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Y Junction in Square and Triangular Lattices Optimization Using the 2D-FDTD Method

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***Abstract*- In this paper we design a brick that will form the photonic crystals network. In particular, we focus on the design of a 1×2 Y-Shaped Splitter used for routing light exhibiting high transmission in triangular and square lattices. The Distribution of the magnetic field, the transmission and the reflection are investigated by numerical simulations using the 2D-FDTD simulation. The obtained spectral transmission result of the optimized 1×2 Y-Shaped Splitter in triangular unit cell is high in comparison with that of a square unit cell. Photonic crystals are considered a good way for realizing compact optical splitters.**

***Index Terms*- Photonic crystals, integrated optics, 1×2 Y-Shaped Splitter, 2D-FDTD.**

I. INTRODUCTION

Photonic crystals (PhCs) consisting of triangular and square lattices of dielectric holes have potential applications as platforms for integrated optical circuits. Photonic crystal structures are suitable for a large number of optical designs, thanks to their unique linear and nonlinear properties as well as the possibility this technology offers to fabricate highly compact devices [1-4]. The use of periodic structures on a nanometeric scale combines novel features with an integration platform for densely packed photonic circuits, which is particularly attractive for optical communications. Photonic crystals (PhCs) 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 periodicity defects 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.
In this paper we aim to develop a basic brick for integrated optics, i.e a 1×2 Y-Shaped Splitter of one omitted row in triangular and square unit cell. The devices studied could be used in future optical interconnects in microelectronics. The simulation was performed using the two-dimensional finite difference time domain (2D-FDTD) method.

II. Y JUNCTION DESIGN

The Y-junction is a basic building block of integrated optics, used as a power divider, mixer, bends,...etc [5-6]. The following proposed study, consists of two branches over two rights single-row waveguides for two types of structures: square and triangular. We begin to study a Y-junction original (not optimized), then depending on results, we will make a suitable optimization corresponding to a certain topology, which will guide us to good results.

III. Y SHAPED SPLITTER IN SQUARE UNIT CELL

A. *Before optimization*

Let us consider the 2D photonic crystal 1×2 Y-shaped splitter illustrated in Fig. 1. We design the PhC structure with a square 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. A fill factor of about 44% and a radius of holes is fixed *r*= 0,348*a* are chosen. In this paper, this structure is excited with TE polarization. A pulsed Gaussian source is used to excite the fundamental waveguide mode at the waveguide input. 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 anti-symmetric). Further details concerning the FDTD method and the Mur absorbing conditions are given in literature [7-9]. 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.

The different results available at the end of simulation: the mapping of the magnetic field Hz and the transmission and reflection spectrum. We present the structure studied in Fig. 1. In our simulations Δx=Δy=0,04 µm and the total number of time steps is 50000. The size of the computing window is 10,4 µm×10 µm. The length of the channel is 0,8 µm.

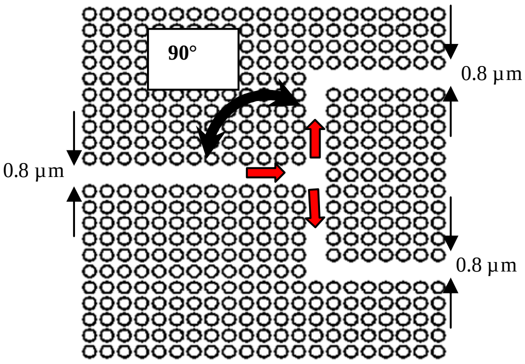


Fig 1. Y-coupler terminated by two waveguides in square lattice.

Fig. 2 shows the spectral response in transmission and reflection of the different ports.

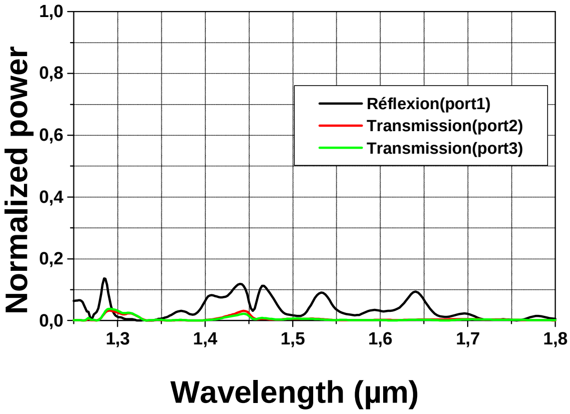
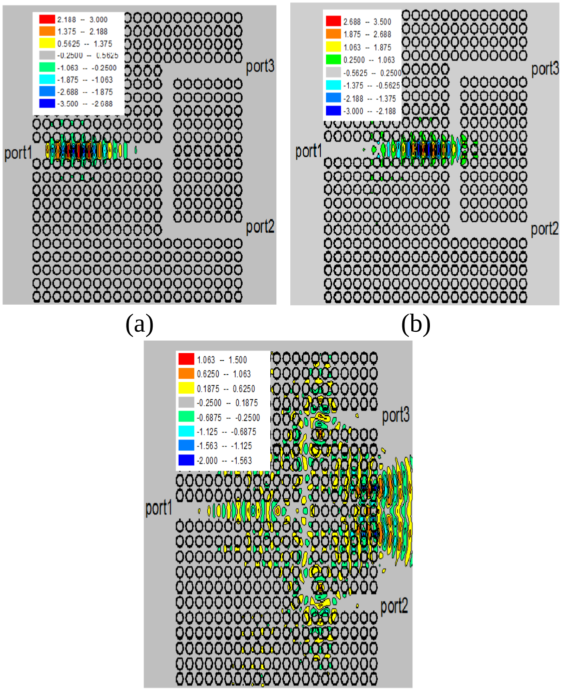


Fig 2. Spectral response in transmission and reflection in different ports.

The 2D-FDTD simulation of this structure presents a very low transmission power; this is clearly visible in the distribution field Hz as shown in Fig. 3.



(a) (b)

(c)

Fig 3. Distribution of the magnetic field Hz (a) for 1500 iterations, (b) for 2000 iterations, (c) 5000 iterations.

Notice well from fig. 3 which presents the optimized Y Splitter that the input wave was significantly altered at the intersection of two corners formed by an angle of 90°.

B. *After optimization*

The characteristic key of the studied topology is the addition of a large number of holes in the center of the junction in order to cancel the modal spread in the surface, and removing a hole in each corner of the junction as shown in Fig. 4.

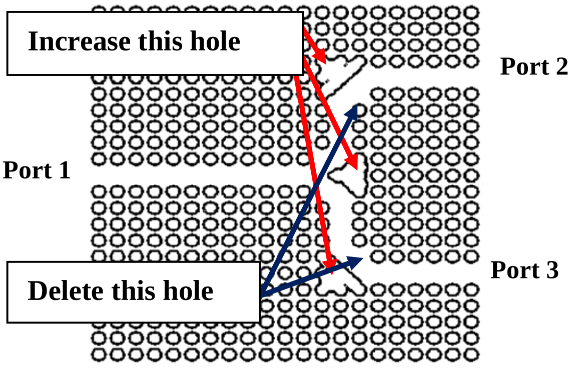


Fig 4. The structure of the optimized Y shaped splitter

In Fig. 5 we represent the transmission and reflection coefficients for each port. The total transmission (port 2+ port 3) is also presented.

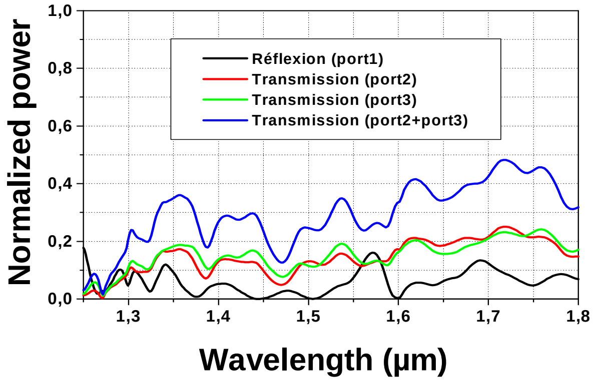


Fig 5. The spectral response in transmission and reflection of the optimized divider in square lattice obtained by 2D-FDTD simulation of the structure shown in Fig. 4.

The Fig. 5 demonstrates the effectiveness of the optimized structure. The transmission is enhanced by this topology. The cartography performed with this divider is given in Fig. 6.

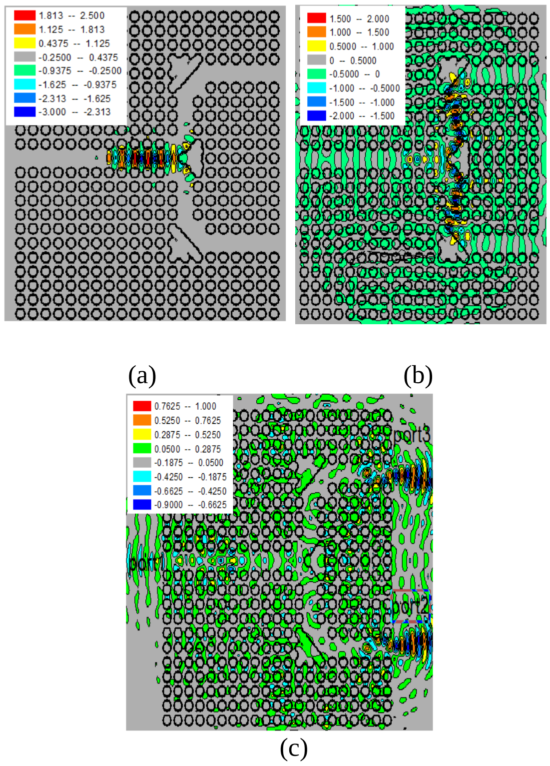


Fig 6. The distribution shape of the optimized magnetic field Hz excited in TE mode. (a) for 1500 iterations, (b) for 2000 iterations, (c) 5000 iterations. The electromagnetic wave injected is divided almost equally in the Y junction.

IV. Y SHAPED SPLITTER IN TRIANGULAR UNIT CELL

A. *Before optimization*

The 2D photonic crystal is similar to those in section III, 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 1×2 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. 7. The structure studied is shown in the figure bellow.

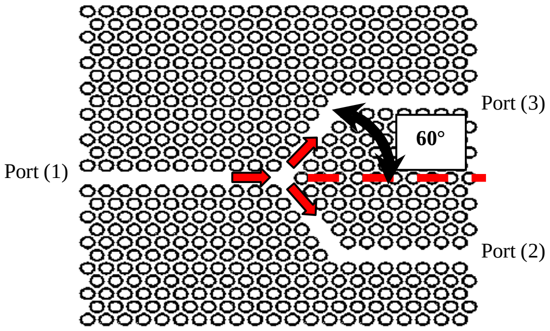


Fig 7. Y-coupler terminated by two guides in square lattice

Fig. 8 illustrates the spectral response in transmission and reflection measured at the different ports of the structure.

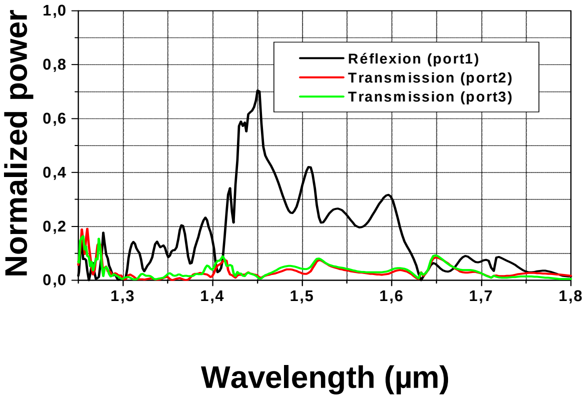
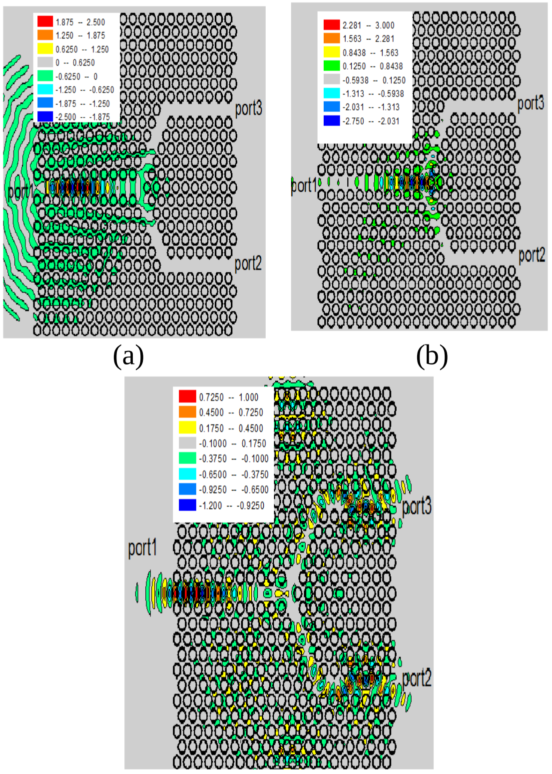


Fig 8. The spectral response in transmission and reflection measured at the different ports of the structure.

The 2D-FDTD simulation of the resulting structure shows a very small amount of transmission in port (2) and port (3).

The visual overview of the magnetic field Hz distribution is shown in Fig. 9 for 1500, 2000 and 5000 iterations.



(a) (b)

(c)

Fig 9. The distribution shape of the magnetic field Hz optimized excited in TE mode. (a) for 1500 iterations, (b) for 2000 iterations, (c) 5000 iterations.

B. *After optimization*

This optimization keeps the same topology as compared to that of the square unit cell, with the exception of the angle between the two PhC waveguides.

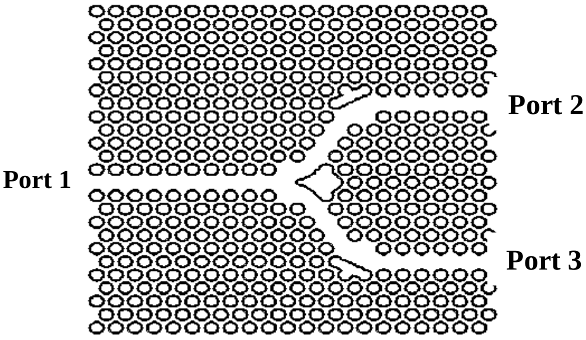


Fig 10. Structure of the optimized Y junction.

Fig. 11 presents the transmission and reflection coefficient in each port. The total transmission (port 2+ port 3) also presented.

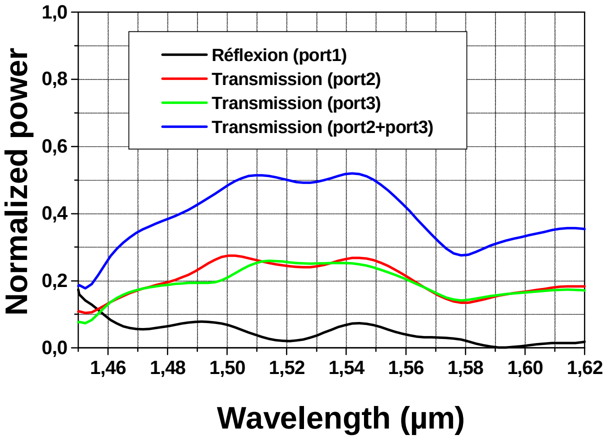
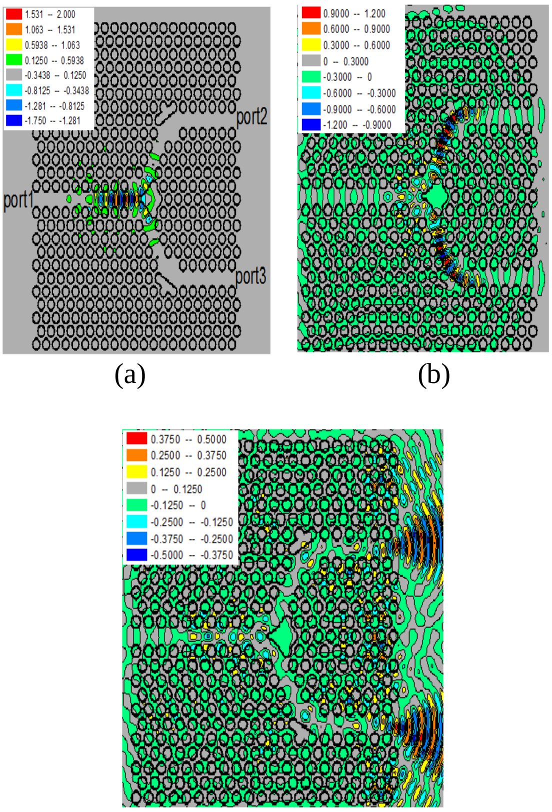


Fig 11. The spectral response in transmission and reflection of the optimized splitter in triangular lattice.

Notice from Fig. 11, a transmission that exceeds 28% for the port (2) and port (3), the total transmission recorded at the wavelength 1.55 µm obtained for the two ports is approximately 50%. The corresponding amount of reflection is almost zero.

We note that adding holes at the center 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 and the total transmission at the output ports is improved in comparison with the not optimized splitter, this is clearly seen in fig. 12 (a), (b) and (c) schematically Hz field distribution in the structure for TE polarisation at different iterations.



(a) (b)

(c)

Fig 12. Distribution of the optimized magnetic field Hz excited in TE mode. (a) for 1500 iterations, (b) for 2000 iterations, (c) 5000 iterations.

V. COMPARISON BETWEEN THE TWO OPTIMIZED Y JUNCTIONS FOR A TRIANGULAR AND SQUARE UNIT CELL

Fig. 13 illustrates the difference in terms of transmission of the Y junctions in triangular and square unit cell optimized previously obtained by the 2D-FDTD simulation.

According to the curves of the spectral response of transmission which are obtained by 2D-FDTD, we note that the transmission obtained in the range [1,45-1,65] µm for a triangular unit cell is high in comparison with that of a square unit cell. This performance is due to the location of air holes in the structure. The square unit cell has many losses in the two branching region, especially at the corners.

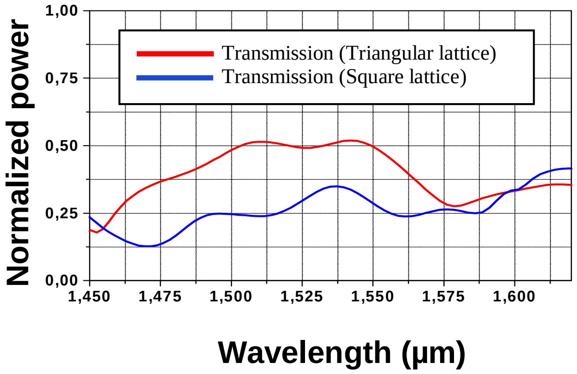


Fig 13. The spectral response in transmission of the optimized 1×2 Y-Shaped Splitter obtained by 2D FDTD simulation for both triangular and square unit cell.

VI. CONCLUSION

In this paper we studied a two-dimensional photonic crystal in the square and triangular unit cell by entering proper optimization in order to increase the transmission and obtain a wide bandwidth at the two output ports. The two dimensional finite-difference time-domain method was employed for the characterization of photonic components. The evaluation of the transmission and reflection spectra for the different components designed has been completed. 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 and mirrors in the corners. We found through this study that the triangular unit cell offers better performance in the amount of transmission than the square one.

REFERENCES

[1] A. G. Edelmann and S. F. Helfert, "Three-dimensional analysis of hexagonal structured photonic crystals using oblique coordinates", Opt. *Quantum Electronics.*, Vol. 41, pp. 243–254, 2009.

[2] J. Lourtioz, H. Benisty, V. Berger and J. Gerard, *Book Photonic Crystals*. Springer-Verlag Berlin Heidelberg, 2008.

[3] V. Tabatadze, Jr. A. Bijamov,D. Kakulia, G. Saparishvili, D. Kakulia, R. Zaridze, Ch. Hafner and D. Erni, "Design and Analysis of Planar Photonic Band Gap Devices", *Int J Infrared Milli Waves*, Vol 29, pp. 1172–1185, 2008.

[4] J. D. Joannopoulos, R. D. Meade and J. N. Winn,"Photonic Crystals: Molding the Flow of Light", Princeton University Press, New York, 2007.

[5] M. K. Moghaddami, M. M. Mirsalehi and A. R. Attari ,"A 60° photonic crystal waveguide bend with improved transmission characteristics". Optica *Applicata*. Vol. 39, 2009.

[6] S. Li. H. W. Zhang, Q. Y. Wen, Y. Q. Song, W. W. Ling and Y. X. Li,"Improved amplitude–frequency characteristics for T-splitter photonic crystal waveguides in terahertz regime", *Appl Phys B*, Vol. 95, pp. 745–749, 2009.

[7] A. Taflove and S. C. Hagness, *Computational Electrodynamics:The Finite-Difference Time-Domain Method*, 3rd edn., Boston, MA: Artech House, 2000.

[8] M. Koshiba, Y. Tsuji and S. Sasaki," High-performance absorbing boundary conditions for photonic crystal waveguide simulations", *IEEE Microwave and Wireless Components Letters*, Vol. 11, pp. 152–154, 2001.

[9] G. Mur, "Absorbing boundary conditions for the finite-difference approximation of the time-domain electromagnetic field equations", *IEEE Trans. Electromagnetic compatibility*,Vol. 23, N°4, pp. 377-382, 1981.