Low-loss and stable integrated optical Y-junction on lithium niobate modulators

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Abstract: *We designed a new type of integrated optical Y-junction which can improve overall performances like optical losses, stability and geometrical dimensions. Optical simulations of the Y-junction on Ti:LiNbO3 waveguide and experimental results obtained confirm the predictions.*

Introduction

Single-mode Y-junctions play a key role in optical-waveguide circuits. These basic building blocks act as optical power divider-recombiner in devices like power splitters, modulators or switches. Actually, research in this field is still active [1] even if that type of fundamental element has been studied for many years [2]. These developments are motivated by the fact that little improvements on the design of the Y-junction can have a strong impact on more complicated integrated optical circuits with many cascaded Y-junctions: splitters, QPSK modulators...

Y-junction must generally meet a number of requirements which are summarized by the following points:

- low insertion loss;
- mode stability (low excitation of higher order modes);
- small longitudinal dimensions.

The main goal of optical designers is to propose the ideal scheme able to optimize these different points.

In this paper we present the development of a new Ti-indiffused LiNbO3 Y-junction and its application to the Mach-Zehnder intensity modulator.

Principle of the new design

Two-dimensional structures of the conventional Y-junction and the proposed Y-junction are depicted in Fig. 1.

The conventional single-mode Y-junction can be divided in three sections [3], the straight-guide section of width Wi, the tapered section where the width widens progressively from Wi to 2Wo+D and finally the branching section with half branching angle α and width Wo. Theoretically, the gap D between the arms tends towards zero but in practice the technological process limits it to a finite value to the order of the micrometer. This type of Y-junction suffers from instabilities due to the large taper width which can support higher order modes poorly recombined in the branches. Moreover, the truncation at the tip of size D can enhance the optical losses and the mode instabilities in a region particularly sensitive.

Taking into account the truncation, we have found a solution which bypass the problem: the single-mode Y-junction is split in two symmetric parts by a line of dimension to the order of the truncation [4]. We called this new structure the “Split-Y-junction”. The Split-Y-junction can be described in two parts (Fig. 1): first the straight single-mode section with two little parallel waveguides of width Wi1 in close proximity D and after the branching section of angle 2α with the width varying from Wi1 to Wo. With a properly choice of parameters Wi1 and D, the straight single-mode waveguide can act as an efficient mode filter. Consequently, there is a better stability of the power splitting ratio. Moreover, as the truncation start from the beginning, no excess losses are generated at the transition between the straight section and the branching separation.

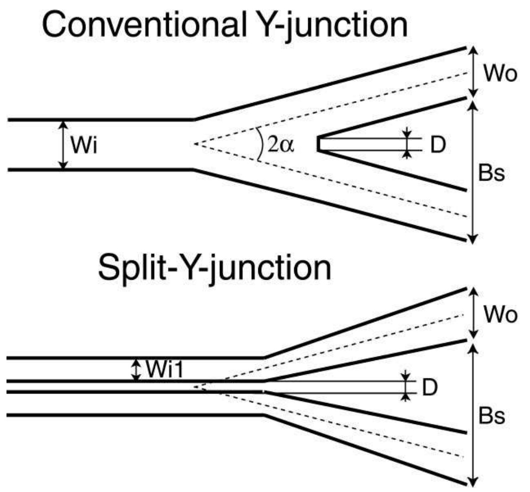

Fig. 1: schematic figure of the conventional Y-junction (up) and schematic figure of the proposed Y-junction (down).

Simulations and results

1. Geometrical dimensions

If we compare the size of each structure (Fig. 1), it seems evident that the Split-Y-junction is more compact than the conventional Y-junction. The length reduction Lr is calculated by the following formula:

$$Lr = \frac{D + Wi1}{Bs} \quad (1)$$

Graphical plots of the length reduction in percentage versus the branch separation are shown in Fig. 2. Whatever the input parameters D and Wi1 are, the gain in length is positive and rapidly increases when the branch separation decreases.

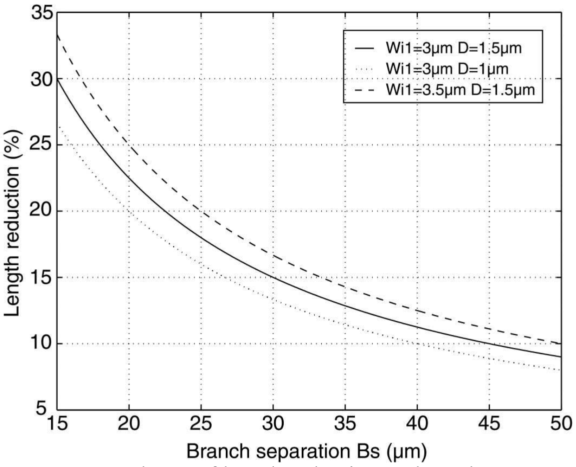

Fig. 2: Dependence of length reduction on branch separation.

For example, if D=1.5μm and Wi1=3μm, the length reduction can vary between 10% and 30% when the branch separation Bs is reduced from 50μm to 15μm.

2. Optical loss

The Y-junctions were modeled using the standard 2D finite-difference beam propagation method. Titanium in-diffused waveguides on X-cut lithium niobate were simulated at 1550nm. Typical dimensions of the Y-junctions are Bs=30μm, Wi=7μm, Wo=7μm, Wi1=3μm, D=1.5μm. The half branching angle α of each Y-junction was adapted to give the same longitudinal length L.

Table 1: Optical loss versus length of Y-junction.

L (μm)	Optical loss (dB) Conventional Y-junction	Optical loss (dB) Split-Y-junction
2000	0.99	0.58
4000	0.17	0.11
8000	0.13	0.02

Table 1 reports the calculated optical loss for three longitudinal dimensions. To give an idea, the corresponding half branching angles are around 0.4°, 0.2° and 0.1°. We note that in all cases the simulated optical losses are lower for the Split-Y-junction than for the conventional Y-junction.

3. Stability of the splitting ratio

Usually, Y-junctions are dependent to interferences effects of the fundamental mode with radiated modes or higher order modes (even or odd) which can come from distortions of the input field due to an imperfect alignment at the fiber-waveguide interface or after a curved waveguide. These effects induce a periodic variation of the splitting ratio at the end of the junction when the length of the straight section varies or when the wavelength changes. The goal of the designer is to model an Y-junction less sensible to these parasitic effects.

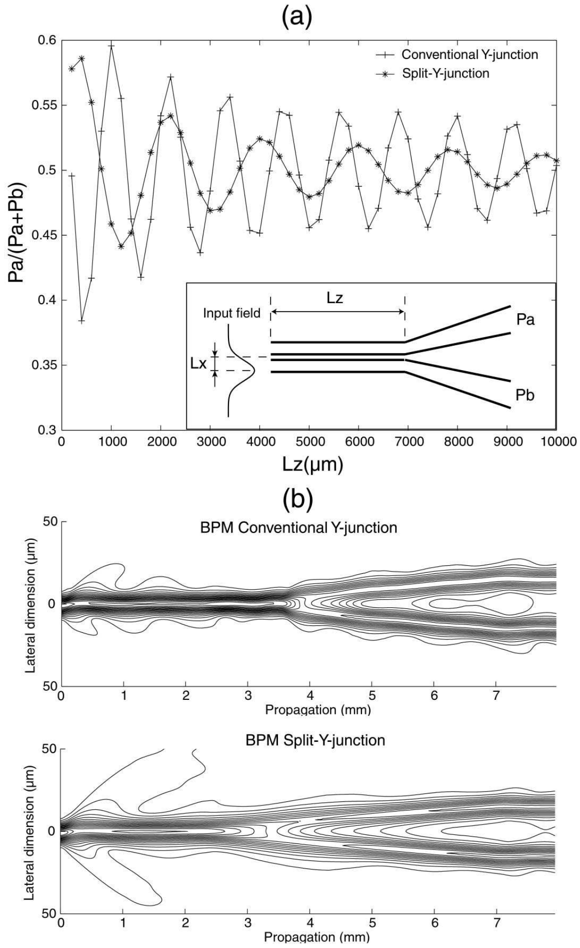

Fig. 2 a) evolution of the splitting ratio when the length Lz of the straight section varies. b) top view of the simulated optical field propagating through the two Y-junctions, Lz=2mm. In all simulations, the input field is a Gaussian mode of waist 10.5μm, the lateral displacement is Lx=1μm and longitudinal dimensions L of Y-junctions are the same.

To analyze the behavior of the Split-Y-junction, we simulated a lateral misalignment Lx (see Fig. 2) of the input field of a standard fiber and we observed the splitting ratio versus the propagation length Lz of the straight section [5].The splitting ratio is defined by the division between the output of one branch and the total output power: Pa/(Pa+Pb) or Pb/(Pa+Pb). Fig. 2 shows the results of the simulation. As stated before, we observe a periodic behavior of the splitting ratio around the symmetrical power splitting and decaying in amplitude with increasing length Lz. The new Y-junction presents superior performances with an amplitude oscillation always lower (around 50%) than the conventional one. One of the main reason is that the straight section of the new Y-Junction acts naturally as a high rejection mode filter because of its narrower equivalent width compared to the conventional Y-junction. In addition, there is no taper able to support higher order modes.

4. Experimental measurements

In order to verify the theoretical predictions, we decided to adapt the Split-Y-junction to the standard X-

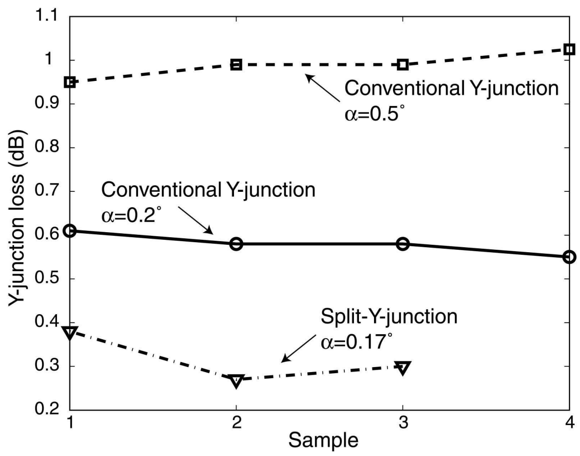

Fig. 3: Loss comparison between Y-junctions on different samples.

cut high speed lithium niobate intensity modulator [6]. Optical waveguides were formed by titanium diffusion. Each Y-junctions were implemented and the half branching angle was chosen to be the varying parameter. The other parameters were the same as those previously used in the simulations. The modulators were optically characterized at a wavelength of 1550nm using a polarization-maintaining fiber at the input and the output. Input light was TE polarized. The optical loss of each Y-junction was estimated by subtraction between a reference straight waveguide inserted on each chip and the Mach-Zehnder interferometer.

Fig. 3. shows the optical loss measured for different values of α. For the conventional Y-junction, the optical loss reduces from 1dB to 0.6dB when the half branching angle decreases from 0.5° to 0.2°. Concerning the Split-Y-junction, the half branching angle of 0.17° gives a value to the order of 0.3dB. If we compare the optical losses between the Split-Y-junction and the conventional Y-junction of the same longitudinal length (α=0.17° and α=0.2° respectively), we note an optical loss reduction of 0.3dB for the Split-Y-junction.

Consequently, we have experimentally demonstrated that, with equal dimensions, the Split-Y-junction exhibits a significant optical loss reduction when compared to the conventional Y-junction.

Conclusions

We have developed a new type of single-mode Y-junction which is better than the conventional Y-junction in terms of dimensions, optical loss and stability of the splitting ratio. X-cut LiNbO3 intensity modulators fabricated with this new design exhibited losses under 3dB including optical connectors and an extinction ratio better than 30dB without sacrificing initial longitudinal dimensions.

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