An integrated polarization splitter and converter

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A new design for an integrated passive polarization splitter and converter is presented. The device consists of a Mach-Zehnder Interferometer with polarization converters in both arms. The position of the converters is such that a phase difference of π radians occurs between TE and TM. This results in polarization splitting in the output coupler. The device is analyzed using the transfer matrix method and fabricated on InP/InGaAsP. First measurement results show a splitting ratio of approximately 10 *dB and a conversion of >90 %. This device can be monolitically integrated with passive and active components.*

Introduction

The polarization state of light 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 [1]. In all these cases, polarization splitters and converters are key-elements.
Passive polarization splitters and converters that are able to be integrated with both active and passive components are preferred. Passive polarization splitting can be achieved by loading a waveguide with metal [2], by mode-evolution [3], or by modal birefringence [4, 5]. Splitters based on the latter have the advantage that they have low loss and show a high splitting ratio. A drawback is their length (1 to 3 mm) compared to other components on the chip.
We present a short, 600 μm long, interference based splitter integrated with a polarization converter. The device consists of a Mach Zehnder Interferometer with polarization converters in both arms.

Principle

The layout of the device is depicted in fig. 1. The device is based on interference. Light

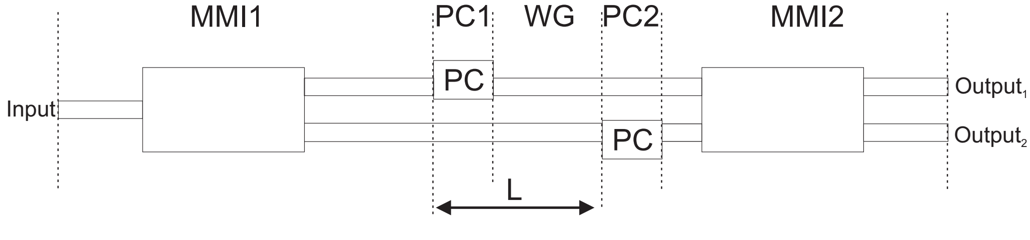
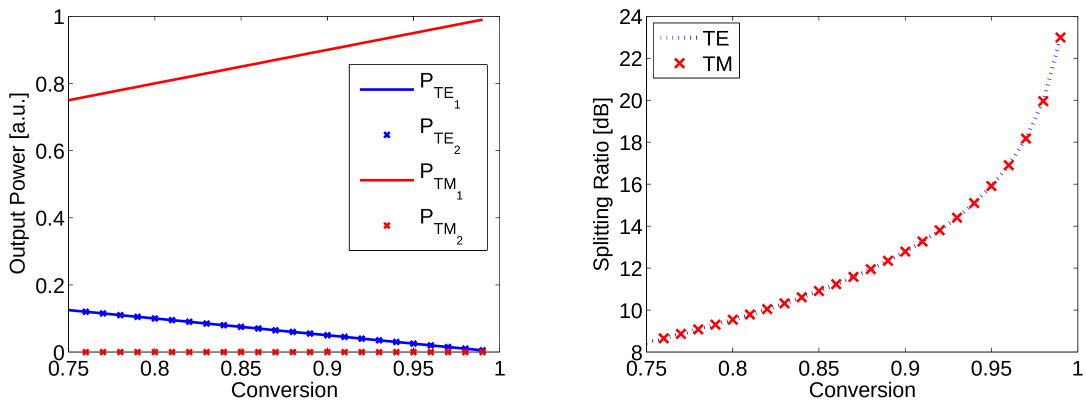


Figure 1: *Schematic of the MZI polarization splitter/converter*

coupled into the input waveguide is split into the two branches with equal power and phase. In the upper branch a polarization converter is placed that rotates the polarization 90^{o}, so after this, the orthognal polarization propagates through this branch.
In the lower branch the light in the original polarization propagates over a distance L before being rotated in a polarization converter. The birefringence in the waveguides causes a phase shift between light in the arms and when both signals are mixed in the output MMI, the phase difference causes one polarization to appear in one of the outputs while the opposite polarization goes to the other output. To achieve the desired splitting, the phase difference between the branches needs to be $\frac{\pi}{2}$ radians, this is obtained when: $L = \frac{\pi}{2(\beta_{\text{TE}} - \beta_{\text{TM}})}$, here $\beta_{\text{TE,TM}}$ are the propagation constants for both polarizations. The polarization converters in the arms consist of an asymmetric waveguide with a straight and a slanted sidewall [6].

Analysis

The performance of the device is analyzed using the transfer matrix method. The splitter is divided into 5 parts as shown in fig. 1: the input coupler (MMI1); a Polarization Converter in the upper arm, nothing in the lower arm (PC1); straight waveguides of length L in both branches (WG); a Polarization Converter in the lower arm, nothing in the upper arm (PC2) and the output coupler (MMI2). Simulation results with TE input as a function of the conversion of the polarization converters in the arms are shown in fig. 2(a). The



(a) Output powers (b) Splitting Ratio

Figure 2: *Simulated performance of the integrated polarization splitter/converter as a function of conversion of the polarization converters in the branches (TE input)*

TE outputs can only be zero if the conversion in the arms equals 1. If the conversion is lower, the non-converted part is split equally over the two branches, therefor the net conversion of the splitter/converter - for TE input defined as the fraction of the power in TM with respect to the total power in output port 1: $c_{net} = \frac{P_{\text{TM}_1}}{P_{\text{TE}_1} + P_{\text{TM}_1}}$ - is always higher than the conversion of the individual converters.
The influence of the coupling coefficient of the output coupler is also investigated, but MMI's can be made tolerant to width deviations [7], so the conversion of the polarization converters in the arms is considered to be the limiting factor in the fabrication.
Fig. 2(b) shows the Splitting Ratio (Total power in wanted port / Total power in unwanted port) of the splitter for a coupling coefficient of 0.5 for MMI2. For a splitting ratio larger

than 13 dB, a conversion larger than 90% is needed.
The waveguides used are 2 μm wide, and deeply etched into a layerstack having a 300 nm InP topcladding, and a 500 nm Q(1.25) filmlayer on an InP substrate. This yields a $\Delta\beta = \beta_{TE} - \beta_{TM}$ of 0.03 μm^{-1}, so for this device a distance L of 52 μm is needed. The total length of the device, including in- and output MMI's is about 600 μm. The splitter can be made shorter by using smaller MMI's.

Fabrication

The processing of the polarization splitter is similar to the process described earlier [6]. The lithographical definition of the waveguides is made in an ASML PAS5500/250 5$\times$ reduction wafer stepper. This allows a very accurate width control, better than 20 nm on a 800 nm line. This machine is advantageous as compared to Electron Beam Lithography, because it has a large writing field, better uniformity and is suited for mass-production.
The etching of the waveguides and the straight side of the polarization converter is done in a CH_4/H_2 RIE. The slanted side is etched in a Br_2-Methanol solution. This etchant etches both InP and InGaAsP anisotropically with an angle of 54^o.

Characterization

Both the integrated splitter/converter as separate polarization converters on the same chip are examined on a setup shown below. The devices are exited using an EDFA and a 2.5 nm

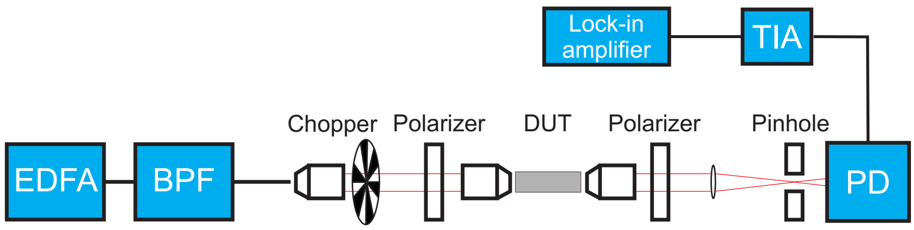
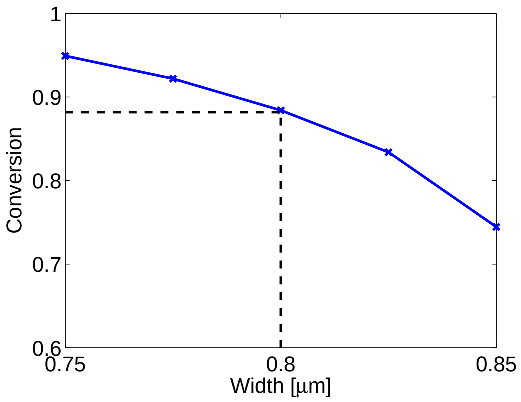


Figure 3: *Setup used for characterization of the polarization splitter and converter. BPF: Bandpass filter, PD: Photodiode, TIA: Trans impedance amplifier*

wide bandpass filter, set to a central wavelength of 1555 nm. This signal is chopped and the polarization is fixed using a polarizer. The light is coupled into the chip and the output is coupled through a polarizer to determine the output polarization. It is detected with a photodiode connected to a trans impedance amplifier and a lock-in amplifier.
The single polarization converters are measured first. The conversion as a function of the width of the device is examined. The results are shown in fig. 4(a).
A conversion of 95% can be achieved for a width of 0.75 μm. The polarization converters used in the splitter are 0.8 μm wide. According to the measurements, this converter will have a conversion of 88%.
The full splitter/converter is measured at the same wavelength. The numbers for the conversion agree well with the expected net conversion if the converters in the arms have a conversion of 88%. The difference between the splitting for TE and TM is caused by the polarization dependence of the output coupler. The coupler is not a perfect 50-50 coupler for TM. This problem is identified and can be solved in a next realization. The low numbers for the splitting ratios are caused by a small phase error (approximately 0.25 radians) in the branches.



(a) Measured conversion as a function of width of polarization converter (the dashed line shows the converter used in the integrated splitter)

SR_{TE}	9.1 dB
SR_{TM}	11.4 dB
c_{TE-TM}	0.91
c_{TM-TE}	0.91

(b) Measured performance of the integrated splitter/converter

Figure 4: *Measurement results*

Conclusions

A novel type of interference based integrated polarization splitter and converter is presented. The device is analyzed using the transfer matrix method. Splitting ratios larger than 95% are expected for conversion ratios of the converters of more than 90%. The polarization converters are the limiting factor in the fabrication process. According to previous work, for a width deviation of 100 nm a conversion $> 90\%$ can be achieved. The device is fabricated and first measurements show a splitting of 10 dB and a conversion of 90 %.

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