A compact passive polarization converter optimized for active-passive integration on InP/InGaAsP

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Abstract: An improved design for an integrated polarization converter is presented. The device is specially suited for monolithic integration with active and passive components on InP/InGaAsP. A novel simplified fabrication process is shown. Measured polarization conversion > 97% agrees well with simulations.

Introduction

Polarization handling is of ever greater importance in modern telecommunications networks. First of all a lot of components in the network are highly polarization dependent, furthermore polarization mode dispersion can degrade the transmission in an optical fiber. On the other hand, the polarization can be employed in e.g. polarization multiplexing, and polarization based filtering. In all these cases, polarization converters (PC) are key-elements.

Passive polarization converters that are able to be integrated with both active and passive components are preferred. Polarization conversion can be obtained by periodically loaded waveguide sections [1, 2, 3], by using integrated bends [4], or by using a single waveguide section with a vertical and a slanted sidewall [5, 6, 7].

One problem of these designs is the difficulty to integrate them with passive and specifically active components. The polarization converters and active components (such as semiconductor optical amplifiers (SOAs) and phaseshifters [8]) can be made in the same layerstack, but the optimal thickness of the topcladding differs by more than 1 µm. For polarization converters a large birefringence is needed: hence a thin topcladding is preferred (typically smaller than 300 nm); for SOAs and electro-optic phaseshifters, a thick topcladding (typically 1500 nm) is needed below the contact to avoid optical losses in the contactlayer. This is clarified in Fig. 1: an SOA, phaseshifter and a conventional polarization converter are shown. Critical lithographical definition is not possible with these height differences which complicates processing and integration of these devices.

A new design is proposed as is shown in the rightmost picture in Fig. 1. This new proposed design uses the same topcladding as an active device and can be easily integrated with the other components. The birefringence with the thicker cladding is only slightly reduced with respect to the thinner cladding. Hence the increase in length for this design is less than 40µm.

Design

The layer stack consists of an InP substrate, a 500 nm InGaAsP[Q(1.25µm)] waveguide layer and a 1500 nm InP topcladding. Simulations with the commercial waveguide solver FIMMWAVE predict an optimal conversion of TE to TM and vice versa larger than 99% for a width of 0.94 µm and a length of 141 µm. A conversion above 95% is expected for a width deviation of 100 nm.

Deviations from the calculated width and length are expected, because the refractive indices used in the simulations are not accurately known for these materials. The total device contains an asymmetric waveguide as the converter section, 1.2 µm wide deep input and output waveguides, coupled to 3 µm wide shallow waveguides via 75 µm long tapers (Fig. 2). At the interface of the input waveguides and the polarization converter section a small ridge is present, perpendicular to the waveguide. This is needed to prevent etching of the input waveguide in the wet etch for the slanted sidewall.

Fig. 1: Cross section of active devices (SOA, phaseshifter), a conventional PC and the new design.

Fig. 2: Overview of the polarization converter including in- and output waveguides and tapers.
**Fabrication**

The polarization converters have strict tolerances, so the converter sections will be defined using Electron Beam Lithography (EBL). EBL is not suited to write large circuits, therefore all other waveguides will be defined using standard optical lithography. The EBL written parts have to be aligned to the optical waveguides. This can be done by the writefields with alignment marks as shown in Fig. 3.

![Fig. 3: Optical waveguides and EBL writefields including EBL alignment marks.](image)

The processing scheme of the polarization converter is shown in Fig. 4.

a. First the waveguides and writefields for the EBL, including alignment marks (Fig. 3), are defined optically into a Silicon Nitride (SiN$_x$) mask. Next the polarization converters are defined in Ti on top of the SiN$_x$ using EBL and a lift-off process.

b. Before etching any waveguide, the second EBL step is done to open the straight side of the PC.

c. Now the nitride at the straight side of PC is opened. The shallow waveguides and the straight side of the PC are etched with CH$_4$/H$_2$ Reactive Ion Etching (RIE).

d. All shallow waveguides are covered with resist, the PC area is opened with a non-critical optical lithography step. The SiN$_x$ at the sloped side of the PC can be openend and RIE etched until 300 nm above the waveguide layer, while etching this side, the straight side is etched even deeper, well below the waveguide layer.

e. Silicon Nitride is deposited on the whole sample and the shallow waveguides are again covered with resist. The SiN$_x$ is etched back using CHF$_3$ RIE. Because of the directional etching, the etched sidewalls stay covered with SiN$_x$, which serves as a mask for wet etching. Br$_2$-Methanol is used to etch the slope. This etchant etches both InP and InGaAsP with an angle of 54° with respect to the surface.

f. Finally all the nitride is removed using an HF solution.

![Fig. 4: Processing scheme of the integrated Polarization converter.](image)

The fabricated converters are shown in Fig. 5. From these figures it is clear that there is an underetch at the shallow side (the sloped side), but there is no underetch at the deep side. This is most probably caused by stress in the masking material during the wet-etching. The influence of this additional underetch on the conversion performance of the device will be very small as can be understood from Fig. 6. The field is located in the InGaAsP layer, below the sloped side. The width of the polarization converter at the position of the waveguide-layer is not strongly affected and thus the tilt of the modes is still correct. However, because the top of the fieldprofile is influenced, the coupling losses will be increased with respect to the design.

**Measurements**

The polarization converters are measured using a setup as shown in Fig. 7. The device is excited using an EDFA with a bandpass filter set to 1555 nm as a source. The filter has a 2 nm bandwidth, large enough to prevent Fabry-Pérot resonances. A polarizer at the input of the chip is used to select the input polarization. At the output another polarizer selects the polarization that is measured using the photodiode and the lock-in amplifier.
The power in both polarizations at the output is measured for both TE and TM polarized light at the input. The conversion is defined as the fraction of the converted polarization in the output power. The conversion $C$ for the two polarizations ($i, j = TE, TM$) is determined from the following equations:

\[ P_{ij} = \alpha_i \alpha_j C P_j; \quad i \neq j \]  
\[ P_{ij} = \alpha_i \alpha_j (1 - C) P_j; \quad i = j \]

where $P_j$ is the input power with polarization $j$, $P_{ij}$ is the output power in polarization $i$ when the input polarization is $j$; $\alpha_i, j$ are the losses for the two polarizations in the input and output waveguides.

By solving these equations, the propagation losses in the input and the output waveguides for the two polarizations are eliminated and the conversion $C$ is obtained:

\[ C = \frac{\sqrt{x}}{1 + \sqrt{x}} \]  
\[ x = \frac{P_{i,j} P_{j,i}}{P_{i,i} P_{j,j}}; \quad i \neq j \]

The maximum conversion from TE to TM and vice versa occurs at 131 $\mu$m length, corresponding to the minimum of the measured conversion.

Fig. 5: SEM photographs of the integrated Polarization converter. Top: transition of a straight waveguide to the polarization converter. Bottom: reverse transition.

Fig. 6: Field profile of a mode in the polarization converter, the structure is indicated by the solid line, the dashed line shows the etched topcladding caused by the underetch.

Fig. 7: Setup used for characterization of the polarization converter. BPF: Bandpass filter, PD: Photodiode, TIA: Trans impedance amplifier

Fig. 8: Measured conversion as a function of width(top) and length(bottom).
half beat length between the modes of the converter section, and back to zero at the full beat length (262 µm). The maximum conversion, for this device is 97.5%.

The large scattering on the measured values is caused by the underetch, this not uniform throughout the whole device. Hence a non-uniform width is obtained along the converter section.

The losses of the polarization converter including input and output tapers are measured to be 2.4±0.3 dB for TE and 2.6±0.3 dB for TM. This value is higher than simulated (less than 0.5 dB), most probably caused by the non-optimal coupling of the waveguide and the converter because of the underetch. This can be optimized by using a more controlled wet etch.

**Conclusion**

A new type of polarization converter is shown, specially suited for easy integration with other active and passive devices. The device is fabricated and measured. The polarization converter shows a maximum conversion larger than 97%.

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**References**


