Analysis of the 1×3 Splitter with Square Lattice Configuration

Fedaouche Amal, ABRI Badaoui Hadjira, and ABRI Mehadj

Abstract—In this letter, the 1 × 3 power splitter with square lattice configuration is numerically investigated using 2-D finite difference time domain simulation. The device is presented and compared with its counterparts in triangular lattice. It is found that efficient total transmission of about 86%, at output ports are obtained around the optical operating wavelength 1.55 µm. The simulation results confirm that the 1 × 3 splitter in square lattice can’t provide an efficient splitting over a broad bandwidth in comparison with the triangular lattice.

Index Terms— Two-dimensional photonic crystals, 2D-FDTD method, 1 × 3 splitter, square lattice, power splitter, optimization.

I. INTRODUCTION

Photonic crystals (PC) have attracted wide attention and shown many fascinating characteristics during the last few decades, particularly due to the ability to interact with light on a wavelength scale pledges ultra-compact structures for integrated optical. Currently several functional devices based on photonic crystals have been provided and are expected to play an important role in the field of optical communications.

With the evolution of optical devices, waveguide bends and splitters have become a pivotal part of power components. Ideally, the basic structure of a splitter is to separate the injected optical signal into a set of outputs which will be divided equally in the ideal case. There are some possible alternative approaches to guiding and splitting optical power from incoming signal into two or more output waveguides such as Y-junctions [1]-[2], T-junctions [3]-[4], directional coupling structure [5], multi-mode interference (MMI) waveguide [6], and self-collimated beams splitter [7-8], etc.

Among all types of photonic crystal optical beam splitters, the Y-junction is the most straightforward optical power splitter [9]-[10], so we choose it as part of our beam splitter, where their design consists of three single defect waveguides combined together at 120° which leads to high reflections and narrow bandwidth operation [11]. To solve these difficulties, the junction and bend must be carefully designed. In order to decrease the multimode problems and bending losses, many researchers investigated theoretically air dielectric rods array. The advantage of this structure is that the waveguide created by removing a single line of rods, the light travels around the sharp bends with high transmission.

In this work, we study the design of 1 × 3 power divider shown in the previous paper [12], that exhibiting an identical amount of power distribution, where the low-loss, bandwidth can be achieved by further optimization of the Y-junction and 60° bends of the splitter, using the similar operation mechanism employed in [12].

Photonic crystals are complex scattering problems [13], which make wave propagation in photonic crystals difficult to examine. Therefore, numerical simulations are crucial for most theoretical analyses. In this regard, a wide range of simulation techniques [14] have been developed and utilized for investigating the scattering and guidance properties of electromagnetic modes in complex photonic crystal structures. The finite-difference time-domain (FDTD) [15]-[16] method has high capability of modeling the periodic structures. It is based on the numerical time-integration of Maxwell’s curl equations.

The contents of this paper are summarized below. In section II, we have integrated Y-junction to design and analyze 1 × 3 power splitter in square lattice configuration, also, we have interpreted its simulation with optimization, and then a comparison with the triangular lattice is presented. Finally, section III provides some conclusion.

II. 1×3 SPLITTER DESIGN AND SIMULATION

The device studied here is composed of a square lattice of air-holes in a dielectric slab InP/GaInAsP/InP. The implementation of this PC slab is a two-dimensional problem with an effective refractive index n_eff = 3.24 embedded in the air. The normalized radius of air holes r = 0.36a, where a is the lattice constant, and an air filling factor of about 47%. These parameters allow opening a photonic band gap for the normalized frequency a/λ ranging from 0.241 to 0.311, where is 1.55 µm corresponding to the light wavelength.

The basic 1 × 3 power splitter is realized by single input photonic crystal waveguide and tree output ports. This device is composed of an 1 × 2 Y-junction by creating two mono rows directed toward ΓM vector to get two output ports and a second defect through ΓK direction by removing one row of air-holes to obtain the third output port, where each output port form an angle of 60 degrees with each of them. The dimensions of this structure are: S_x=21 µm in length, S_y=14 µm in width, the 2-D FDTD mesh size are: Δx=Δy=0.05, and the perfectly matched layers are used to absorb the outgoing waves.

Let us concentrate in this section on the enhancing of the transmission and reducing the reflection by optimizing the 1x3 junction, to get a broad bandwidth at the output ports of the power splitter; in order to get an identical beam-splitting ratio at 1.55 µm for optical C-band wavelength inspired from [11],

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topology optimization scheme is used to modify the structural distribution at the splitting region, where we employ two methods to change the origin topology, firstly we get the external junction curve lobes to the interior of the bend, using reflecting mirror at the junction bend. Secondly, we eliminate holes radius in front of the reflective mirrors; defect hole with radii added in the middle of the junction, and including two triangles so that the circle already added, is in the middle of the distance between them, as is shown in the zoom in Fig. 1, the latter therefore functions as a power reducer for output 2. The main parameter of the added defect are $L_1$, $L_2$ and $L$ where $L$ denotes the length between the centers of the holes in symmetry, the layout of the triangle is shown in Fig. 1. In our simulations, we are interested only in the TE polarized light. The transmission properties are calculated using the FDTD method, where we have used $50000$ iterations for the FDTD computation. The spectrum of the transmission power at each output for chosen optimum parameters with different wavelengths ranging from $1.50 \mu m$ to $1.58 \mu m$ has been plotted in Fig. 2.

The simulation results obtained by 2-D FDTD show clearly the degradation of splitter performances in the range of wavelengths ($1.50 \mu m$ to $1.58 \mu m$). The amount of total transmission recorded at the wavelength $1.55 \mu m$ obtained for the three ports is $\sim 86\%$. In the other hand, we note that there is a low transmission and unequal division in the three output channels.

<table>
<thead>
<tr>
<th>Table I. 1 × 3 Power Splitter in Square Lattice Transmission Performances Comparison with Triangular Lattice</th>
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<tbody>
<tr>
<td>Operating domain</td>
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<tr>
<td>Ref. [12]</td>
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<tr>
<td>Our Work</td>
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In order to show the performance of our structure in terms of transmission and splitting, a comparative study has been made with our work in [12], where the results show that the device can effectively split the input optical beam to the tree output channels. So by comparison between the results of the two works mentioned in the table I, we can see that a high transmittance and an equal multi output channels are achieved in our 2D photonic crystal waveguide $1 \times 3$ power splitter in triangular lattice. However, different wavelengths may experience different transmitance.

### III. Conclusion

In summary, in this paper we have presented the design of a $1 \times 3$ Y-splitter in square lattice based on 2-D PC using the 2-D FDTD method. By optimization of junction geometry, our design demonstrates a poor power transmission in comparison with the one in triangular lattice. As a result of the 2-D FDTD simulation, we reached $85.37\%$ of transmission for the splitter at the wavelength of $1.55 \mu m$, which is unable to divide the input power equally into three outputs at a wide bandwidth. In the last part, we have seen that $1 \times 3$ Y-splitter in triangular lattice has high transmission efficiency and identical splitting ratios over a wide bandwidth in comparison with the one in square lattice.

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### References


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