

Design and simulation of the optimum single mode Y-branch splitter with different types of waveguides in two branches

M. KAVOSH TEHRANI*, M. HAMI

Institute of Optics and Laser, Malek-Ashtar University of Technology, Shahin Shahr 83145/115, Iran

In this paper, different single-mode Y-branch splitters are simulated based on symmetric Y-branch comprising different waveguides (straight, S-Bend Cosine, S-Bend Sine and S-Bend Arc waveguides) with a channel profile of proton-exchanged lithium niobate. Apart from the waveguides length of the two branches, all other parameters such as the width of the waveguides and separation of the two branches are considered fixed. The distance between the two output waveguides is $127\mu\text{m}$ (center-to-center), which is suitable for the connection with the fibers. For each structure, the excess loss of the splitter is checked, and according to the minimum loss, optimum length of waveguide is determined. Finally, an optimum single-mode Y-branch splitter is selected.

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1. Introduction

Y-branch splitters are important components in optical integrated circuits (OIC) and have been widely used in power splitters, Mach-Zehnder interferometers, optical switches, and phase modulators. Lithium niobate (LiNbO_3 , LN) is usually used for hosting OIC devices. Many techniques such as ion/metal diffusion (e.g. titanium indiffusion [1,2] or the proton exchange [3]) and ion beam implantation [4] are used to fabricate waveguides in LiNbO_3 . Waveguides made by Ti diffusion cannot operate at very high power densities in the visible [2]. In addition, it was reported that the ion beam implantation can negatively affect the surface properties, e.g. by increasing the hardness and resistance to oxidation [1]. Due to its distinct advantages such as simplicity, cheapness, large index change, and relatively low exchange temperature (as compared to Ti indiffusion) [5], Proton-exchange (PE) technique is an attractive method for fabricating low-loss and high-quality waveguides in LN. Since the waveguide achieved by this process cannot transmit TM polarization, only the TE polarization is propagated in it. A conventional Y-branch structure consists of an input waveguide and two branching waveguides as shown in Fig. 1. In all of Y-branch splitters, by increasing the spacing between outer waveguides, the branching angle is increased leading to more loss in output. To date, several efforts have been made to overcome the loss problem, especially when the branching angle is large [6-10]. S-shaped bends are widely used in integrated optical circuits because they provide low-loss transitions between parallel waveguides with a lateral offset and are relatively easy to design and fabricate [11].

Since two branches either can have the shapes of S-Bend Sine, S-Bend Cosine and S-Bend Arc, or can be straight waveguides with a certain branching angle, in this paper, the influence of branches structure on the loss is investigated. To do this, the distance between the branches is considered to be unchanged, but their type will be changed; and for each structure, the optimum length is obtained. Finally, an optimum single-mode Y-branch splitter with a splitting ratio of 50:50 at $1.55\mu\text{m}$ is simulated. The minimum loss is provided for each structure so that the minimum value of loss is related to the structure of S-Bend Cosine waveguides.

2. Y-branch splitter with different waveguide sections

A conventional Y-branch structure consists of an input waveguide and two branching waveguides. We consider a Y-branch splitter including two tapered waveguide sections (in input ports), two S-Bend (or straight) waveguide sections and two tapered waveguide sections (in output ports) as shown in Fig. 1. In this structure, according to selected widths for all waveguides, only one mode is allowed to propagate in it. Therefore, this structure will be a single-mode Y-branch splitter. In all simulations of this paper, the width of all waveguides and tapered waveguide length and type will be unchanged. The separation of output branches is fixed ($127\mu\text{m}$) because of limitations in manufacturing and physical connections (also this value is suitable for coupling to optical fibers). All dimensions of the device are listed in Tables 1. In fact, by changing the length and type of waveguides of the two branches, simulations are done for

each case by optiBPM software, and their losses are checked. Finally, the optimal length is obtained for each type of waveguide selected in branches.

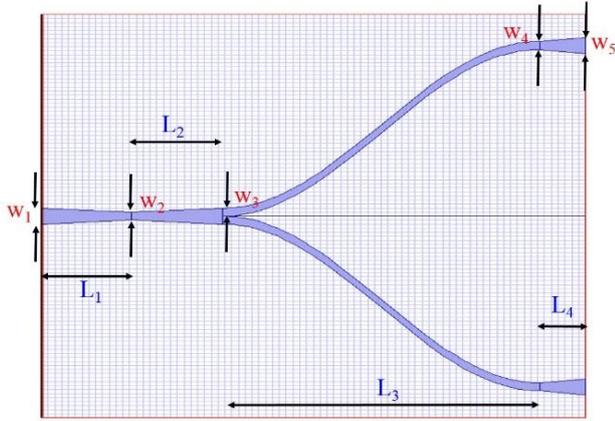


Fig. 1. Schematic illustration of Y-branch splitter with S-Bend waveguides

Table 1. Device dimensions

w_1, w_5	$6\mu\text{m}$ (fixed)
w_2, w_3, w_4	$3\mu\text{m}$ (fixed)
L_1, L_2	$1000\mu\text{m}$ (fixed)
L_3	variable
L_4	$500\mu\text{m}$ (fixed)

The proposed structure of Y-branch splitter is based on a PE channel profile formed on an x-cut LN substrate. Proton exchange in LN replaces a few lithium ions by hydrogen ions (or protons) to make channel waveguides in LN substrate with a grade-function index profile. For our channel waveguide designs, toluic acid was applied as a source of hydrogen ions. The temperature and process time are considered $250\text{ }^\circ\text{C}$ and 4 hours, respectively. The design specifications are listed in Table 2.

Table 2. Design specifications

Wafer and guiding channel	
Device dimensions: Length with	Variable 0.15 mm
Crystal cut direction	x-cut
Propagation direction	y
Substrate material (wafer)	LiNbO_3
Cladding	air
Thickness: Cladding substrate	$10\mu\text{m}$ $100\mu\text{m}$
Proton-exchange process specifications	
Proton source	toluic acid
Process time	4h
Temperature	$250\text{ }^\circ\text{C}$
Diffusion constant	$7.02 \times 10^7 \mu\text{m}^2\text{h}^{-1}$
Activation energy	75.58 kJmol^{-1}

3. Simulation results

According to Tables 1 and 2, Y-branch splitter is designed by optiBPM software. Since the device is formed on an x-cut LN substrate, we analyzed its performance for TE-polarized optical inputs with a test wavelength of $1.55\mu\text{m}$. We have evaluated the splitter in terms of the excess loss to obtain the optimal design. The excess loss of the splitter is defined as [12]:

$$\text{excess loss} = -10 \log_{10} \left(\frac{P_{out}}{P_{in}} \right) \quad (1)$$

Where, P_{out} is total output power and P_{in} is the input power. For each type of waveguide such as S-Bend Sine,

S-Bend Cosine and S-Bend Arc, and straight waveguides, simulations are performed for different values of L_3 ($1000, 1500, 3500, 7500, 11500$ and $15500\mu\text{m}$), and then the excess losses are checked. Therefore, we can obtain the optimal length of waveguides (i.e. L_3) for each of them. For this purpose, the relative optical power as a function of propagation distance for different values of L_3 is plotted. Fig. 2(a-d) show the relative optical power of the device for the different waveguides (such as S-Bend Sine, S-Bend Cosine and S-Bend Arc, and straight waveguides) applied into two branches.

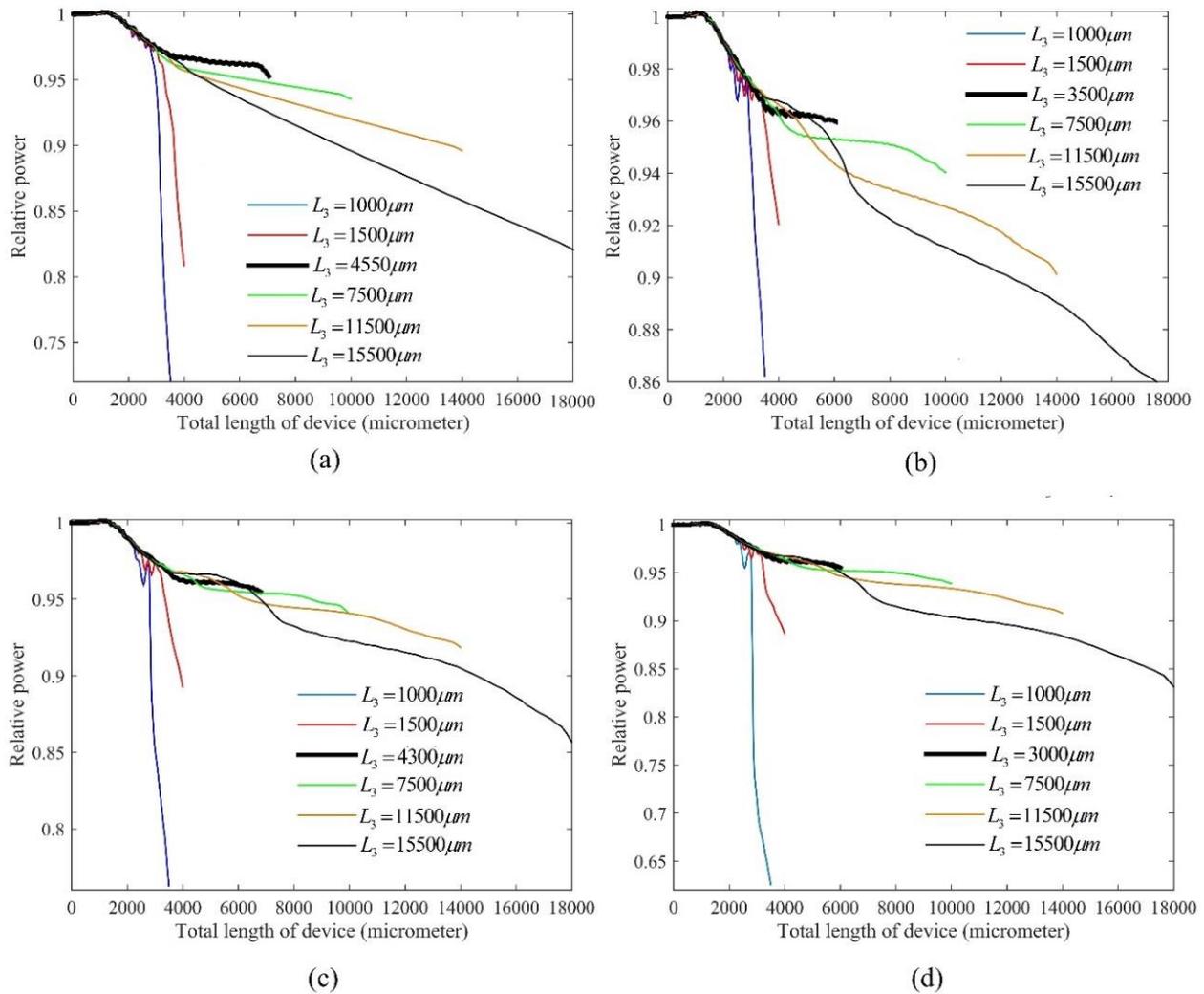


Fig. 2. Relative optical power as a function of propagation distance for different waveguides in two branches; (a) straight waveguide (b) S-bend cosine waveguide (c) S-bend Sine waveguide (d) S-bend Arc waveguide

In Figs. 2(a-d), the curves of the optimum length are black and thicker. According to these figures, if straight, S-Bend Cosine, S-Bend Sine, and S-Bend Arc waveguides have been used in two branches, the maximum relative powers are 0.950, 0.96, 0.953 and 0.954, respectively. According to equation (1), the minimum excess losses of the splitter are 0.22, 0.18, 0.21 and 0.20 dB. The optimum lengths for these waveguides are 4550, 3500, 4300 and 3000 micrometers for straight, S-Bend Cosine, S-Bend Sine, and S-Bend Arc waveguides, respectively. Therefore, if we want to design an optimum single-mode Y-branch splitter according to data from Tables 1 and 2 (with minimum length), S-Bend Cosine waveguides are the best choices for two branches.

For optimum Y-branch splitter, 2D and 3D optical field distributions are presented in Fig. 3(a) and 3(b), respectively. According to Fig. 3(a,b), it is clear that optical field distribution in output ports is symmetric and there is a minimum imbalance between two output ports. In this paper, the optimum Y-branch splitter has designed and simulated to use in multifunctional integrated optical chip (MIOC). Since the MIOC will be used in Fiber Optic Gyroscope (FOG), to avoid any nonreciprocal and spurious phase difference, the perfect symmetry in the beams path is required. So the splitting ratio of two branches should be equal (the splitting ratio of 50:50).

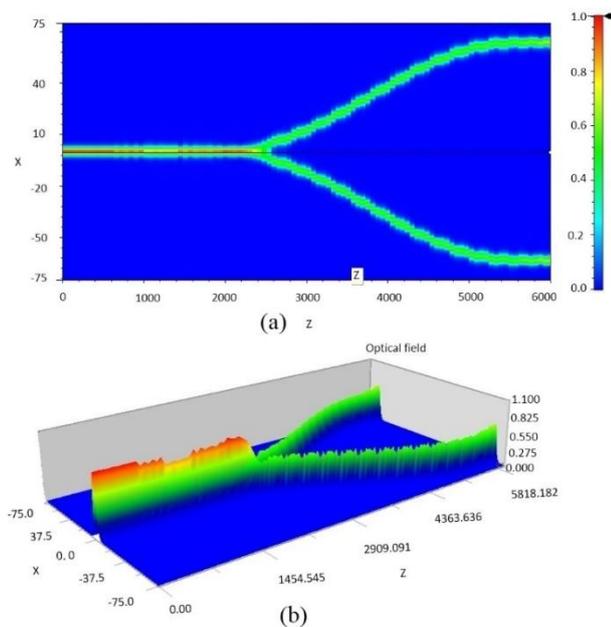


Fig. 3. (a) 2D and (b) 3D optical field distributions in XY plane

4. Conclusion

A single-mode Y-branch splitter including two tapered waveguide sections (in input ports), two S-Bend (or straight) waveguide sections (in two branches) and two tapered waveguide sections (in output ports) was considered. By changing the length and type of waveguides of the two branches, simulations were made for each case by optiBPM software; and their losses were checked. The optimal length was obtained for each type of waveguide selected in branches. The minimum excess losses of the splitter were 0.22, 0.18, 0.21 and 0.20 dB for straight, S-Bend Cosine, S-Bend Sine, and S-Bend Arc waveguides used in two branches, respectively. It also became clear that if we want to design an optimum single-

mode Y-branch splitter according to data from Tables 1 and 2 (with minimum length), S-Bend Cosine waveguides are the best choices for two branches.

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*Corresponding author: m_kavosh@mut-es.ac.ir