Short 2 × 2 polarization splitter in InP/InGaAsP using polarization converters

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We present a short, 800µm, interference based, 2 × 2 polarization splitter. The device consists of a Mach Zehnder Interferometer with polarization converters in the arms. Birefringence in the waveguides causes a phase shift between light in the arms. This phase shift has an opposite sign for the two orthogonal polarizations. For a 2 × 2 splitter an additional polarization independent phaseshift of π/2 in one of the arms is necessary. This phase difference corresponds to a length of 120 nm and is obtained by tilting the input and output couplers of the MZI. First results show a splitting ratio of approximately 9 dB.

Introduction

Polarization is an important property of light. First of all a lot of components in telecommunications networks 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, polarization diversity [1] and polarization based filtering [2]. 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 [3], by mode-evolution [4, 5], or by modal birefringence [6, 7]. 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) which is large compared to other components on the chip. Shorter splitters based on photonic crystal waveguides [8] are reported, but these have the disadvantage of higher losses and more complex processing.

Most of these components are 1 × 2 devices, designed for splitting only. We present a compact, 800 µm long, integrated 2 × 2 polarization splitter/combiner, based on polarization converters.

Principle

The device is based on a previous design [9] and consists of a Mach Zehnder Interferometer with polarization converters in both arms, as is depicted in Fig. 1.

Light coupled into the input waveguide of the first Multi Mode Interference coupler (MMI) is split into the two branches with equal power. The signals in both arms have a phase difference of $\frac{\pi}{2}$. For the polarization splitter, the phase in both arms has to be
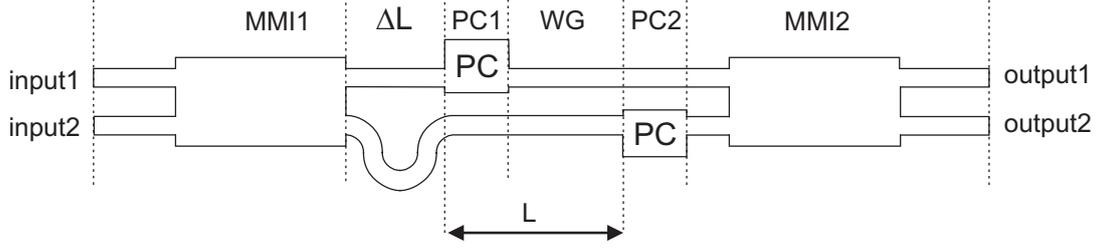
Figure 1: *Schematic of the MZI polarization splitter/converter*

equal, so in one arm a path length difference ΔL is present to have a polarization independent phaseshift $\frac{\pi}{2}$. In the upper branch a polarization converter is placed close to the input MMI, which rotates the polarization over 90°. After this, the orthogonal 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 second polarization converter. The birefringence in the waveguides causes a phase shift between light in the arms. This phaseshift is equal in magnitude but opposite in sign for both polarizations. When both signals are combined 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 $\pm\frac{\pi}{2}$ radians. This is obtained when: $L = \frac{\pi}{2(\beta_{\text{TE}} - \beta_{\text{TM}})}$, where $\beta_{\text{TE,TM}}$ are the propagation constants for the two polarizations.

The polarization converter consists of a ridge waveguide with a straight and a slanted wall [10, 11].

Simulation

Simulation results with TE polarized light at the input as a function of the conversion $(c = \frac{P_{\text{TM}}}{P_{\text{TE}} + P_{\text{TM}}})$ of the polarization converters in the arms are shown in Fig. 2. Splitting ratios larger than 95% are expected for conversion ratios of the converters of more than 90%.

The splitting ratio as a function of the length of the path length difference for a conversion of 95% is shown in Fig. 3. The length has to be correct within ± 30 nm to achieve a splitting ratio larger than 90%.

Design and fabrication

The pathlength difference of 120 nm ($\triangleq \pi/2$), in the arms of the MZI is achieved by tilting the in- and output MMI coupler at an angle of 1°. In this way sharp deeply etched bends, in which unwanted polarization conversion can occur, are avoided. The waveguides used in the splitter are 1.2 μm wide, and deeply etched into a layerstack having a 1500 nm InP topcladding, and a 500 nm Q(1.25) waveguide layer on an InP substrate. This yields a $\Delta\beta = \beta_{\text{TE}} - \beta_{\text{TM}}$ of 0.02 μm^{-1}, so for this device an offset L between the converters of 78 μm is needed. The total length of the device, including in- and output MMI's is about 800 μm. The device is coupled with tapers to 2.5 mm long shallow waveguides (etched 100 nm into the waveguide layer) at both the in- and outputs.

The fabrication is based on the processing for polarization converters [10]. The lithographical definition of the device is done using Electron Beam Lithography (EBL). The
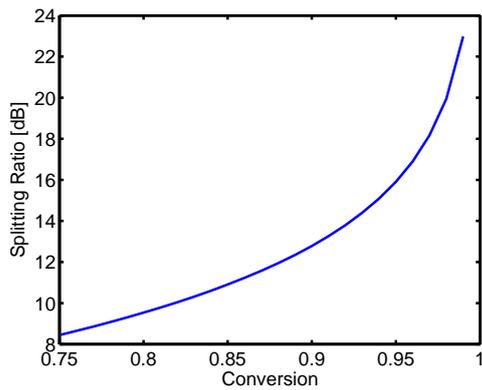
Figure 2: *Simulated splitting ratio as a function of conversion of the PC*
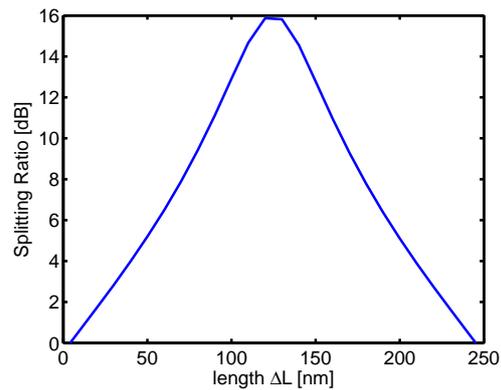
Figure 3: *Simulated splitting ratio as a function of the path length difference*

EBL pattern is aligned on optically defines in- and output waveguides. All waveguides are etched using CH_4/H_2 Reactive Ion Etching. The sloped sidewall of the polarization converters is etched using a Br_2-Methanol solution. This solution etches both InP and InGaAsP and stops at a crystal plane oriented at 54°to the substrate.

Characterization

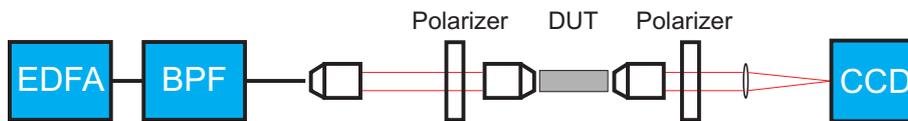The integrated splitter is examined on a setup as shown below. The devices are exited

Figure 4: *Setup used for characterization of the polarization splitter and converter. BPF: Bandpass filter, CCD: InGaAs CCD camera*

using an EDFA and a 2.5 nm wide bandpass filter, set to a central wavelength of 1555 nm. 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 an InGaAs CCD camera to observe the 2 outputs at the same time. The obtained image (Fig. 5(a)) is analyzed to obtain the power in both outputs simultaneously. From this, the splitting ratio (SR) is determined by integrating the intensity in both ports over a fixed width.

Measurement results show 9 dB splitting ratio. The polarization converters in the arms show a conversion of approximately 90%. According to Fig. 2 this should yield a splitting ratio of 13 dB. The discrepancy with the measured result is most probably caused by polarization dependent MMIs, and is presently being investigated.

Conclusions

An interference based integrated 2×2 polarization splitter and converter is presented. The device is based on a previous design for a 1×2 polarization splitter. Splitting ratios larger than 95% are expected for conversion ratios of the converters of more than 90%.
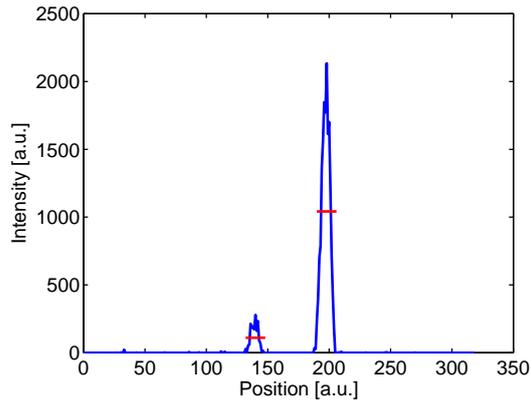
SR_{TE}	4 dB
SR_{TM}	9 dB
c	0.88 ± 0.02

(a) Measurement of the power in both outputs using a CCD camera

(b) Measured performance of the integrated splitter

Figure 5: *Measurement results*

The device is fabricated and first measurements show a maximum splitting of 9 dB and a conversion close to 90%.

References

[1] T. Barwicz, M.R. Watts, M.A. Popović, P.T. Rakich, L. Socci, F.X. Kärtner, E.P. Ippen, and H.I. Smith. Polarization-transparent microphotonic devices in the strong confinement limit. *Nature Photonics*, 1(1):57–60, January 2007.

[2] R. Hanfoug, J. J. G. M. van der Tol, L. M. Augustin, and M. K. Smit. Wavelength conversion with polarisation labelling for rejection and isolation of signals (POLARIS). In *Proc. 11th Eur. Conf. on Int. Opt. (ECIO '03)*, pages 105–108. Prague, Czech Republic, April 2–4 2003.

[3] P. Albrecht, M. Hamacher, H. Heidrich, D. Hoffmann, H.-P. Nolting, and C. M. Weinert. TE/TM mode splitters on InGaAsP/InP. *IEEE Photon. Technol. Lett.*, 2(2):114–115, February 1990.

[4] M. R. Watts, H. A. Haus, and E. P. Ippen. Integrated mode-evolution-based polarization splitter. *Opt. Lett.*, 30(9):967–969, May 2005.

[5] J. J. G. M. van der Tol, J. W. Pedersen, E. G. Metaal, Y. S. Oei, H. van Brug, and I. Moerman. Mode evolution type polarization splitter on InGaAsP/InP. *IEEE Photon. Technol. Lett.*, 5(12):1412–1414, December 1993.

[6] J. J. G. M. van der Tol, J. W. Pedersen, E. G. Metaal, J.-W. van Gaalen, Y. S. Oei, and F. H. Groen. A short polarization splitter without metal overlays on InGaAsP-InP. *IEEE Photon. Technol. Lett.*, 9(2):209–211, February 1997.

[7] L.M. Augustin, J.J.G.M. van der Tol, R. Hanfoug, W.J.M. de Laat, M.J.E. van de Moosdijk, P.W.L. van Dijk, Y.S. Oei, and M.K. Smit. A single etch-step fabrication-tolerant polarization splitter. *J. Lightwave Technol.*, 25(3):740–746, March 2007.

[8] V. Zabelin, L.A. Dunbar, N. Le Thomas, R. Houdré, M.V. Kotlyar, L. O'Faolain, and T. F. Krauss. Self-collimating photonic crystal polarization beam splitter. *Opt. Lett.*, 32(5):530–532, March 2007.

[9] L.M. Augustin, R.Hanfoug, J.J.G.M. van der Tol, and W.J.M. de Laat. A compact integrated polarization splitter/converter in InGaAsP/InP. *IEEE Photon. Technol. Lett.*, 19(17):1286–1288, September 2007.

[10] L.M. Augustin, J.J.G.M. van der Tol, and E.J. Geluk. Short polarization converter optimized for active-passive integration in InGaAsP/InP. *IEEE Photon. Technol. Lett.*, 19(20):1673–1675, October 2007.

[11] H. El-Refaei, D. Yevick, and T. Jones. Slanted-rib waveguide InGaAsP-InP polarization converters. *J. Lightwave Technol.*, 22(5):1352–1357, May 2004.