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Design of Photonic Crystal Polarization Splitter on InP Substrate

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Abstract: In this article, we suggested a novel design of polarization splitter based on coupler waveguide on InP substrate at 1.55μm wavelength. Photonic crystal structure is consisted of two dimensional (2D) air holes embedded in InP/InGaAsP material with an effective refractive index of 3.2634 which is arranged in a hexagonal lattice. The photonic band gap (PBG) of this structure is determined using the plane wave expansion (PWE) method by RSOFT Bandsolve software. Band diagram also show an overlap of two photonic bandgaps for both TE and TM about 1.55 μm wavelength. Also, the band structure is calculated for a lattice constant of 625 nm and a radius of 266.6 nm. The proposed polarization splitter has a transmission spectral of 75% and 70% for the TE and TM polarized light, respectively. The proposed polarization splitter is realized in a standard semiconductor technology on InP substrate at 1.55 μm wavelength and can be easily monolithically integrated with other planar integrated circuits.

Keywords: directional coupler, polarization splitter, photonic crystal, InP materials.

1. Introduction

The photonic laboratories conduct researches in the areas of Photonic crystals (PhCs) over the past two decades which such nanostructures boost the capability of computers and telecommunications in the near future. Photonic crystals (PhCs) are artificial multidimensional periodic structures with a period of the order of optical wavelength in which the refractive index modulation gives rise to stop bands for optical waves within a certain frequency region known as photonic band gaps (PBGs) [1-3].

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Since the PhCs allow strong control over the propagation of light, one of the most fundamental applications of the PBGs are photonic crystal waveguides. PhC waveguides can be formed by the introduction of line defects into otherwise perfect PhC. A PhC directional waveguide coupler can be designed by placing two 2D PhC waveguides in close proximity of each other [3-5].

PhC structures are highly sensitive to the polarization of incident light. So, it is possible to design polarization controller devices such as polarization splitter [1], polarization filter [2], and polarization converter [3]. A polarization splitter is a device which can separate the incoming polarization states. In addition, InP-based monolithic integrated optic devices have been broadly developed by photonic chips researchers due to the capability for monolithic integration of transmitter, receiver, switch, laser, and modulator on one chip [4].

Several types of polarization splitter, based on two dimensional (2D) PhCs, have been investigated [1-6]. Wu [7] realized a photonic crystal-based polarization splitter by using differential dispersions of TE and TM modes in the wavelength range of 1250-1300 nm on GaAs substrate. They could separate E- and H-polarized beams by 10° after propagation through a 20 µm photonic crystal structure. Zabelin [8] demonstrates a self-collimating beam splitter which shows a large reflection for TE and a high transmission for TM polarization optical field at wavelength windows of 1.55µm on InP substrate. The transmission was reported about 35% for TM and 30% for TE polarized field. A polarization splitter based on the waveguide coupler is designed with the specifications of a 32 µm long device and a bandwidth of 120 nm which operates at a wavelength of 1.55 µm. This device is composed of dielectric rods in air background in honeycomb structure [9]. Morita [10] suggested a resonant-coupling-type polarization splitter on the photonic crystal waveguide. The device includes hexagonal holes in a medium with a refractive index of 3.4. Two line defects with elliptical air holes and a microcavity hole are introduced in the photonic crystal geometry which separates the incoming polarized field. The proposed device has a very short length of 4a (a is the lattice constant).

In this article, we suggested a polarization splitter based on coupler waveguide of PhCs which lead to different propagation directions for the TE and TM polarized light. Our polarization splitter is realized in standard semiconductor technology on InP substrate at 1.55 µm wavelength and can be easily monolithically integrated with other planar integrated circuits.

The proposed polarization splitter is formed by two photonic crystal waveguides. Designing a polarization selective coupler, in which one polarization can couple between the two channels, while another one cannot, can make a polarization splitter.

2. Design structure

The filter layer stack is composed of a 500nm InGaAsP film layer with a bandgap wavelength of 1.25μm (denoted as Q(1.25)) and an InP cladding layer of 1500 nm thick on an InP substrate. The refractive indices of InP/Q(1.25) are 3.1693/3.3640 at 1550 nm wavelength. The effective refractive index of the three-layer slab waveguide (InP/Q(1.25)/InP) is determined to be 3.2634 by using COMSOL software at a wavelength of 1.55 μm.

The geometry of two-dimensional PhC having a hexagonal lattice with a lattice constant of a is shown in Fig.1, which consists of low air holes (with radius r) in a high dielectric background. The bandgap of this structure is determined using the plane wave expansion (PWE) method by RSOFT Bandsolve software. Fig. 2 shows the 2D band diagram for a hexagonal hole type lattice in dielectric having a lattice constant of 625 nm and holes radius of 266.6 nm in K-direction (Γ-M-K-Γ) for TE and TM modes. As it can be seen, this structure shows an overlap of two photonic bandgaps for both TE and TM modes about 1.55 μm wavelength. The overlap normalized frequency of the photonic bandgap is between 0.3984 and 0.4142 corresponding to the wavelengths of 1.508 μm to 1.568 μm for TM and TE modes. It is enough for the optical communication networks in the window of 1530 to 1570 nm. Also, the band structure is calculated for a lattice constant of a=625 nm and a radius of r=266.6 nm in K-direction (Γ-M-K-Γ) for TM mode (Fig. 3).

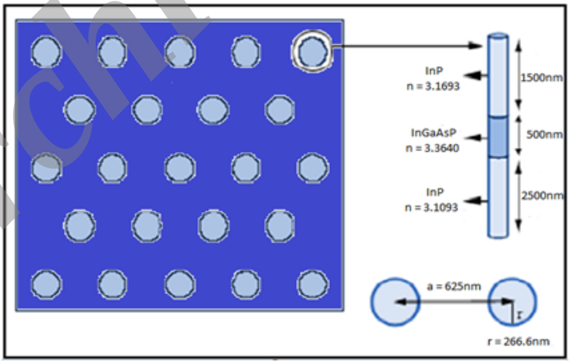


Fig. 1. Geometry of pillars in a square lattice together with layer specifications.

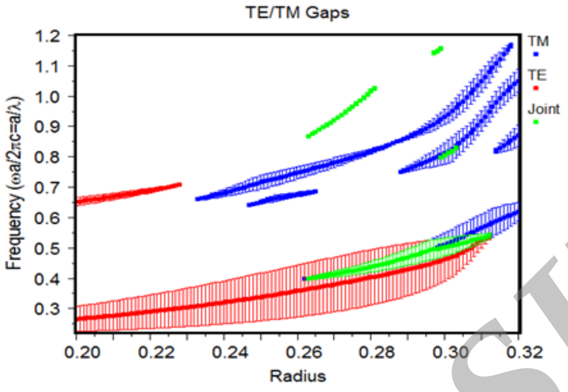


Fig. 2. 2D band diagram of a hexagonal array of air holes in high-index dielectric, having a radius of 266.6 nm and the lattice constant of 625 nm.

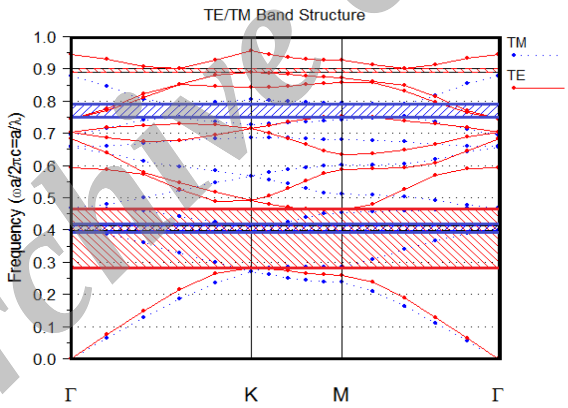


Fig. 3. Band diagram of both TE and TM modes.

3. Simulation results

In Fig. 4, the 2D-structure of the polarization beam splitter is shown. The proposed photonic crystal polarization splitter has a dimension of 21×15a2. To determine the transmission spectral response of the polarization splitter, the FDTD method with perfectly matched boundary (PML) conditions is carried out using RSOFT Full wave [11]. The grid size in the x- and y-directions (Δx and Δy) are set to $\Delta x=\Delta y=0.033a=19.5$ nm to have maximum accuracy and time step is chosen $\Delta t \le 1/c\sqrt{\Delta x^2+\Delta z^2}$ to have stability condition, where c is the speed of light in free space. The incident light is considered as a gaussian pulse beam with a width of a to cover whole frequency range of the bandgap window. The proposed polarization splitter is designed using 2 line defects introduced into the photonic crystal structure. These line defects create a two waveguide path for TE and TM polarization modes. To improve the coupling spectrum of the TE polarized light, some elliptical holes can enhance the output power as shown in Fig. 4. To split the TE polarization light, it has been used the effect of coupling. The distribution of the TE and TM polarized beams are plotted in Fig. 5. By launching a continuous wave (CW) at the center wavelength of 1.55 μm. Fig. 6 illustrates the transmission spectral of the TE and TM polarized lights at wavelength range of 1.53-1.57 μm.

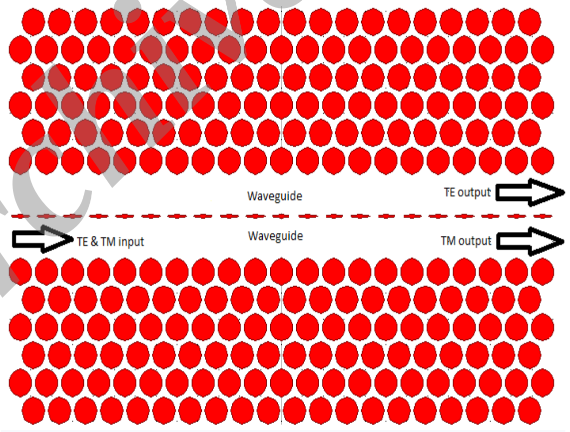
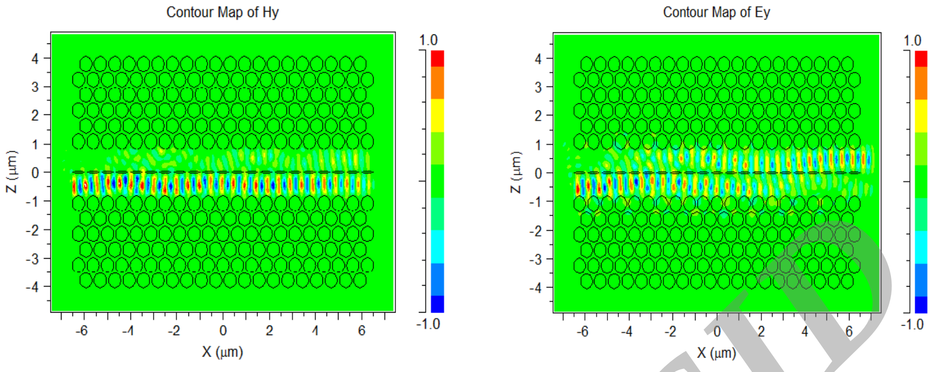
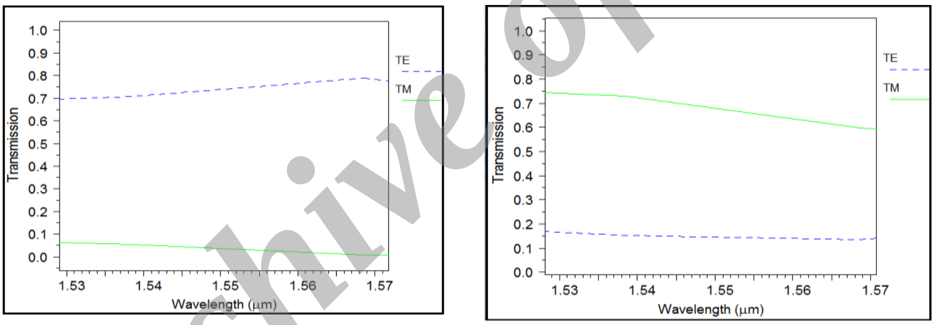


Fig. 4. 2D-geometry of the polarization splitter.



(a) (b)

Fig. 5. Optical field distribution for the TM, (a) and TE, (b) polarized light.



(a) (b)

Fig 6. Transmission spectral of two outputs for the TM, (a) and TE, (b) polarized light.

4. Conclusion

We described a polarization splitter based on air holes on high-index background in a hexagonal lattice. At first, we introduced the layer stack of 3D-structure and then the bandgap and band diagram of photonic crystal are determined. They show that TM mode can cross in the first waveguide but TE mode coupled to second waveguide. The novel design utilizes the photonic bandgap and coupler waveguides approaches to separate the TE and The TM polarized optical field. The spectral transmission of the TE and TM polarized light for each output channel are determined which shows an enhancement respect to the similar devices.

5. References

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