

Design of a short polarization converter on InP/InGaAsP using asymmetrical waveguides

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Simulation results are presented for a short polarization converter using asymmetrical waveguides, containing one sloped sidewall and one vertical sidewall. The angles of both modes with respect to the coordinate axes have been calculated as a function of the waveguide width. Polarization converters with one section (length is 196 μm), one period (2 sections) or 2 periods can be realized by selecting the suitable width and length of this waveguide. Tolerance of width and length of the waveguide and thickness of film layer for the polarization converter have been analyzed and will be discussed.

Introduction

Several types of polarisation converters in InP-based circuits have been proposed and demonstrated experimentally. The desired combination of low loss, high conversion efficiency and simple design is very hard to obtain, however. We propose a simple structure based on the waveguide sections with angled facets first introduced by van der Tol¹ et al. In our design, the facets are etched exclusively in the waveguiding layer over the full depth of this layer. This simplifies the processing, obviating the need for precise etch depth control. Our design also provides a strong coupling between the quasi TE- and TM mode such that a few converter sections are needed for full polarisation conversion. In the case that only one section is needed the two modes are almost degenerate. The consequence with respect to the width tolerance of the waveguides has first been analysed by Lafontaine and Tzolov² for this case. A realisation of their design for GaAs/AlGaAs waveguides has been presented by Huang³ et al. Here, we present a converter design for InP/InGaAsP waveguides. A comparison of a single section converter with two- and four- section converters will be discussed at the conference.

Polarization converter principle and design

The single-section converter waveguide is depicted in Fig. 1, together with the field distribution of the major components of the quasi TE fundamental mode. The profiles of the quasi TM mode are similar. The analysis has been carried out with the vectorial 3D-mode solver FIMMWAVE (Photon Design). The layer structure of the converter section on top of the InP substrate is an InGaAsP ($\lambda_g = 1.3 \mu\text{m}$, thickness 600 nm) waveguide layer and a 300 nm InP cladding layer (not shown in Fig. 1). One sidewall is almost vertical (84° with respect to the horizontal plane), the other is oriented along the (111) crystal plane (54°); both are etched through to the substrate. The profiles of the E_x and E_y components of the quasi TE mode (E_x is horizontal, E_y is vertical) are almost identical, except for a scaling factor.

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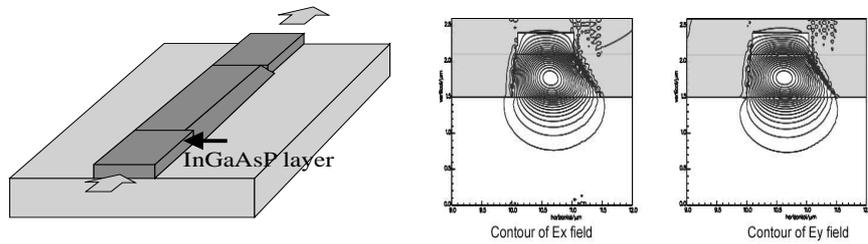


Fig 1. The one- section polarisation converter and the E_x and E_y field contours of the quasi TE mode in the converter section.

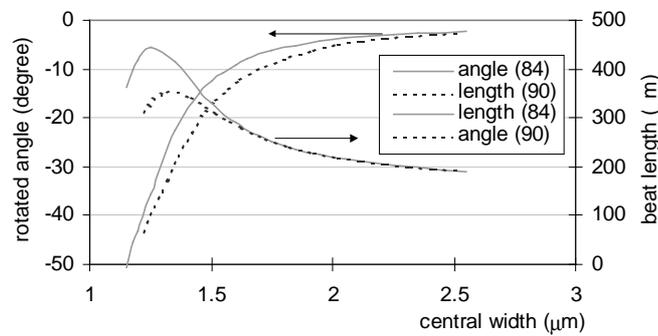


Fig. 2 The polarisation angle of the TE quasi mode and the interaction length as function of the center width of the converter section.

This means that the ratio E_y/E_x very well describes the polarisation angle of the mode. The two modes (TE and TM) appear to be perpendicularly polarised. The polarisation angles of the fundamental modes depend strongly on the waveguide width of the converter section. Fig. 2 shows the polarisation angle of the TE quasi mode and the interaction length between the two quasi- modes as function of the width in the middle of the waveguide layer (central width) of the converter waveguide. Two cases are considered: an exactly vertical side wall (90°) and a more realistic near-vertical side wall (84°), showing the influence of a small angular misorientation. Since a converter of N sections can be regarded as a set of $\lambda/2$ waveplates with the axes tilted at the polarisation angle of the eigenmode (alternatively positive and an equal amount negative), the polarisation angle needed for an N -section converter is $45^\circ/N$. The width of a converter with N sections can now be found from Fig. 2. The (centre) widths of the polarisation converter sections are found to be $1.18 \mu\text{m}$, $1.33 \mu\text{m}$ and $1.51 \mu\text{m}$ and their lengths about $200 \mu\text{m}$, $400 \mu\text{m}$ and $640 \mu\text{m}$ for single- two- and four- section converters respectively. Since the actual loss of a converter section is expected to be quite high ($\sim 10\text{-}20 \text{ dB/cm}$), the shortest converter is preferred.

In Fig. 3a a graph of the mode conversion efficiency for a single-section converter between two straight waveguides as function of the length of the section and in Fig. 3b the efficiency for the section with optimal length as function of the width is depicted. From this graph it is found that a variation of $0.1\mu\text{m}$ of the centre width causes a 10% power drop, consequently the width tolerance is very strict. The width and offsets of the input and output straight waveguides have to be optimised because the mode size of the straight waveguide must match the mode size of the converter waveguide. Widths of $1.0\mu\text{m}$, $1.16\mu\text{m}$, and $1.34\mu\text{m}$ are optimal for the straight waveguides for one-, two- and four- section converters respectively. The offsets between the straight waveguides and the converter waveguides appear to be optimal when the vertical walls are in line. The mode conversion is also sensitive to the thickness of the InGaAsP waveguide layer. According to our simulation the conversion efficiency changes less than ± 0.05 if the thickness of the waveguide layer varies between 580 nm to 620 nm .

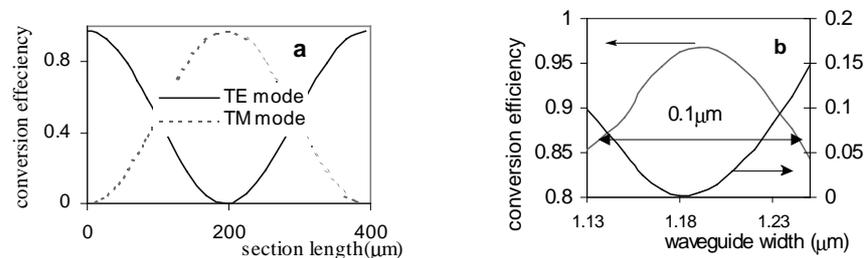


Fig. 3 Mode conversion efficiency for the two mode of a single-section converter with TE input. **a** as function of the length, **b** as function of the width.

Processing

For fabricating a waveguide with one angled sidewall and one vertical sidewall at least two process steps are needed. Selective an-isotropic wet chemical etching of InGaAsP creates an angled sidewall at an angle of 54° ((111) facet) with the horizontal plane. By choosing the temperature and the composition of the anisotropic etchant correctly a small and stable undercut ratio (=undercut/etch depth), stable etch rate and smooth etched wall can be obtained. Fig.4 shows the InGaAsP etch characteristics as the function of amount of H_2SO_4 in the etchant $\text{H}_2\text{SO}_4/\text{H}_2\text{O}_2/\text{H}_2\text{O}$ (x ml: 10 ml: 100 ml) at 20°C . An amount of 20 ml H_2SO_4 is found to give a stable etching rate of 80 nm/min , and the smallest undercut ratio (0.33). For an etch depth of $0.6\mu\text{m}$, this means an undercut of $0.20 \pm 0.02\mu\text{m}$, which can be corrected for in the design. The nearly vertical sidewall is fabricated with a $\text{CH}_4\text{-H}_2$ Reactive Ion Etch / O_2 descum process⁴ optimized for low loss waveguides using a Ti mask. To meet the strict width tolerance for the converter waveguides, we use e-beam lithography (direct write), which can produce patterns with a tolerance within a few nm. The pattern is transferred into the InP cladding layer with RIE, using a Ti mask obtained with lift-off. During RIE or Wet Chemical Etching one side of the polarization converter waveguide is masked. The result is also shown in Fig.4.

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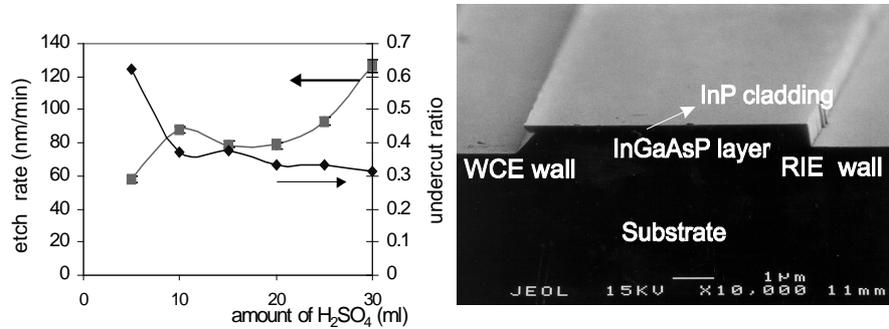


Fig.4 Etch rate and undercut ratio of the InGaAsP waveguide layer with an InP masking layer as function of the selective etchant. Also shown is an electron micrograph of a test converter waveguide. The undercut is clearly visible

Conclusion

Design options for a short polarisation converter on InP consisting of alternating angled sections have been studied. The dimensions are quite critical for the shortest design consisting of one section of 200 μm length, but the tolerances can be met by utilising e-beam writing of the waveguide structure and using controlled underetch of the Wet Chemical Etching process for the angled facets of the converter.

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