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DOUBLE BENDS AND Y-SHAPED SPLITTER DESIGN FOR INTEGRATED OPTICS

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Abstract—We present new designs of waveguide components in photonic crystal structures used for routing light exhibiting high transmission. In particular, we focus on the design of a brick that will form the PhCs network, i.e., a double bends and Y-shaped splitter. Photonic crystals are considered a good way for realizing compact optical bends and splitters. The PhC consists of a triangular array of holes etched into InP/GaInAsP/InP heterostructure. Propagation characteristics of the proposed devices are analyzed utilizing two-dimensional finite difference time domain (FDTD) method. The FDTD simulations confirm their unprecedented efficiency and robustness with respect to wavelength and structural perturbations. The PhCs transmission properties are then presented and discussed. Numerical results show that a total transmission of about 75% at output ports is obtained.

1. INTRODUCTION

Photonic crystals (PhCs) are of great interest in both physics and engineering communities. These PhCs consist of an ensemble of periodic optical scatterers which, through their coherent interaction, induce a photonic band structure and eventually a band gap for certain optical frequencies. Photonic crystals offer numerous potential applications and promise to greatly enhance the control over the flow of light and, consequently, to initiate important technological developments in the fields of semiconductor lasers, LED-based lighting

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or highly integrated all-optical signal processing. Photonic crystals are structures whose dielectric index varies periodically across the wavelength. Indeed photonics engineering such as fiber optics, filters, lasers, amplifiers, microresonators, polarizers and rotators, etc., follow this property to control the light propagation. In a simple vision, simply introduce defects of periodicity in selected areas within the crystal to achieve the desired optical components (guides, bends light ...), and pair them to form a true photonic circuit. In particular, the design and implementation of efficient optical waveguides by inserting a linear defect in a triangular 2D periodic lattice where it is expected the existence of localized modes along the linear defect in a selected direction. The various components are produced from as linear defects.

Photonic Crystal structures have been heralded as a disruptive technology for the miniaturization of opto-electronic devices, offering as they do the possibility of guiding and manipulating light in sub-micron scale waveguides [1–3]. Applications of photonic crystal guiding the ability to send light around sharp bends or compactly split signals into two or more channels. Bends and splitters are important components for designing photonic circuits. While straight waveguides and bends have now been studied extensively, the very important problem of bends and junctions that is essential for the operation of more complex circuits which are built around PBG structures has only recently received attention [4–7].

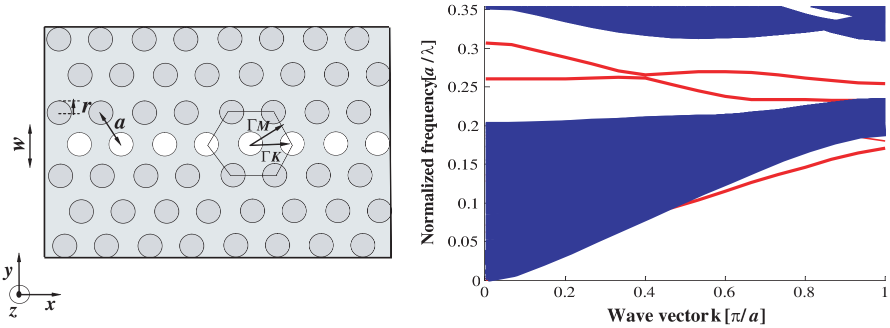
In this paper an attempt was made to design compact Photonic Crystal structure used for routing light ie a double bends and Y-shaped splitter which consists of one input photonic crystal waveguide PhCW and two output PhCWs with optimized transmission characteristics. The simulation was performed using the two-dimensional finite difference time domain (FDTD) method. The FDTD method will easily perceive the mechanisms involved in these devices.

2. SIMULATION RESULTS AND DISCUSSION

To validate our results numerically, we use a finite-difference time-domain (FDTD-2D) method to simulate the wave propagation inside the double bend and the Y-shaped splitter in a two-dimensional photonic crystal.

2.1. Double Bend Design

For simplicity, only a 2D photonic crystal is considered in the present paper. The 2D PhC structure support a photonic band gap in the region $0.235 < a/\lambda < 0.315$ for TE polarized light. Even the PhC



(a) (b)

Figure 1. (a) Design of the triangular photonic-crystal waveguide. (b) Dispersion curves of the guided modes in a W1KA PhC waveguide.

waveguide of one missing row along the axis ΓK (W1KA) as shown in Fig. 1(a) has two guided modes, as shown in Fig. 1(b) (The guided modes in the PhC waveguide are calculated using the plane wave expansion method). However, these two modes have different symmetries (even and odd) with respect to the center line parallel to the waveguide. With carefully chosen input light, only the fundamental (even) guided mode will be excited. Therefore, the W1KA waveguide can be considered as a single mode waveguide in this case. The waveguides, which are obtained by removing one or several rows of rods, are along the direction of the longer side of the computational domain.

A photonic band gap (PBG) effective guide must meet certain basic criteria and this must be one that the guide is single mode in the operation range to avoid any possibility of coupling between modes when the periodicity is locally changed. In addition, it is possible to cancel this by resonance introduction, while reducing operating range of the bend. To clearly visualize this problem, we are interesting to analyze the PhC bend response. The adopted method to conduct the numerical study is illustrated in Fig 2. The PhC structure is inserted between two waveguides of width w directed along the axis ΓK and forming an angle of 60° with the guide directed along the axis ΓM The injection of the fundamental mode is directly in the guide. It is not only to guide the light beam in a rectilinear manner, what interests us is to make the photonic circuitry and more particularly a bend function.

We design the PhC structure with a triangular lattice of air holes. The dielectric material has a dielectric constant of 10.5 (that is, refractive index of 3.24, which corresponds to the effective refractive index in an InP/GaInAsP/InP structure). The lattice constant is set

0.48 µm and air filling factor of about 44%. In this paper, this structure is excited with TE polarization. A pulsed Gaussian source is used to excite the fundamental waveguide mode at the entrance of the input waveguide. We have used in this paper a two-dimensional FDTD code that captures the simulation parameters (spatial discretization step, simulation mode (TE/TM), number of iterations), the injection conditions (injection of a guided mode through a Huygens surface) and the boundary conditions Type (Wall, symmetric or antisymmetric).

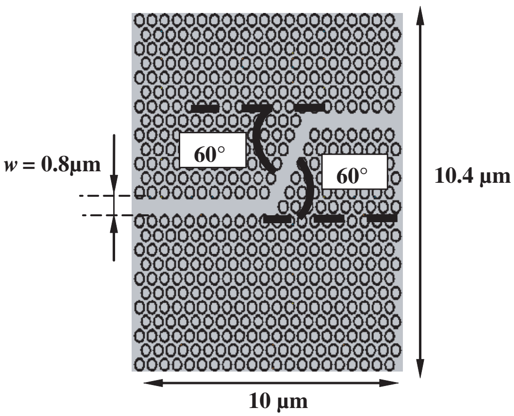


Figure 2. Layout for the FDTD modeling of the transmission through a double bends PhC waveguide. The photonic crystal is a triangular lattice of air holes ($r = 0.348a$) in a dielectric medium ($\varepsilon = 10.5$). The W1KA PhC waveguide is obtained by removing 1 row of air holes.

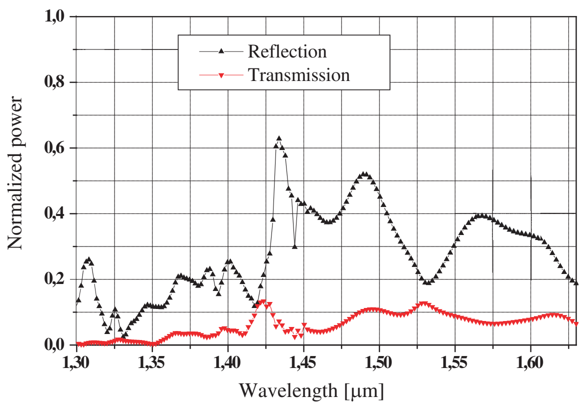


Figure 3. Normalized transmission and reflection spectra at the output port for the not optimized double bend.

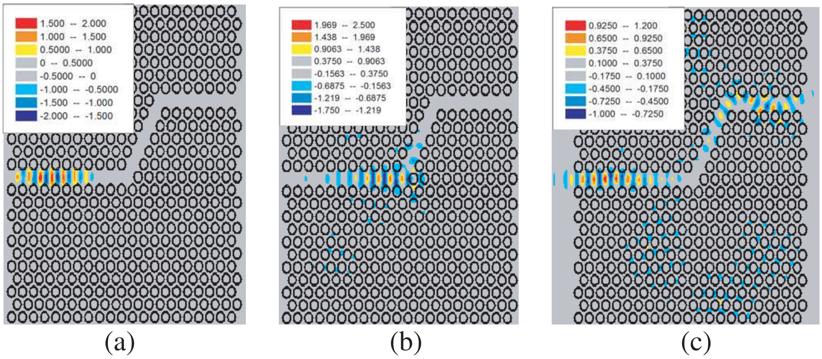


Figure 4. The distribution shape of the magnetic field Hz excited in TE mode. (a) For 15000 iterations. (b) For 20000 iterations. (c) For 30000 iterations.

Further details concerning the FDTD method and the Mur absorbing conditions are given in literature [8, 9] This paper presents only the conditions of absorption-type wall that simulate an infinite domain containing the entire structure study by investigating the lowest digital interfaces. In our simulations $\Delta x = \Delta y = 0.04\,\mu\text{m}$ and the total number of time steps is 50000. The size of the computing window is $10.4\,\mu\text{m} \times 10\,\mu\text{m}$. The length of the channel is $0.8\,\mu\text{m}$

Figure 3 shows respectively the spectral response in transmission and reflection for the double bend waveguide and excited by TE mode through a Huygens surface.

The results of the 2D FDTD simulation shows clearly the low transmission obtained in the range [1.30 µm–1.65 µm], we also recorded a weak transmission with maximum of about 12%. Notice that the power reflection is important and reaches 62% this explains that there is no guided modes in this double bend structure due to losses at the two corners. However, the passage of the wave through this PhC, the mode of the straight guide W1KA will be coupled with that of the guide (curved), a coupling efficiency is less than unity where increased losses.

The two-FDTD results of the simulated magnetic field maps Hz for the modelled structure is shown in Figs. 4(a)–(c). The wavelength of the incident plane wave is set to 1.55 µm.

From Figs. 4(a)–(c) one can clearly see the resulting map of the wave propagation in the PhC structure at different iterations 15000, 20000 and 30000. Figs. 4(a) and (b) respectively shows clearly the scattered light in the intermediate part between the two bends and the return of power to the input waveguide reflecting a strong reflection and a weak transmission. Although most of the light that reaches the edge of the computational cell is absorbed by the boundaries, some light gets reflected back from the end of the waveguide.

In order to obtain a better transmission and a wide bandwidth while reducing losses due to bends, an optimization based on modifying the topology is conducted by inserting mirrors in the corners (the addition of several holes) and deleting holes situated in the external bends. The size of holes was designed to be $r = 0.348a$. The resulting optimized bend structure is shown in Fig. 5.

The normalized transmission and reflection spectra at output port for the double bend obtained numerically are displayed in Fig. 6.

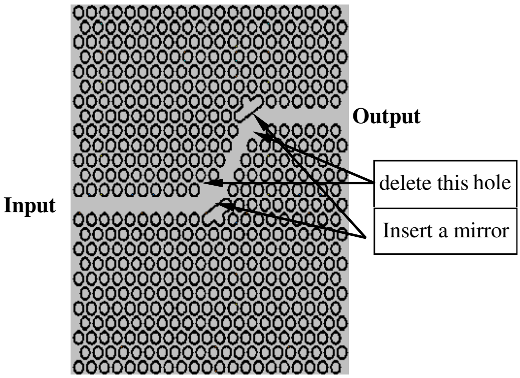


Figure 5. Topology optimization design of the double bend.

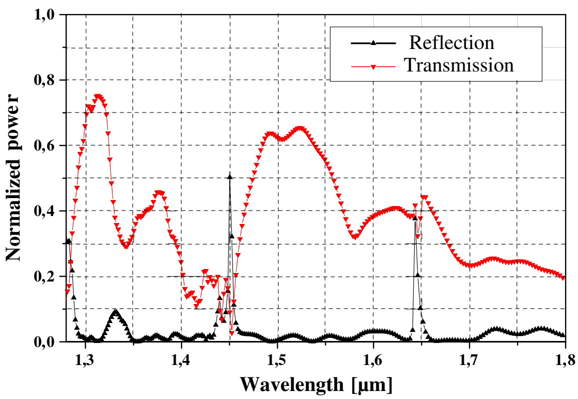


Figure 6. Spectral response in transmission and reflection of the optimized double bends obtained by the two-dimensional finite difference time domain (FDTD) simulation.

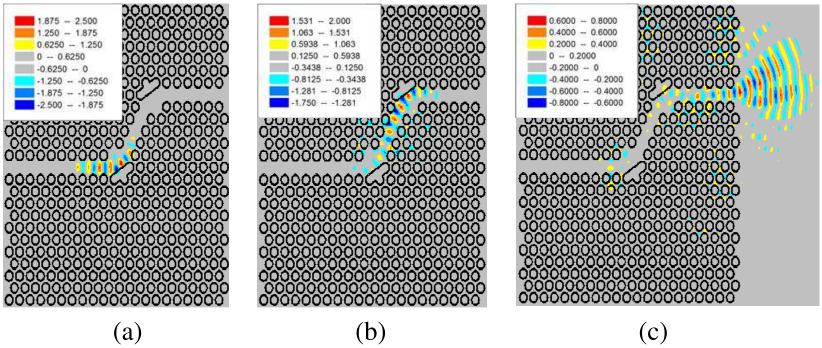


Figure 7. The distribution shape of the magnetic field Hz of the optimized bends excited in TE mode. (a) For 15000 iterations. (b) For 20000 iterations. (c) For 30000 iterations.

According to Fig. 6 there is a transmission that exceeds the 6% that spans the range [1.47 μm–1.57 μm]. The maximum value is around 75%. Transmission recorded at 1.55 μm is of about 55%. The reflection is null. This reflects an almost total transmission of the wave through double bends. We note that the transmission was significantly altered. The transmission properties are clearly improved with this configuration, the propagation mode is not affected by the accident posed by the corners, allowing the wave to follow the direction of bends.

The resulting map of the magnetic field Hz of the optimized double bends in TE mode for various iterations is show in Fig. 7.

The distribution shape of the magnetic field Hz (TE polarization) for respectively 15000, 20000 and 30000 iterations as show in Figs. 7(a)–(c) demonstrates clearly the guided phenomenon of the fundamental mode in the double bends and the light reaches the end of the waveguide.

2.2. Y-shaped Splitter Design

In this section we focus on the optimization and the design a Y-shaped splitter junction by entering proper optimization in order to increase the transmission and obtain a wide bandwidth at two output ports The 2D photonic crystal is similar to those in Section 2.1, etched through InP/GaInAsP/InP heterostructures and a fill factor of about 44%, radius of holes $r = 0.348a$ were chosen for a triangular lattice to obtain a photonic band gap (PBG) around 1.55 μm exist for the telecom wavelengths. We construct a Y optical splitter on a 10.4 μm × 10 μm PhC structure by insertion of appropriate line defects, of which the branching region is shown in Fig. 8. The optimization consist of modifying the topology of the initial Y-shaped junction by deleting holes situated in the external bends and inserting mirrors in the corners as in the case of double bends and make additional holes at the centre of the junction to avoid mode expansion. We also gradually vary the size of the holes at the junction. The size of the initial hole was designed to be $0.348a$ and the second $0.625a$. The resulting optimized bend structure is shown in Fig. 8 and the normalized transmission and reflection spectra at output port for the Y-shaped splitter are displayed in Fig. 9.

Notice from Fig. 9 there is a transmission that exceeds 42% for port (2) and 32% for port (3), the total transmission recorded for the two ports is of about 75%. The corresponding reflection is null. We note that adding holes at the centre of the junction, the mode expansion is suppressed, also the optical volume is then reduced, the mode cannot expand and the excitation of higher order modes is suppressed, resulting in clean and efficient splitting. The propagation mode is not affected by the accident posed by the corners allowing the wave to follow the direction of bends. The transmission properties are improved with this configuration, This is clearly seen in Figs. 10(a), (b) and (c) schematically Hz field distribution in the structure for TE polarisation at different iterations.

The distribution shape of the magnetic field Hz (TE polarization) for respectively 15000, 20000 and 30000 iterations as show in Figs. 10(a)–(c) demonstrates clearly the guided phenomenon of the fundamental mode in the double bends and the light reaches the end of the splitter.

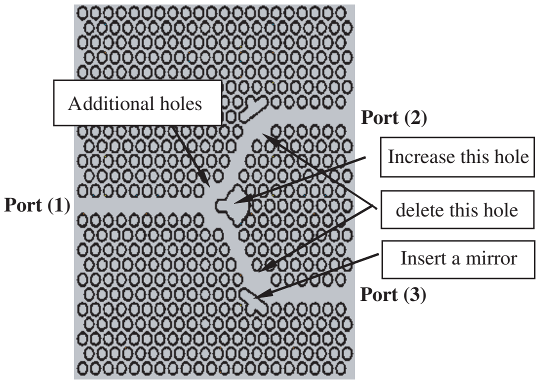


Figure 8. Topology optimization design of the splitter.

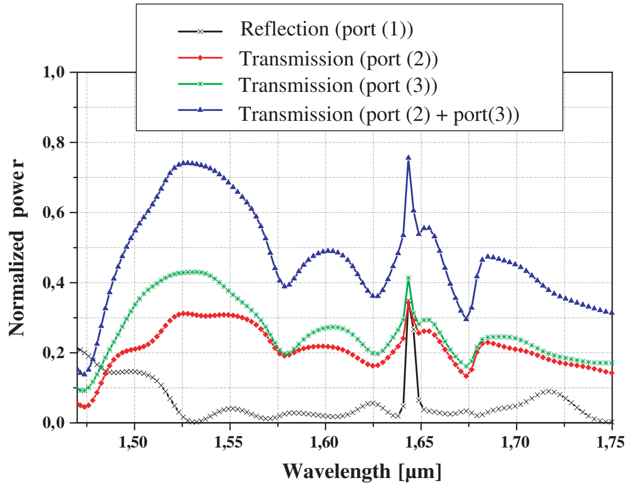
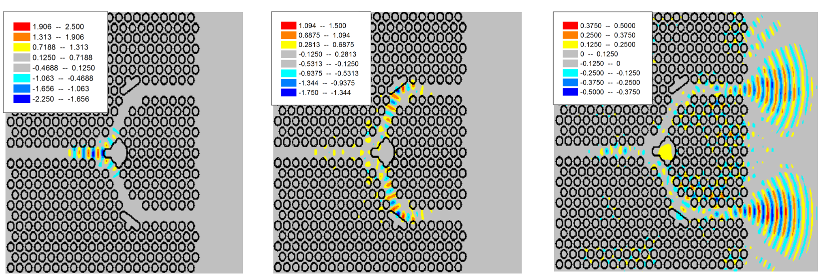


Figure 9. Computed transmission and reflection spectra of the optimized splitter obtained by the two-dimensional finite difference time domain (FDTD) simulation for the structure illustrated in Fig. 8. The electromagnetic power in the output port splits almost equally into the two PCW output ports throughout the waveguiding band.



(a) (b) (c)

Figure 10. The distribution shape of the magnetic field Hz of the optimized splitter excited in TE mode. (a) For 15000 iterations. (b) For 20000 iterations. (c) For 30000 iterations.

3. CONCLUSION

In this paper, we have designed a double bends and Yshaped optical splitter made of linear-defect waveguides in PhCs, and analyzed their properties using the two dimensional finite-difference time-domain method. First and from simulations, we showed that the double bend PhC circuit transmission curves could reach a high value on a broadband by optimizing the double bands topology. Second our analysis focused on the problem of splitting, supported by numerical results, they suggest that the availability of effective splitters. We have found that the incident power splits almost equally in the two output ports with high transmission efficiency. To reduce the mode expansion at the branching region, we have performed numerical simulations on Y-shaped waveguide branches in the splitter, and achieved an improvement of transmission by placing the defects of extra rods in the branching region. A total transmission of about 75% at output ports is obtained.

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