Single-section Polarisation Converter on InP/InGaAsP using asymmetrical waveguides

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Single- section integrated Polarisation Converters using a waveguide with one sloped and one vertical wall have been realized and show a conversion efficiency of over 80%. The converter section has a length of 200 μm. The total length of the device, including input and output waveguides, is 600 μm. The lowest insertion loss of this device is about 2db. The converters are fabricated using e-beam writing and a combination of RIE dry etching and wet chemical etching. The conversion efficiency as function of waveguide width has been measured. These results are in good agreement with the simulations.

Introduction

Polarisation converters for photonic integrated circuits received a renewed interest in recent years, because the polarisation uncertainty of the light emanating from fibres seriously degrades the performance of the integrated photonic circuits. To prevent such a degradation, either all the integrated components have to be polarisation independent or only one polarisation direction should be used. In the latter case, the unused polarisation can be detected also by adding a polarisation splitter/converter combination at the front end. Several types of polarisation converters in LiNbO3 [1] and InP-based [2] circuits have been proposed and demonstrated. Van Dam [3] designed a converter, using bend modes, that yields 85% conversion efficiency at the correct bend radius. In order to obtain a polarisation converter with low loss and high conversion efficiency, an new polarisation converter structure with angled facets was first introduced by van der Tol[4] et al. A realisation of this design for GaAs/AlGaAs waveguides with only a single converter section with an angled waveguide has been presented by Huang [5] and Rahmanet [6]. The shortest single-section polarisation converter on InP/InGaAsP has been described and simulated by the authors[7]. Here we present further calculations of the coupling efficiency which are based on our previous analysis, together with the experimental results. This converter has been fabricated using, for the first time, both e-beam lithography and e-beam aligment.

Polarisation converter design

The structure of a single-section polarisation converter is depicted schematically in Fig. 1. The device consists of a converter section, two deep-etched coupling waveguides and two standard shallow-etched waveguides used as input- or output waveguide. The layer structure of the converter section on the InP substrate is a 600 nm thick InGaAsP (λ_g= 1.3 μm) waveguide layer and a 300 nm InP cladding layer. The converter section has one almost vertical side-wall (84° with respect to the horizontal plane) and one sloped side-wall oriented along the (111) crystal plane (54°). The electrical field of each of the two fundamental modes in the converter section is at an angle with respect to the horizontal plane and to a very good approximation both modes are orthogonally polarised. Fig. 2 presents the calculated angle of one of the modes and the beat length between both modes as function of the width of the converter section. From Fig. 2 the length and width of a single-section polarisation converter can be determined. The polarisation angle of both modes is + and - 45° in that case. All simulations have been carried out using the vectorial 3D-mode solver FIMMWAVE (Photon Design).

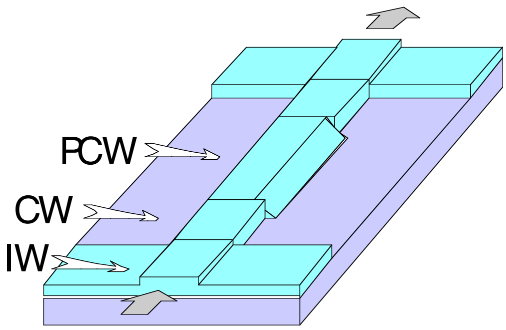

Fig 1. *Schematic structure of the single- section polarisation converter.*

IW: input waveguide
CW: coupling waveguide
PCW: polarisation converter waveguide .

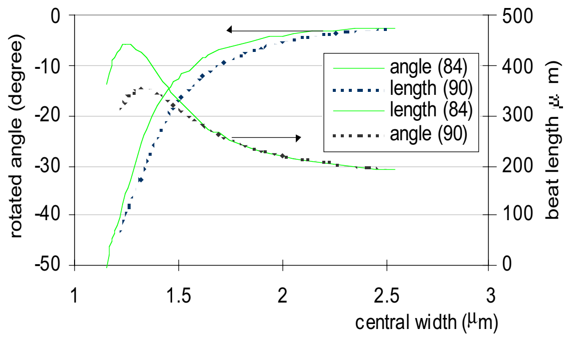

Fig. 2 *The polarisation angle of the TE quasi mode and the interaction length as function of the center width of the converter section. Dotted: 84° angle; solid: 90° angle (vertical) of the side-wall.*

Since the propagation loss of a standard shallow-etched InGaAsP waveguide on InP substrate (<1 dB/cm for both polarisations at a wavelength of 1.55μm) is much lower than that of a deep-etched waveguide (5 dB/cm for TE and 7 dB/cm for TM), use of the first type is preferred. However, simulation reveals that the coupling efficiency between a shallow-etched waveguide and the converter section is very low compared to the efficiency of a deep-etched waveguide /converter combination, the latter having negligible loss.

Therefore, a deep-etched waveguide is used between the converter section and the shallow-etched waveguide. An optimised, 3 μm wide deep-shallow coupling has been used to couple the two. It is connected by adiabatic tapers to both waveguides. The calculated loss is 0.1 dB per junction.

Fig. 3 gives the calculated coupling efficiency as a function of the width of the deep-etched waveguide and of the offset between this waveguide and the converter section. The optimal width of the straight waveguide is 1.0 μm and of the converter section it is 1.2 μm. The optimal offset is 0.1 μm.

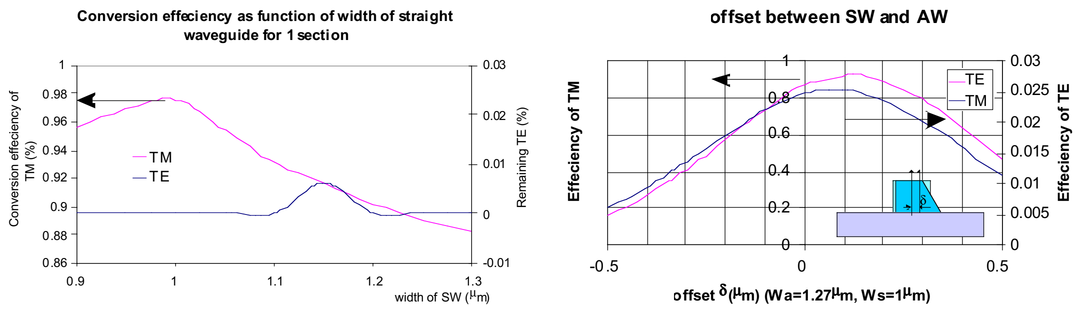

Fig 3. *Calculated coupling efficiency from the deep-etched waveguide to the converter section as function of the width of the deep-etched waveguide(left) and of the offset of this waveguide with the converter section(right).*

Manufacture and experimental results

The waveguide structure was written in PMMA with e-beam lithography. The written parts were dissolved in a MIBK:IPA (=1:3 in volume) developer, followed by evaporation of 60 nm Titanium and lift-off. The Ti mask was used for the subsequent RIE [8] with CH_3/O_2 to etch the shallow-etched waveguides. Prior to this, 7 x 7 μm^2 alignment markers were defined in a 100 nm thick Si-nitride layer, also by e-beam lithography in PMMA. They were etched 1 μm deep into the wafer to get a good contrast for alignment in subsequent e-beam steps. The critical step is the deep RIE into the substrate after the shallow etch step, since only one side of the 1.2 μm wide waveguide should be etched. The same Ti masking technique as in the previous step was applied, using the e-beam alignment markers for accurate alignment. Together with the Ti mask from the previous step, the new Ti mask covered top and one side of the waveguide. After the deep etch and removal of the Ti mask, the last e-beam litho was carried out, now covering the deep etched side-walls with PMMA and opening a window on the other side-walls for the selective wet chemical etch. Here, the InP top layer serves as a self-aligned mask for the etching of the waveguide layer.

The converters were measured in a transmission setup containing polarisers at the input and output sides. Both TE and TM components were measured at the output, and compared to the (TE-) output of a neighbouring reference waveguide. The results of the measurements on a set of four converters are shown in Fig. 4, where the light at the input was TE polarised. The results for TM input are similar. The solid curves represent the simulation. They were shifted 0.4 μm to the right along the horizontal axis to fit to the experimental data. This indicates an undercut of the sloped side of approximately 0.4 μm, somewhat larger than the expected 0.3 μm. The data agree with the calculations within the experimental error except at both ends of the width scale. The converters of 1.1 μm width show no conversion at all; they merely reproduce the polarisation state at the input. This can be explained by examining the curves of the beat length (Fig. 2) more closely. They show a sharp drop at small widths: at a width of 1.1 μm (not shown in the curve) this beatlength is half of the optimal value, meaning the

length of the converter (~ 200 µm) is exactly one beatlength instead of the half-beatlength needed for full conversion.
From the measured output intensities an insertion loss of 1.7 dB and a polarisation conversion ratio of 80% is obtained.

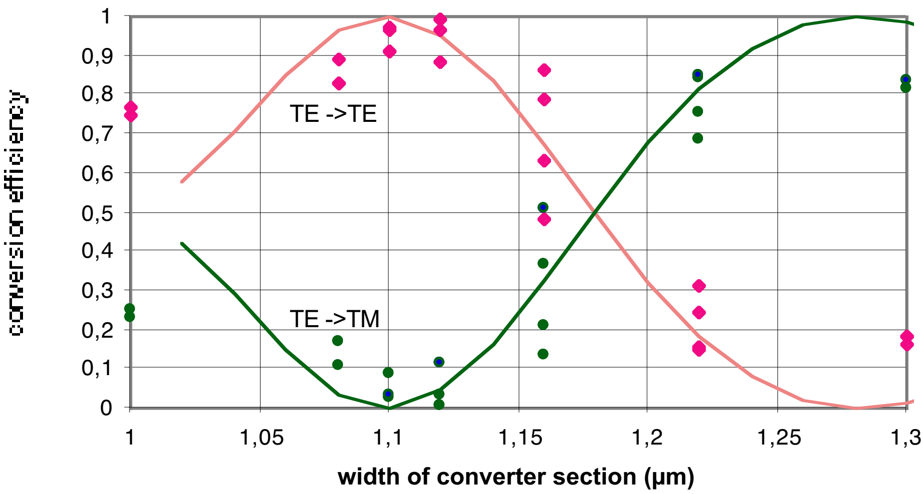

Fig 4. *Measured TE-TM conversion efficiency and remaining TE polarisation of a single-section polarisation converter. The result of the simulation (continuous curves) are shown for comparison.*

Conclusion

An single-section integrated polarisation converter with an overall length of 600 µm has been simulated and realised in InP/ InGaAsP waveguides. The TE-TM polarisation conversion efficiency was better than 80% and the loss was less than 2 dB, about 1 dB lower than the loss of the curved [3] polarisation converters.

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