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Design of Compact TE Polarized 2 Dimensional Photonic Crystal based Y junction Power Splitter

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Abstract:
Photonic crystals provide the opportunity to design ultra-compact power splitters for their capability to localize light in small regions. This area has received huge interest of researchers for equal and efficient distribution of power among the branches of the splitter. However these splitters suffer from the challenges of severe backward reflections at the sharp corners and the complexity in the design at the fabrication level. This paper presents an ultra-compact (10 x 10 µm2) two dimensional photonic crystal (PC) based power splitter with two output ports for applications in photonic integrated circuits (PICs). The splitter is based on a Y junction with multiple line defect photonic crystal waveguide (MLDPCW). The PC based optical power splitter is designed with tuning rods at the corners of each output channel as well as at the junction to optimize the resonance effect and resulted in an overall efficiency of 88%. The results and the design of the proposed splitter are promising for implementation in the future optical integrated circuits.

Keywords: Photonic crystal, photonic integrated circuits, multiple line defect photonic crystal waveguide, finite difference time domain, plane wave expansion, photonic bandgap.

I. Introduction

Photonic crystals (PCs) are the artificially designed structures by periodic variation of dielectric constantthat can control the light propagation[1]. This periodicity of dielectric constant can be obtained in one, two or three directions and hence PCs can be categorizedas 1dimensional (1D) PCs, 2 dimensional (2D) PCs, 3dimensional (3D) PCs. PCs are able to localize, manipulate and control the light propagation at micro and nano scale. Ultra compact photonic devices can be designed by the PCs that can revolutionize the future photonic integrated circuits (PICs). The propagation of electromagnetic (EM) waves in a structure whose periodicity is comparable to the wavelength of wave in free space results in a photonic bandgap (PBG). PBG is like the forbidden band in case of semiconductor materials and waves with frequencies within this bandgap would be completely trapped inside the material and others will be totally reflected on the surface of such materials independent of the angle of incidence and mode [2]. PC based devices have been the focus of research in recent years for the development at nano and micro scale level.

As a result of unique features, PCs can be used to design various optical devices like optical filters, couplers, power splitters etc. PCs are the most suitable candidates for the future opto integrated circuits because of their capability to design ultra-small optical devices [3]. Among the various optical devices power splitter is the most important component for distributing power to different sections on a PIC. There are various methods of dividing input power equally into multiple branches of power splitter, for example straight waveguide, directional coupler based splitter, Multimode waveguides etc. [4] proposed an optical power splitter of triangular lattice with air holes created on the PBG effect of PC waveguide. The transmission efficiency of 49.5% is achieved over a bandwidth of 70nm by presenting a defect hole in the PC waveguide.The size of the splitter is 10x12μm^2.[5] proposed a 10x13μm^{2}1x3 power splitter based on silicon slab PC with triangular lattice and holes of air. Two drop holes are placed at the junction to interact with the entering EM wave and reported 33% transmission efficiency in each branch at 1550nm.[6] proposed a PC slab based 1x3 power splitter with identical power distribution. Flexible structural defects are introduced in the structure to achieve the desired equal splitting of 29.6%, 28.9% and 30.5% at 1550nm optical wavelength. [7] reported an optical power divider in a 2D PC with triangular lattice with one input and four output ports. The splitter consists of a directional coupler and Y junction with four output branches. A transmission efficiency of 22% is obtained in each output branch. The power splitter designs presented in the literature have considerably large area so the compactness feature is missing in existing designs of the splitter.Large size can cause the problems at the fabrication level and are not suitable for applications in PICs. Moreover, these designs also suffer from severe backward reflections and transmission losses due to mode mismatch and bending losses [8].These limitations can be overcome by introducing certain defects at the junction and sharp bends of the splitter. This paper aims topresent an ultra-compact (10 x 10 μm^2) 2DPC based power splitter with two output ports for application inPICs.The paper is organized as follows-Section II presents the details of the design of the Y junction splitter. Section III presents the results and discussions of the optimized splitter structure followed by section IV which presents a brief conclusion.

II. Design Description

In this paper an ultra-compact 2D PC based Y junction power splitter with two output ports is proposed. Suitable defects are introduced across the junction and the bending region to decrease the reflection losses and equally divide power at the two output ports of the divider with improved efficiency. The 1x2 splitter design is based on a hexagonal lattice with holes of air. The distance between two air holes is 1 micrometer which is known as the lattice constant and is indicated by ‘a’. PC based linear waveguide defects (PCLWD) are used to design the 1x2 power splitter with extra rods placed at the junction region as well at the bends of the waveguide to avoid reflections and to obtain maximum transmission efficiency. The EM waves travels through a periodic configuration whose periodicity is comparable to the wavelength of the wave. There exists one PBG for TE polarization that ranges from 0.269228 λ/a -0.453655 λ/a where λ is the wavelength of free space and ‘a’ is the lattice constant as shown in figure 1.

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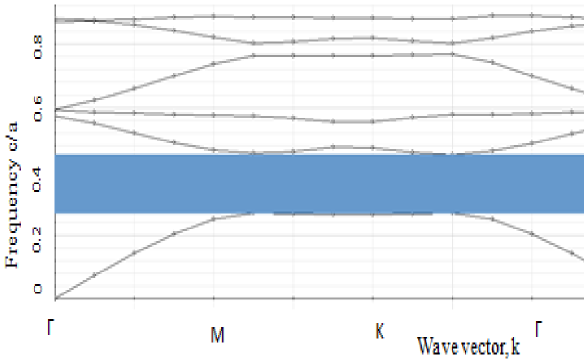

Figure 1: Photonic Bandgap diagram for 2D PC based hexagonal lattice for TE polarization

The designed splitter is very compact with the dimensions of 10 µm x 10 µm and is based on a silicon (Si) substrate of refractive index n_1 of 3.47 in which holes of air are inserted with refractive index n_2 of 1 and radius of 0.2a. The number of rods is 13 x 10 and the performance characteristics are analyzed at 1550nm.

The input source consists of a Gaussian modulated continuous wave at 1.55 µm and is configured in positive z-direction. The air holes are removed to introduce defects at certain positions to create a Y shaped splitter as shown the figure 2. The Y junction is the simplest structure and can be easily converted into 1x N splitter without complications at the fabrication level. Nine Tuning rods are inserted at the bends and nine rods are placed along the output arm 1 and 2 of the optical power splitter with a radius of 0.1 Four more tuning rods are positioned at the splitting junction of the splitter with a radius of 0.1a and a big tuning rod is also placed behind these rods with a radius of 0.25a to provide the resonance effect at the splitting area for optimum power flow towards the output and minimum reflectionas shown in figure 2..

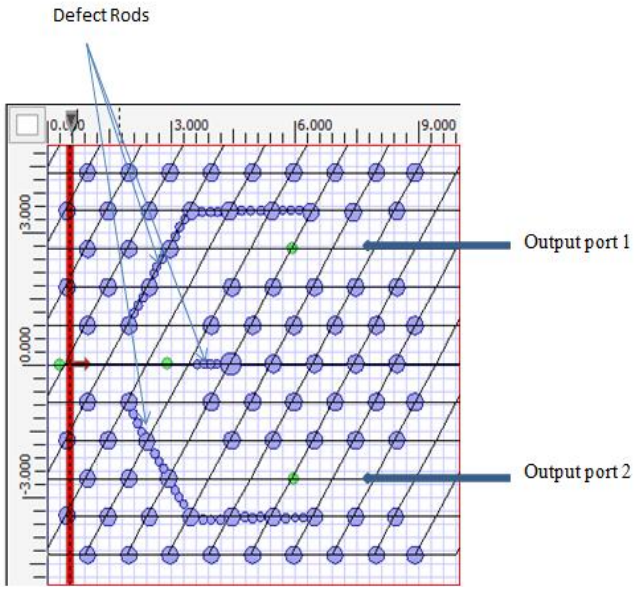

Figure 2: 2 Dimensional PC based Y junction splitter structural defect rods

III. Results & Discussions

Plane Wave Expansion (PWE) technique is used to analyze the PBG and finite difference time domain (FDTD) technique is applied to evaluate the performance of the designed splitter. Four observation points are positioned across the two output arms, one at the junction point and one behind the input source to observe the reflection as shown by green dots in the figure 2.These observation points located along each arm of the splitter measure the electric and magnetic field distribution in the positive z direction. For the optimization of the proposed design the defect rods act as reflectors for reducing the backward reflection and leakage of light at the corners of the waveguide. Resonator is realized by introducing a big defect rod at the junction area of the splitter which resonates maximum power into the output branches. The splitter is excited with transverse electric (TE) polarization. A sufficiently wideband Gaussian modulated pulse is injected into the input port at 1550nm and the mesh parameters used are 0.1 um (delta X) X 0.1 um (delta Z) with 100 cells in the X and Z path. Anisotropic perfectly matched layers (APML) are placed as absorbing boundary conditions around the wafer.

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The number of APML layers is equal to 10. The simulation is carried out for 10000 time steps for evaluating the final results. Figure 3 (a-d) presents the response of time varying electric field E_y for input port, output ports and for backward reflections respectively.

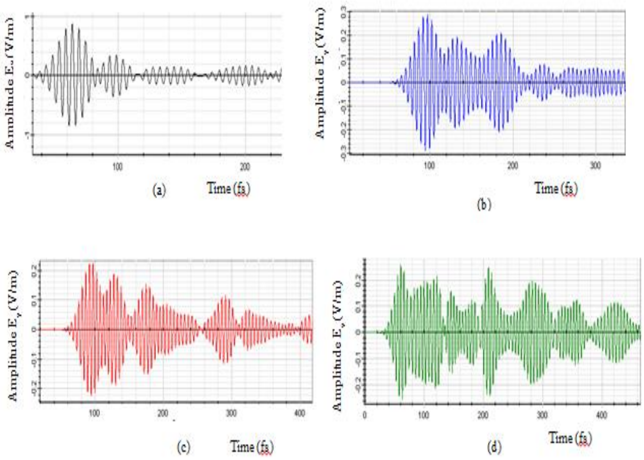

Figure: 3 (a-d) Amplitude of time varying electric field E_y at the input port, output port 1, output port 2 and behind the input source of the

Further the normalized input power and output power distribution along the input and output ports of the splitter at 1.55 µm is represented in figure 4a to4c respectively. The reflection losses in the splitter are represented in figure 4d. As inferred from the results the input port has a normalized power of 0.01 at 1.55µm as shown in figure 4a. The normalized power distribution in arm 1 and 2 of the splitter is 0.004 and 0.0048 as indicated in figure 4b and 4c respectively. The reflections losses are reported as 0.0028 as represented in figure 4d. Therefore from the results the overall efficiency of the proposed splitter is computed as 88%. Table 1 presents the comparison of different designs of splitter reported in the literature on the basis of wavelength, area and lattice structure.

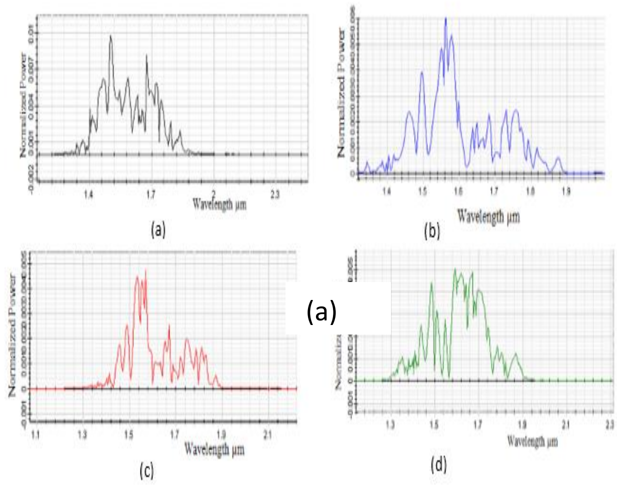

Figure: 4Transmission characteristics for Y junction splitter, (a) Input Normalized Power = 0.01 (b) Output Power in Port 1 = .0048 (c) Output Power in Port 2 = .004 (d) Reflection losses= .0028

Table1: The comparison of different designs of splitter based on area

References	Wavelength (µm)	Area (µm^2)	Structure
Tianbao Yu et.al [4]	-	10x12	Triangular lattice of air holes
Din Chai Tee et.al [5]	1.55	10x13	Triangular lattice of air holes
Md. Mahfuzur Rahman et.al [12]	1.56	21x15	Hexagonal lattice Silicon Dielectric rods in air
Peiyuan Zhang et.al [13]	1.55	10.54x17.98	Square lattice of dielectric rods
Simranjit Singh et.al [14]	1.9	21x10	Rectangular lattice of elliptical air holes
Proposed by this paper	**1.55**	**10x10**	**Hexagonal lattice of air holes**

As shown in table 1 the compactness feature is missing in the designs of the splitters presented in the literature [4-5, 12-14].Large size can cause problems at the fabrication level and are not suitable for applications in PICs. However the proposed splitter design in this paper has small footprints which will open new prospects for the design of ultra-compact optical devices. The proposed design can play a vital role for the

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development of miniaturized photonic integrated devices which leads to further progress in the field of all optical integrated chips. It can be seen from the graphs that for the proposed design the transmission efficiency obtained is 88% across the two output arms of the splitter. Almost equal power distribution is achieved across the parallel arms of the splitter by setting the radius of defects in the coupling area. This can be attributed to the fact that the conventional Y junction splitter suffers from severe backward reflections and radiation losses due to mode mismatch and sharp bends of the waveguide. In order to minimize the same, the PC based optical power splitter has been designed with tuning rods at the corners of each output channel as well as at the junction to optimize the resonance effect. These tuning rods act as reflectors for reducing the backward reflection and leakage of light at the corners of the waveguide.

IV. Conclusion

An ultra-compact 2D PC based Y junction power splitter has been presented in which structural defects have been precisely introduced to obtain maximum transmission efficiency with minimum backward reflections. The splitter is designed at 1550nm wavelength and is simulated using FDTD approach. The PC based optical power splitter has been designed with tuning rods at the corners of each output channel as well as at the junction to optimize the resonance effect and reduce reflection lossesfor optimum power flow towards the output These tuning rods act as reflectors for reducing the backward reflection and leakage of light at the corners of the waveguide and resulted in an overall efficiency of 88%. The proposed design can play a vital role for the development of miniaturized photonic integrated devices which leads to further progress in the area of all optical integrated chips.

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