Design of an extra-low-loss broadband Y-branch waveguide splitter based on a tapered MMI structure

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Abstract: An optimal design for an extra-low loss buried waveguide Y-branch splitter is presented over a broadband wavelength range from 1500~1600 nm. A tapered multimode waveguide section, earlier used to reduce the excess loss, is optimized when the light distribution at the end of the multimode waveguide section is matched to the profile of the symmetric supermode for the structure of the two branching waveguides. An optimization that combines genetic algorithm and a gradient-based search method are used to obtain the optimal geometrical parameters for the multimode waveguide section as well as the widths for the input and branching waveguides. An excess loss of 0.015 dB@1550 nm was obtained after the proposed optimization. For these optimized parameters, even when packaging induces a typical offset between input standard singlemode fibre and waveguide, the wavelength dependence of the output ratio between the two branches is small (less than 0.03 dB).

1. INTRODUCTION

A Y-branch structure fabricated by planar technology is a fundamental element in constructing photonic integrated circuits such as power splitters, Mach–Zehnder interferometers, and hybrid-integrated optical transceivers. Previously, the conventional Y-branch was found to suffer severe radiation loss when the branching angle is larger than 2^o [1]. To reduce the loss, the branching angle must be small and the length of splitter device must be extended. To date, several efforts have been made to overcome the loss problem, especially when the branching angle is large [2, 3]. Adding a microprism at the junction is one of the possible approaches. The function of the microprism is to compensate the phase mismatch caused by branching to reduce the radiation loss. However, the fabrication process is quite complex and suffers from misalignment of the microprisms at the junction. Low loss bending has been also achieved by utilizing coherently coupled bends [4]. Q. Wang [5] has presented a low loss Y-branch waveguide splitter utilising a multimode interference (MMI) waveguide section as a transition region with appropriate widths for the input and the branching waveguides. The designed Y branch has an excellent performance in a very wide wavelength range, which means the Y-branch waveguide splitter can be further integrated into a ratiometric wavelength measurement system [6]. In this paper, an extra-low-loss buried waveguide Y-branch splitter based on a tapered MMI structure is proposed and presented operating over a broadband wavelength range from 1500~1600 nm. With optimized parameters, the wavelength dependence of the output ratio between the two branches (~ 0.03 dB over ~100nm) is negligible even with a mismatching offset between the input standard singlemode fibre and a waveguide introduced during packaging.

2. BACKGROUND OF DESIGN

A conventional Y-branch structure consists of an input waveguide and two branching waveguides, as shown in Fig. 1. The two branching waveguides can either have the shape of a cosine arc or they can be straight waveguides with a certain branching angle. However, a Y-branch with cosine-arc branching waveguides has a more compact size as compared with the one with straight branching waveguides.

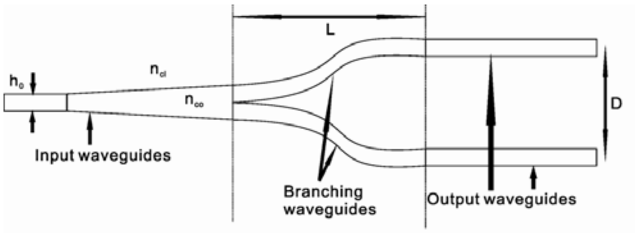


Figure 1. Schematic of conventional Y-branch waveguide splitter.

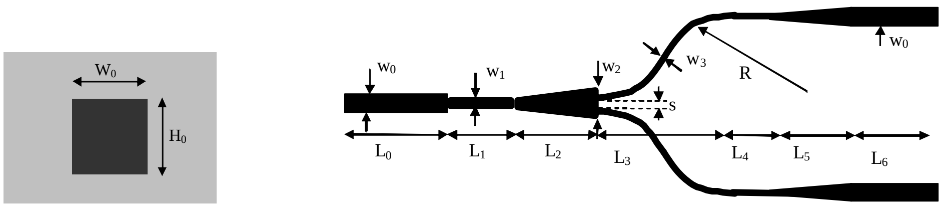
Silica-on-silicon waveguides have a number of advantages, such as low propagation loss and high fibre matching efficiency. Therefore the silica-on-silicon buried waveguide is considered in this paper. Conventionally there is a gap between the two branching waveguides for convenience of fabrication. The gap between the buried branching waveguides fabricated by plasma enhanced chemical vapor deposition technology should not be less than 2 µm, to avoid air voids at the tip of the branch after the cladding layer is deposited. The excess loss is an important characteristic of the Y-branch structure. Many methods for minimizing the excess loss have been recently proposed [7]. However, the existence of the gap degrades greatly the actual performance of the device, further induces the insertion loss and the non-uniformity of a splitter consisting of cascaded Y branches.

The MMI waveguide has many advantages and can be used to construct planar lightwave circuits for different purposes such as splitting, combining, and routing [8-11]. The self-image theory is usually used to determine the geometrical parameters of the MMI section and the positions of the input and output waveguides. Power splitters based on a multimode waveguide section between the input and output waveguides have been proposed and fabricated earlier [9,10]. In this paper a tapered MMI waveguide section is adopted: such a tapered MMI waveguide has a narrow width and therefore can support only two or three eigenmodes between the input and the branching waveguides. The excess loss of the device is then reduced by optimizing the geometrical parameters of the tapered multimode waveguide section, the end width of the tapered waveguide, the width of the branching gap, and the width of the branching waveguides. This paper presents an optimal design for a low-loss Y-branch structure with a tapered multimode waveguide section and the branching gap mentioned above.

3. OPTIMAL DESIGN OF THE GEOMETRICAL PARAMETERS

The buried waveguide cross section is shown in Fig. 2(a); the core and cladding refractive indices and the waveguide width and height were assumed to be: n_{core}=1.4553; n_{clad}=1.4444, W_0=5.5 µm and H_0=5.5 µm, respectively. In order to obtain a splitter with a low excess loss, several parameters such as the widths W_2 of the tapered waveguide section, W_1 of the tapered input waveguides, the gap s between the branching waveguides and the width W_3 of the branching waveguides need to be optimized.

A genetic algorithm and a gradient-based search method are chosen as the optimization method. In the optimization process, the length of the multimode waveguide section is chosen on the basis of the principle of operation of MMI couplers, such as 1000 µm. However, the other four geometrical parameters W_1, W_2, W_3, and s have large variation ranges and therefore large search ranges in the genetic algorithm, thus good initial values (which are close enough to the global maximum) are difficult to find for these parameters. It is well known that a gradient search method can be easily trapped by a local maximum in such a case. Therefore, in the present paper, we first use the genetic algorithm for the design. After a number of iterations, when the convergence of the genetic algorithm slows down, we use a gradient search method to speed up the convergence by using the parameters obtained from the genetic algorithm as good initial values for the gradient search method.



(a) (b)

Fig. 2 (a) Cross section of input waveguide; (b) Schematic of the proposed Y-branch waveguide splitter.

Fig. 3 shows the optical intensity field distribution of the proposed Y-branch splitter calculated using the Beam Propagation (BPM) method. In this simulation, L_1=1500 μm, w_1=4 μm; W_0=5.5 μm; W_2=14 μm, s=2 μm, W_3=4 μm; L_0=1000 μm; L_2=1000 μm; L_3=1529.6 μm; R=30000 μm; L_4=1000 μm; L_5=1000 μm. The excess loss versus wavelength is shown in Fig. 4 which illustrates the excess loss between the sum of two output ports and input port of the integrated device. The excess loss of the proposed Y-branch splitter is only 0.015 dB at a wavelength of 1550 nm, which is much lower than the calculated results presented in Ref. [5].

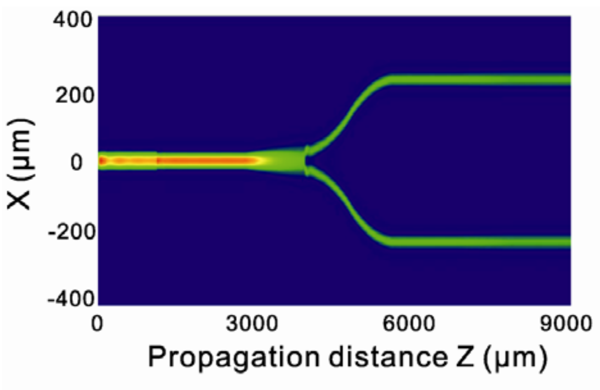


Fig. 3 Optical intensity field distribution of the proposed Y-branch waveguide splitter when L_1=1500 μm and w_1=4 μm.

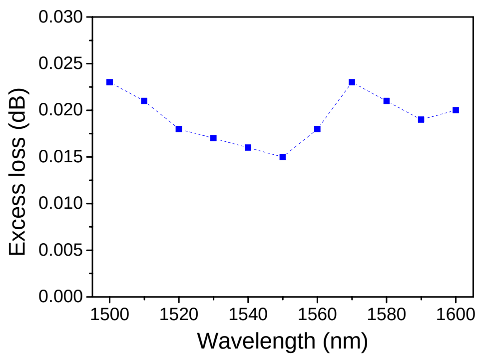


Fig. 4 Calculated excess loss as a function of wavelength.

A major challenge in the use of silica on silicon buried waveguides for photonic lightwave circuit technology is the efficient coupling of light to/from an optical singlemode fibre because of the large mode mismatch between the input optical fibre and the silica buried waveguide. The alignment precision of the optical fibre to a buried waveguide may be limited in practice by the device packaging technique used. To help minimize manufacturing costs therefore it is important to estimate the tolerance of the splitter performance to a typical alignment errors induced by the limitations of the packaging technique. Therefore an estimate of the effect of a typical offset between the input standard singlemode fibre and the packaged waveguide needs to be considered and calculated.

With the developed optimization method, the corresponding light propagation in the case of fibre position shift by ±0.4 μm from the centre is presented in Fig. 5, when L_1= 3000 μm and w_1= 3.5 μm. From the input port of the integrated device, L_0, illustrated in Fig. 2(b), one can see that the optical mode field propagating with in the waveguide of L_0 section, is disturbed by the mismatching significantly, compare with the optical mode pattern of L_0 shown in Fig. 3. It was found that the wavelength dependence of the imbalance is still small (see Fig. 6 the fibre shift is assumed to be ±0.4 μm), even when there is a typical mismatching offset of ±0.4 μm between the input fibre and input port of integrated splitter device.

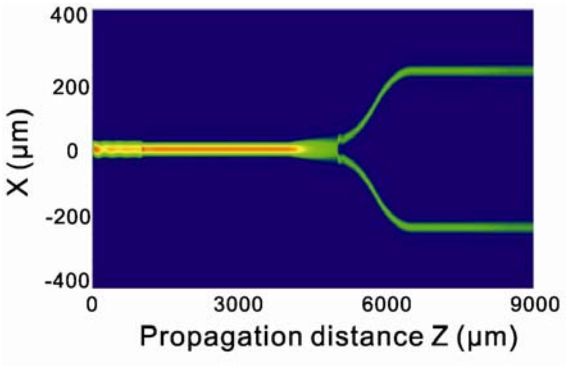


Fig. 5. Optical intensity field distribution of the proposed Y-branch splitter, when L_1= 3000 μm and w_1=3.5 μm; a typical offset of ±0.4 μm between the input singlemode fibre and the input port of the splitter is assumed.

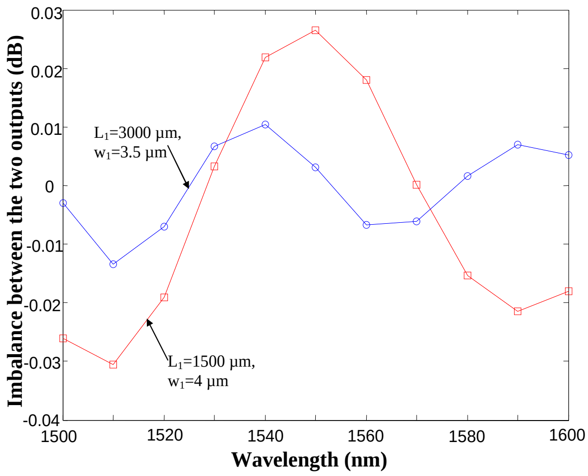


Fig. 6 Imbalance between the splitter output ports after the optimization for the two cases of: L_1= 3000 μm and w_1=3.5 μm (blue line); and L_1=1500 μm and w_1=4 μm (red line).

4. CONCLUSION

An optimal design for an extra-low-loss buried Y-branch splitter based on a tapered multimode waveguide has been presented over a wide wavelength range (1500~1600 nm). An optimization method that combines a genetic algorithm and a gradient-based search method have been used to obtain the optimal geometrical parameters for the multimode waveguide section as well as the widths for the input and branching waveguides. An extra-low excess loss of 0.015 dB at a wavelength of 1550 nm has been obtained after the optimization. An offset between the input standard singlemode fibre and waveguide in packaging has been considered and the result shows that there is very small wavelength dependence (~0.03 dB) of the output ratio between the two branches. There is significant potential for the useful application of the proposed Y-branch structure in integrated optical devices, such as 1×N power splitters and switches, in the future.

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