Polarization Manipulation in Photonic Integration on Indium Phosphide

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Abstract
The possibility to manipulate polarization in a Photonic Integrated Circuit (PIC) gives new design options. This will be illustrated with POLIS, an integration scheme based on polarization. Also the polarization manipulating devices will be introduced.

Introduction

Polarization is a problem for integrated optics, since a planar geometry implies different behaviour for TE and TM polarized modes. On the other hand, the polarized modes are very stable. This implies that polarization can be used to increase performance. In system experiments polarization is often used as a parameter to create extra functionality. The essential polarization manipulating devices in that case are retardation plates, polarizers and polarizing beam splitters. The last few years polarization manipulating integrated devices are developed, which can fulfil the same role as their bulk counterparts. This makes it possible to use polarization as a useful parameter in photonic integrated circuits as well. Here an example will be given, regarding the important issue of combining active and passive functions on one InP-chip [1-3]. First short descriptions of the polarization manipulating devices are given. Then the application in a polarization based integration scheme (POLIS) will be presented, illustrated with experimental results. We concentrate on InGaAsP/InP, the material most suitable for PICs to be used at telecom relevant wavelengths.

Polarization manipulating devices

The relative strength of the polarized modes can be controlled with polarization converters and polarization splitters/filters. Here we will introduce a complete set of basic building blocks for polarization handling.

Polarization converter: Polarization conversion can be obtained with a narrow waveguide having one slanted sidewall (fig. 1, which shows a device designed for integratability [4]). This rotates the polarization of modes by 45°. A TE (or TM) mode from a symmetric input waveguide, equally excites the two rotated orthogonal modes then. These modes propagate with different propagation constants β_1 and β_2. After half of the beat length ($L_{\lambda/2}=\pi/2(|\beta_1-\beta_2|)$) the rotated modes recombine to a TM (or TE) mode in a symmetric output waveguide. In this way full conversion between TE and TM is possible. Recently some other polarization converters have been published, which promise even shorter devices [8] or single mask fabrication [9].

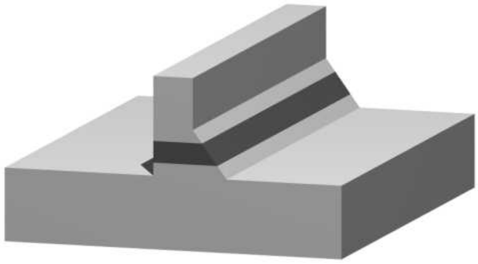

Fig. 1: A passive polarization converter, [4]. The converter length is about 125 μm. Conversions above 99% can be obtained in devices with <1 dB loss.

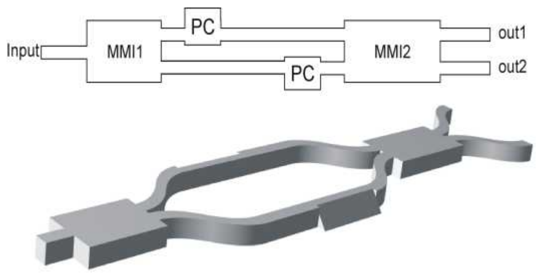

Fig. 2: Top view and schematic of the polarization splitter, based on an MZI with polarization converters (fig. 1) in the branches [5].

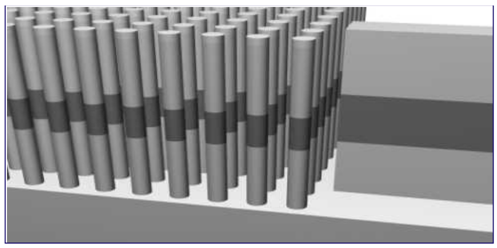

Fig. 3: Polarization filter based on photonic crystal pillars, with coupled ridge waveguide [6].

Polarization splitter: Our polarization splitter (fig. 2, [5]) consists of a Mach-Zehnder interferometer with polarization converters in the branches. This creates a polarization dependent phase difference between the branches, which is used for polarization splitting. A splitting ratio of 10 dB has been demonstrated.

Polarization filter: For a very pure state of polarization in high performance applications filtering of the polarization is needed. The polarization splitters can be used for this, but they are rather bulky and have difficulty achieving high extinction. A short and high-extinction polarization filter is realized with photonic crystals [6]. We developed a TE-filter based on pillar photonic crystal (fig. 3), which is compatible with the layer stack and processing of PICs. A photonic crystal waveguide was realized which supports propagation of only the TM-mode. A 4 µm long device provides 20 dB extinction.

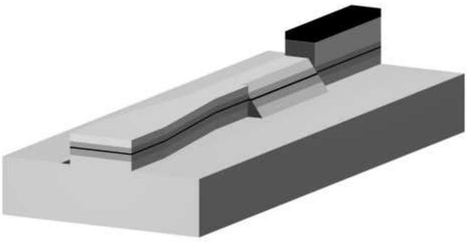

Fig. 4: Integrated waveguide and detector within POLIS. (input waveguide, taper, polarization converter (see fig. 1) and detector.) [7]

Application using polarization: POLIS

The possibility to control the polarization in a PIC can be used to create functionality, e.g. for advanced high speed optical communication systems, where polarization multiplexing or alternating polarization between subsequent pulses is applied. Here we show one possibility specific for integration of functions: polarization used to define active and passive functions. Other examples of polarization use to create enhanced integrated circuits can be found in refs. [10-12].

POLarization based Integration Scheme (POLIS)

In a compressively strained QW splitting of light- and heavy-hole bands leads to different band edges for TE and TM. In between these band edges there is a spectral region where change of polarization implies change from transparency to absorption (or vice versa). This is the basis of the POLarization based Integration Scheme (POLIS, [7]). Polarization defines the active or passive

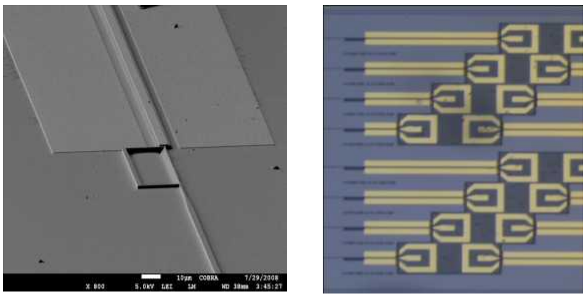

Fig. 5: Realized integrated waveguide-polarization converter-detector (left),. Detectors with varying lengths (right).

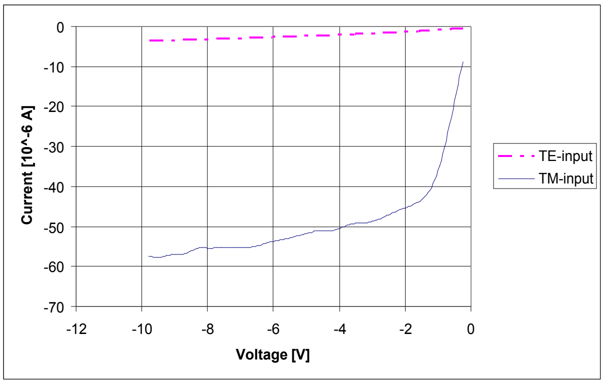

Fig. 6: Experimental results for the integrated waveguide-detector.. Responsivity as a function of detector length [7]

part of the circuit. Coupling between these parts is achieved with polarization converters. The advantages are that only one growth step is needed and that circuit layout is flexible regarding the position of active and passive regions (see figs. 4 and 5). The first integration within the POLIS concept combines a passive waveguide (propagating TM), a polarization converter and a photo detector (detecting TE, fig. 6). An external response of 0.234 A/W is measured, (uncorrected for coupling losses, 5 dB). The dark current is a few nanoamperes. The absorption length is below 230 µm; short enough to allow detection at frequencies >10 GHz.

Conclusions

Through the development of integrated polarization manipulating devices, e.g., polarization converters and splitters, it is possible to use polarization for enhancing functionality. One examples of this is given, with polarization defining material to obtain active (detection in this case) and passive (waveguiding, polarization conversion) functions.

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