speed optical integrated circuits. *Optical Engineering*, *61*(06). https://doi.org/10.1117/1.oe.61.6.060902

14) Rajasekar,R.,Latha,R.,&Robinson,S.(2019,September).Ultra-contrastratio optical encoder using photonic crystal waveguide. *Materials Letters*, *251*, 144–147. https://doi.org/10.1016/j.matlet.2019.05.040

15) D'souza,N.M., & Mathew, V.(2016,June). Interference based square lattice photonic crystallogic gates working with different wavelengths.

16) *Optics &Laser Technology*,*80*,214–219.https://doi.org/10.1016/j.optlastec.2016.01.014

17) Fan,R., Yang, X., Meng,X., &Sun,X.(2016, July21). 2D photonic crystallogic gates based on self-collimatedeffect. *JournalofPhysicsD:*

18) *AppliedPhysics*,*49*(32),325104.https://doi.org/10.1088/0022-3727/49/32/325104

19) Parandin,F., & Karkhanehchi, M.M. (2017,January).Terahertzall-optical NOR and AND logicgates based on 2Dphotonic crystals.

20) *SuperlatticesandMicrostructures*,*101*,253–260.https://doi.org/10.1016/j.spmi.2016.11.038

21) Tang,C.,Dou,X.,Lin,Y.,Yin,H.,Wu,B.,&Zhao,Q.(2014,April).Designofall-opticallogic gatesavoidingexternalphaseshifters ina two-dimensional photonic crystal based on multi-mode interference for BPSK signals. *Optics Communications*, *316*, 49–55. https://doi.org/10.1016/j.optcom.2013.11.053

22) Ishizaka,Y.,Kawaguchi,Y.,Saitoh,K.,&Koshiba,M.(2011,July).Designofultracompact all-opticalXORand AND logicgateswithlow power consumption. *Optics Communications*, *284*(14), 3528–3533. https://doi.org/10.1016/j.optcom.2011.03.069

23) Christina, X. S., &Kabilan, A. P. (2012, April3). Design of opticallogic gates using self-collimatedbeams in2Dphotoniccrystal. *Photonic Sensors*, *2*(2), 173–179. https://doi.org/10.1007/s13320-012-0054-7

24) Rani, P., Fatima, S., Kalra, Y.,&Sinha, R. (2017, September). Realization of all optical logicgates using universal NAND gatesonphotonic crystal platform. *Superlattices and Microstructures*, *109*, 619–625. https://doi.org/10.1016/j.spmi.2017.05.046

25) Hussein,H.M.,Ali,T.A.,&Rafat,N.H.(2018,March).NewdesignsofacompletesetofPhotonicCrystals logicgates. *Optics Communications*, *411*, 175–181. https://doi.org/10.1016/j.optcom.2017.11.043

26) Shaik,E.H.,&Rangaswamy,N.(2015,December19).Improveddesignofall-opticalphotoniccrystallogicgatesusingT-shapedwaveguide.

27) *OpticalandQuantumElectronics*,*48*(1).https://doi.org/10.1007/s11082-015-0279-y

28) Pirzadi,M.,Mir,A.,&Bodaghi,D.(2016,November1).RealizationofUltra-AccurateandCompact All-OpticalPhotonicCrystalORLogic Gate. *IEEE Photonics Technology Letters*, *28*(21), 2387–2390. https://doi.org/10.1109/lpt.2016.2596580

29) Andalib,P., &Granpayeh, N. (2008,December 10). All-optical ultracompact photonic crystal AND gate based on nonlinear ring resonators.

30) *Journal of the Optical Society of America B*,*26*(1),10.https://doi.org/10.1364/josab.26.000010

31) Serajmohammadi,S.,&Absalan,H.(2016,June).AllopticalNANDgatebasedonnonlinearphotoniccrystalri ngresonator. *Information Processing in Agriculture*, *3*(2), 119–123. https://doi.org/10.1016/j.inpa.2016.04.002

32) Surendar,A., Asghari, M., & Mehdizadeh, F.(2019, May25). A novel proposal for all-optical1-bit comparator using nonlinear PhCRRs.

33) *PhotonicNetworkCommunications*,*38*(2),244–249. https://doi.org/10.1007/s11107-019-00853-z

34) Jalali,S.M.,Soroosh,M.,& Akbarizadeh,G.(2019). Ultra-fast 1-bit comparator using nonlinear photonic crystal based ringer sonators. *Vol. 4,*(No. 3), 59-71 http://jopn.miau.ac.ir/article_3620_4f1f70678e51c36588c08081f8d10f3d.pdf

35) Serajmohammadi,S.,Alipour-Banaei,H.,&Mehdizadeh,F.(2019,May).Anovelproposalforalloptical1-bit comparatorusingnonlinear PhCRRs. *Photonics and Nanostructures - Fundamentals and Applications*, *34*, 19–23. https://doi.org/10.1016/j.photonics.2019.01.002

36) Fakouri-Farid, V.,&Andalib, A. (2018,November). Design and simulation of an all optical photonic crystal-basedcomparator. *Optik*, *172*, 241–248. https://doi.org/10.1016/j.ijleo.2018.06.153

37) Parandin, F., Olyaee, S.,Kamarian, R., & Jomour, M. (2022, June29).Design and Simulation of Linear All-Optical Comparator Basedon Square-Lattice Photonic Crystals. *Photonics*, *9*(7), 459. https://doi.org/10.3390/photonics9070459

38) Seraj,Z.,Soroosh,M.,&Alaei-Sheini,N.(2020,January17).Ultra-compact ultra-fast 1-bit comparator based on a two-dimensionalnonlinear photonic crystal structure. *Applied Optics*, *59*(3), 811. https://doi.org/10.1364/ao.374428

39) Monisha,S.,Saranya,D.,&Rajesh,A.(2018,December1).Designandanalysisofmulti-hexagonalreversibleencoderusingphotonic crystals. *Optical and Quantum Electronics*, *51*(1). https://doi.org/10.1007/s11082-018-1718-3