Improved tolerance in polarisation splitters

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A new design for a passive polarisation splitter is presented. The device consists of a directional coupler with tapered waveguides. The modal birefringence for 3rd order modes for TE and TM polarisations is employed to selectively couple one polarisation. Tapered waveguides in combination with a tapered coupling region are used to create more tolerant designs. Because of the tapered region, the coupling condition is met for a larger width span, compatible with standard optical lithography.

BPM simulations show a width deviation of 150 nm still yields a splitting better than 95%.

Introduction

Photonic integrated circuits (PIC) usually behave differently for different polarisations of light. Modern telecommunication networks based on single-mode fibre do not keep the state of polarisation. The incoming light in a chip therefor has an undefined polarisation, yielding an undefined behaviour. To overcome this problem, different approaches can be applied. One approach is to remove polarisation dependency by changing the properties of the material and the waveguides. This can be very hard and will be compromising with respect to optimal performance. The alternative is to manipulate the polarisation on the chip. In this way, optimised components can be used and the polarisation can be matched to yield optimal performance. Polarisation splitters will be very important in this approach. Passive polarisation splitting is preferred to minimize power consumption and to avoid the need for tuning. Passive polarisation splitting can be achieved by loading a waveguide with metal [1], by mode-evolution [2], or by modal birefringence [3]. Splitters based on the latter have the advantage that they are short, have low loss and a high splitting ratio. A drawback of this design is the very stringent fabrication tolerances. In this paper a new design for a polarisation splitter based on modal birefringence is presented. Tapered waveguides in combination with a tapered coupling region are used to achieve more tolerance in fabrication.

Principle and Design

The polarisation splitter is based on modal birefringence. The splitter consists of an asymmetric directional coupler with a narrow and a wide waveguide. The widths are chosen such that the propagation constant of the fundamental mode in the narrow waveguide equals the propagation constant of an higher order mode in the wide waveguide for one polarisation only as is shown in fig. 1. This figure shows that for TE the modes are resonant. Only the resonant polarisation will couple to the wide waveguide and over a distance equal to the coupling length, the light in this polarisation is fully transferred to the wide waveguide.

To calculate the resonant modes, the propagation constant as a function of the width is calculated using the effective index method. In fig. 2 the effective index as a function of

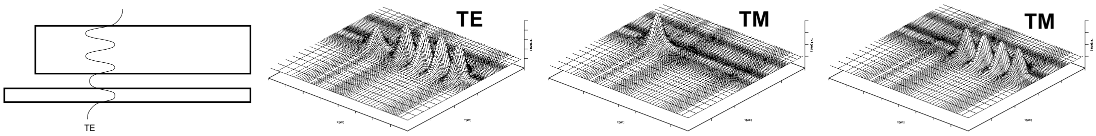

Figure 1: *Principle (left), resonant mode for TE and non-resonant modes for TM*

the width of the waveguide is plotted. The indices match for TE00 and TE03 for widths of 0.8 μm and 6.9 μm respectively.
Furthermore for a width of 6.9 μm no TM mode is resonant with the fundamental mode for the narrow width. To match the index for an higher order TM mode, the width has to be changed by more than 750 nm. This large deviation yields a window for tapering while preserving the mismatch for TM.
Fabrication can introduce a change in width of the waveguides, which changes the effective index, yielding a mismatch between the resonant modes. To compensate for this, the wide waveguide is tapered and the narrow waveguide is kept constant. In the tapered device, the coupling region shifts along the taper when width deviations Δw occur. The shift ΔL can be calculated in the following way:

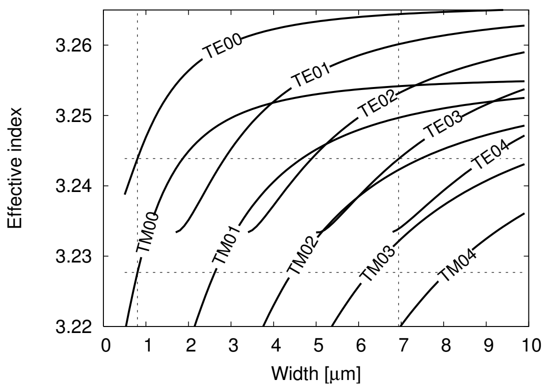

Figure 2: *Effective index vs. width*

$$\left(\frac{\partial\beta}{\partial w}\right)_{w2}\frac{dw}{dz}\Delta L \;+\; \left(\frac{\partial\beta}{\partial w}\right)_{w2}\Delta w \;=\; \left(\frac{\partial\beta}{\partial w}\right)_{w1}\Delta w \tag{1}$$

In this equation $w1$ refers to the narrow waveguide as $w2$ refers to the wide; the leftmost term is the change in propagation constant β along the taper, with $\frac{dw}{dz}$ the taper angle. The second term is the change of the propagation constant in the wide waveguide as the width changes with a fraction Δw. Finally the right side is the change in propagation constant for a width deviation in the narrow waveguide.
In order to have a defined coupling, the coupling constant has to be fixed in the coupling region. As the coupling region depends on Δw, the coupling constant also has to change with Δw. The coupling constant depends on the distance d between the 2 waveguides, so d should also be tapered along the length of the device, in such a way that at the coupling region position a fixed d is obtained. The dependence of d on Δw is:

$$d \;=\; d_0 \;-\; \Delta w \;+\; \frac{dd}{dz}\Delta L \tag{2}$$

with the second term on the right hand side indicating the direct change because of the width deviation and the third term the effect of the tapered distance between the waveguides. These terms have to cancel out, so $\frac{dd}{dz} \;=\; \frac{\Delta w}{\Delta L}$. Combining (1) and (2) results in the relation between the taper angle of the wide waveguide $\alpha_T \;=\; \tan\left(\frac{dw}{dz}\right)$ and the taper angle of the coupling region $\alpha_c = \tan\left(\frac{dd}{dz}\right)$:

$$\frac{dd}{dz} = \frac{dw}{dz}\frac{\left(\frac{\partial\beta}{\partial w}\right)_{w2}}{\left(\frac{\partial\beta}{\partial w}\right)_{w1} - \left(\frac{\partial\beta}{\partial w}\right)_{w2}} \tag{3}$$

The propagation constant as a function of width $\left(\frac{\partial\beta}{\partial w}\right)$ is obtained from the tangent to the lines drawn in fig. 2.
The coupler is cascaded to couple the 3rd order TE mode to the fundamental mode at the output waveguide and to have an additional filtering for the unwanted polarisation. The schematic of the polarisation splitter is depicted in fig. 3.

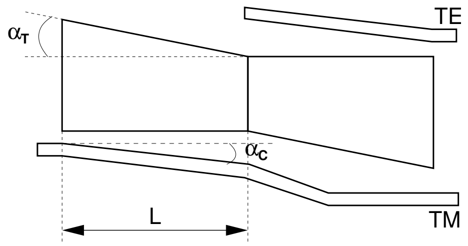

Figure 3: *Schematic of the polarisation splitter*

Results

The proposed device is simulated using 2D BPM to get the optimal length and to investigate the fabrication tolerances. The total length of the simulated device is 2×1425 μm. The topview of the propagated field in the splitter for both polarisations is plotted in fig. 4. It is clearly visible that TE couples to the central (wide) waveguide and then couples to the output waveguide. TM does not couple strongly to the wide waveguide and stays in the narrow waveguide.

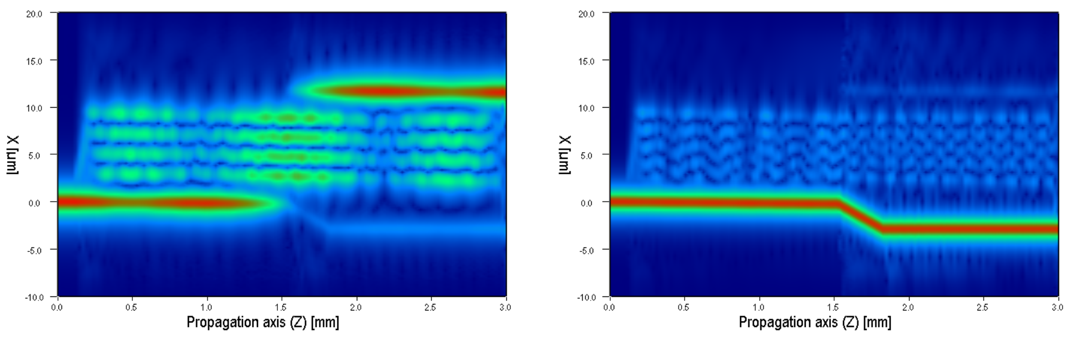

Figure 4: *Topview of the propagated field in the polarisation splitter for TE (left) and TM (right)*

A splitting ratio of more than 95% is needed for practical applications [4]. The splitting ratio of the polarisation for TE is defined as $SR_{TE} = 10 \log\left(\frac{P_{TE(TE)}}{P_{TE(TM)}}\right)$; for TM a similar definition is valid. The SR is calculated as a function of the width deviation. The results are plotted in fig. 5 for both polarisations. The SR for this splitter is compared to a splitter without tapers (the original design), and to a splitter without a tapered coupling region, but with a tapered central waveguide.

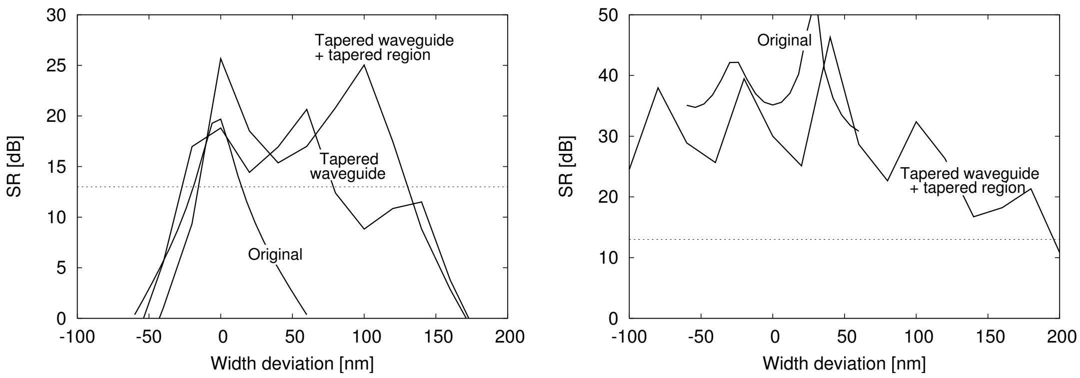

Figure 5: *Polarisation splitting ratio as a function of width for TE (left) and TM (right)*

The dashed line in fig. 5 points out an SR of 13 dB or a splitting ratio of 95%. The new design of the splitter with both a tapered coupling region and a tapered waveguide is more tolerant than the other designs. A width deviation of 150 nm still yields an ER of 13 dB. This allows the component to be fabricated with standard lithography.

Discussion and conclusions

A tolerant design for a polarisation splitter is presented in this paper. Tapered waveguides together with a tapered coupling region enhance the tolerance. A width deviation of 150 nm yields a splitting ratio of 95%. This is an increase in the width tolerance of more than a factor of 3 as compared to a straight device. These tolerances can be achieved by applying standard lithography.

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