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Novel Compact Polarization Converters Based on Ultra Short Bends

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***Abstract*—A novel integrated polarization converter based on ultra short bends is presented, which has a potential for low loss and small device size. A conversion value of 85% was experimentally measured with excess loss of 2.7 dB and overall dimensions of 975 × 83 μm. Also 45% conversion was measured with extremely low excess loss of 0.4 dB for a device size of 760 × 86 μm.**

I. Introduction

POLARIZATION independent operation is an important issue in optical communication systems. Polarization converters can be used to make optical components polarization independent by inserting them in the middle of a component is such a way that a signal applied at the input traverses half of the component in one and the other half in the orthogonal polarization state. The principle was demonstrated by Takahashi for silica-based phased-array demultiplexers [1]. For application of the principle to compact InP-based components, integrated converters are required. An interesting device is the periodically alternating asymmetrically loaded waveguide [2]–[4]. In this letter, we present a novel integrated converter that is based on ultra short bends and which has a potential for low loss and small device size.

II. Design

Experiments on waveguide bends with very small bending radii (down to 30 μm) have been reported earlier [5]. Results show that when a deeply etched waveguide structure (as shown in Fig. 1) is used, low insertion loss can be obtained with very small bending radii. Numerical analysis with a 2-D vectorial method of lines (MOL) mode solver [6] reveals that in such deeply etched waveguides the nondominant transverse field component strongly increases if the bending radius is chosen sufficiently small. Fig. 2 shows the transverse X- and R-components of the TE-polarized zero-order mode for a bending radius of 50 μm (graphs of the TM-polarized zero-order mode are almost identical). In this example almost 40% of the total field power is in the nondominant X-component, which is equivalent to a rotation of the principal axis of more than 35° with respect to the principal axis of a straight waveguide. So the TE and TM polarized modes degenerate into two hybridly polarized modes. If a waveguide bend with opposite curvature is connected to such a bend, both modes will be excited. The coupling efficiency is high because the intensity profiles of the hybrid modes match very well. In the case of a 50-μm bending radius the coupling loss is as low as 0.2 dB. The two modes propagate with different phase velocities and at a length $L = L_\pi$ (the beatlength, defined as $L_\pi = \pi/(\beta_{\mathrm{TE}} - \beta_{\mathrm{TM}})$, in which β_{TE} and β_{TM} are the propagation constants of the TE and TM zero-order mode respectively), the combined fields will show a polarization rotation.

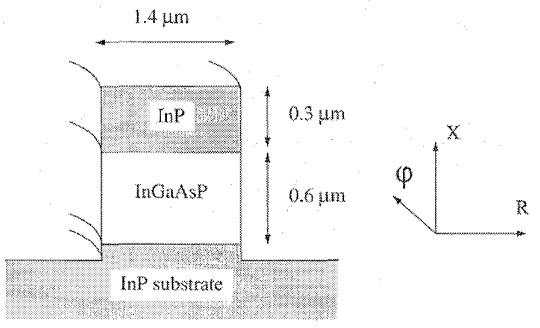

Fig. 1. The deeply etched waveguide structure as used for the polarization converter.

The polarization conversion was experimentally measured using the layout as shown in Fig. 3. Two U-bends, consisting of four arc segments with a segment angle α, are placed in series. This segment angle is varied between 10 and 80°, allowing different beatlengths between two subsequent junctions. Two devices were designed: one with and one without lateral offsets between the segments. Waveguides of 3.0 μm width are used to connect the U-bends to each other, and are used for in- and output waveguides, because they are known to have low propagation losses [5]. The transition between these wide waveguides and the 1.4 μm narrow bends was done using an adiabatic taper with a length of 50 μm. The (maximum) total device size is 975 × 83 μm.

III. Fabrication

Waveguides have been fabricated in a MOCVD-grown InP–InGaAsP(λ_g = 1.3 μm)–InP ridge waveguide structure.

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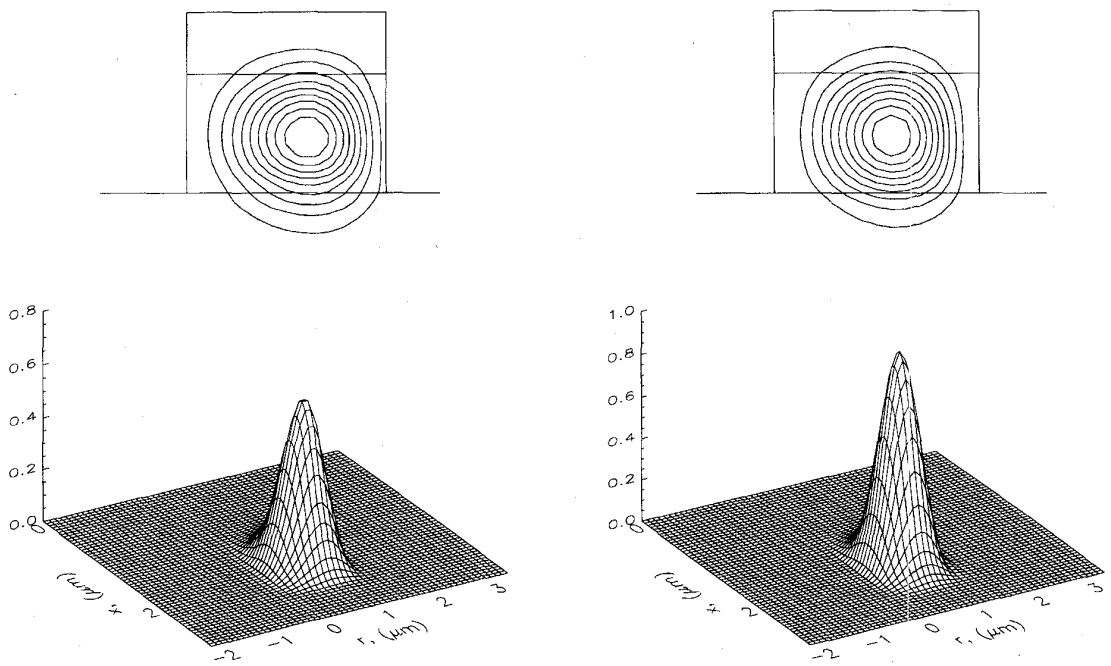


Fig. 2. Contour (top) and surface (bottom) intensity plots of the nondominant X-component (left) and the dominant R-component (right) of the TE-polarized zero-order mode in a waveguide bend with a 50 μm radius.

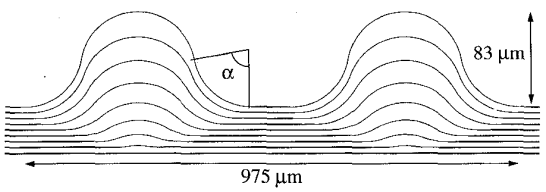


Fig. 3. Schematic layout of the polarization converter, in which the segment angle is depicted as α.

A 100-nm-thick PE-CVD deposited SiNx film was used as a masking layer, and waveguides were etched completely through the guiding layer into the substrate employing a CH_4/H_2 RIE etch/descum process to reduce the scattering losses [7]. Waveguide losses were measured 1.0 dB/cm and 2.2 dB/cm for widths of 3.0 μm and 1.4 μm, respectively, both for TE and TM polarization. The sidewall angle was measured to be 13° off verticality.

IV. Experimental Results

A Fabry–Perot laser operating at a wavelength of 1508 nm was used to measure the performance of the polarization converters. TM polarized light was launched into the input waveguide and at the output a polarization filter was used for separate measurement of the TE and TM response. In Fig. 4(a), the conversion values are shown versus the segment angle. The converters with a bending radius of 50 μm show the most interesting measurement results: a polarization conversion of 85% was measured at a segment angle of 70°. The corresponding excess loss is shown in Fig. 4(b) and is only 2.7 dB. Low conversion values (<20%) were measured for small bending radii (<50 μm), and are not shown in the graph. Also

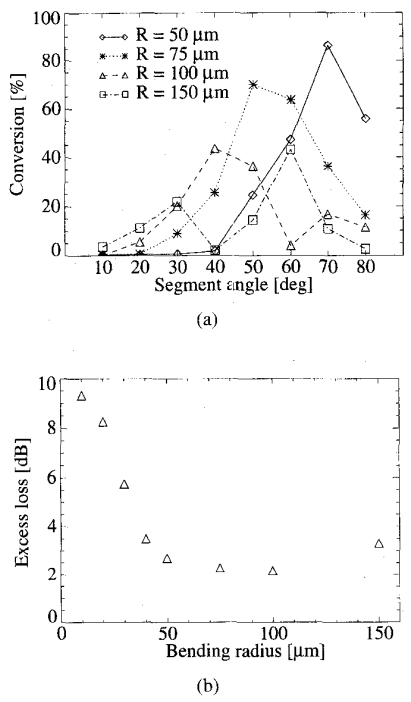
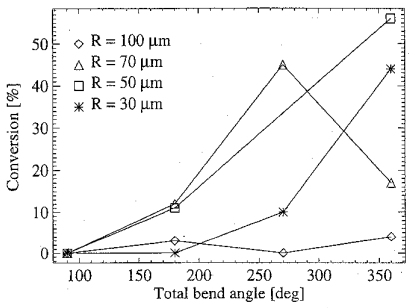
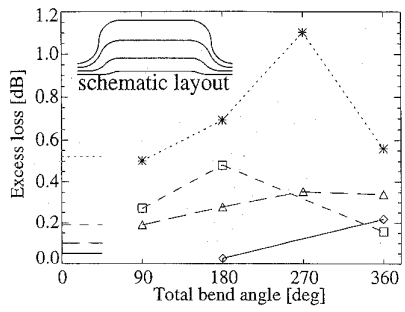


Fig. 4. Measurement results of the first experiment polarization converters: polarization conversion (a), and excess loss (b).

a beat between TE and TM polarization is clearly observed. The appropriate beatlengths are 120, 130, 140, and 300 μm, for bending radii of 50, 75, 100, and 150 μm, respectively, which deviate significantly from calculations (>1 mm). This may be due to the nonvertical sidewalls which could not be included in the modeling. Excess loss values, which are shown



(a)



(b)

Fig. 5. Measurement results of the second experiment polarization converters: polarization conversion (a), and excess loss (b).

in Fig. 4(b), showed negligible dependence on the segment angle. Furthermore, the application of lateral offsets between the curved sections appear to have neglegible influence on the conversion as well as on the excess loss.

For a second experiment, another converter layout was used. In this case the converter consists of two S-bends, made of two arc segments, connected to each other with a 50-μm straight waveguide [as shown in Fig. 5(b)]. Again the segment angle was varied in order to obtain different beatlengths between two subsequent junctions. The measured polarization conversion is shown in Fig. 5(a). In this figure, it can be seen that a conversion value of 45% was measured at a bending radius of 70 μm. The corresponding excess loss value can be found in the graph of Fig. 5(b) and is less than 0.4 dB. This is the lowest excess loss value for a polarization converter reported so far. A conversion value of 45% is also obtained with a 30 μm bending radius. The excess loss is then slightly higher: 0.6 dB.

V. Conclusion

A novel type of polarization converter has been realized using deeply etched narrow InP–InGaAsP ridge waveguide bends with small bending radii. It combines low loss (2.7 dB) with compact device size (975 × 83 μm) and high polarization conversion (>85%). Also a 45% converter was realized with extremely low excess loss (0.4 dB), and a device size of 760 × 86 μm. It is demonstrated that with deeply etched waveguide bends with small radii strong polarization conversion can be obtained.

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