TE/TM-mode pass polarizers and splitter based on an asymmetric twin waveguide and resonant coupling

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***Abstract*—A new passive TE/TM-mode polarization filter for an InGaAsP/InP material system based on an asymmetric twin waveguide (ATG) and resonant coupling is investigated. Linear taper sections with different taper angles are introduced to couple between the two vertically separated waveguides. At a wavelength of 1.55 μm extinction ratios (ER) of 20 dB for the TE- and more than 10 dB for the TM-mode are reported for devices shorter than 400 μm. Furthermore we show, this concept can be expanded to a polarization splitter.**

I. INTRODUCTION

The TE/TM polarizations in semiconductor waveguides give rise to a variety of options, such as polarization diversity receivers [1], polarization shift keying [2] and polarization diversity multiplexing [3]. Different approaches to design TE- and TM-pass polarizers have already been demonstrated. One way to realize a polarizer is to make use of the high birefringence of a material. Polarizers based on lithium niobate [4] or polymers [5] were demonstrated. However, for photonic integrated circuits (PICs), multiple components have to be easily integrable to InGaAsP/InP systems to simplify and therefore reduce the cost of packaging.

Here we report simulation results for a TE/TM filter with a short length of less than 400 μm and a high power extinction ratio of 20 dB for the TE mode and more than 10 dB for the TM mode. The filter could be repeated several times to improve the suppression rate. A concept is shown how the polarizer can be modified into a beam splitter by bending the upper waveguide and introducing some MMI-like section for the diluted waveguide. Additionally, the concept is based on an asymmetric twin waveguide with one waveguide designed to improve fiber coupling [6].

II. DESIGN CONCEPT

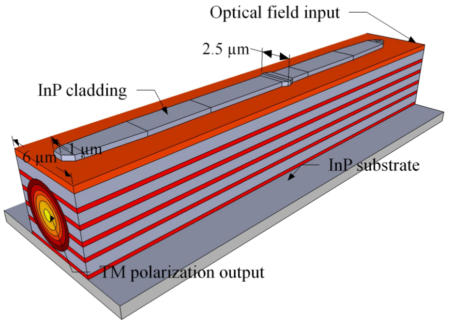

Fig. 1. Sketch of the TM-pass polarizer

Basic theoretical studies on asymmetric waveguides and vertical couplers were already carried out [7]. Here we can demonstrate simulation results for an InGaAsP/InP structure that can be integrated into a PIC. The structure consists of a large spot size lower waveguide and small spot size upper waveguide. The layers are as follows: five 50 nm thick layers of InGaAsP (λ_g = 1350 nm) are interspersed by 700 nm thick layers of InP. The upper waveguide on top of this structure has two 1 μm thick cladding layers of InP and a 150 nm thick core layer of InGaAsP (λ_g = 1400 nm). The large waveguide is designed to guide only the fundamental TE- and TM-mode. Because of the waveguide's nearly circular mode size of 6 μm, it enables the direct coupling of the fiber to the device. The upper waveguide has a significantly higher propagation constant. Therefore, the fundamental modes of the waveguide are hardly affected by the large underlying waveguide for a width of the upper waveguide of 2.5 μm. Nevertheless, both waveguides can be brought to resonance by down-tapering the upper waveguide. This makes it possible to couple the optical field from one waveguide to the other. At a width of 1 μm the upper waveguide does not guide any modes and the field is just in the lower waveguide.

Here we show that by using the lower waveguide as an input point, the TE- or the TM-polarization of the optical field at a wavelength of 1.55 μm can be filtered out. This is achieved by the taper concept sketched in Fig. 1. The upper waveguide starting width is 1 μm. It is then expanded to 2.5 μm by six linear tapers with different lengths and again contracted to 1 μm. The exact layout is displayed in Tab. I.

Since the ATG is birefringent, the resonance point for the TE- and the TM-mode is reached at a different width of the

978-1-61284-878-5/11/$26.00

TABLE I
CONFIGURATION OF THE TM-PASS POLARIZER

section no.	start-width (μm)	end-width (μm)	length (μm)
1	1.00	1.55	5.00
2	1.55	1.65	5.00
3	1.65	1.80	50.00
4	1.80	1.95	70.00
5	1.95	2.10	90.00
6	2.10	2.50	1.00
7	2.50	2.50	2.00
8	2.50	2.10	1.00
9	2.10	1.95	17.00
10	1.95	1.80	70.00
11	1.80	1.65	50.00
12	1.65	1.55	5.00
13	1.55	1.00	5.00

upper waveguide. Additionally the tapers around the resonance points are steep, causing power transfer from the fundamental input to the first order mode. Mode beating is provoked. These effects make it possible to transfer only one polarization state back to the fundamental mode of the large spot size, lower waveguide with low losses. The other mode is still located in the upper waveguide and is finally coupled into the substrate modes, because of the steep last taper.

The same principle can be applied to a TE-pass polarizer. However, since the propagation constant of TE-polarization is higher than that of TM-polarization for this structure, the concept has to be slightly modified. To obtain a TE-pass polarizer the start and end width of the whole device are the same, but an additional taper (start-width: 2.10 μm, end-width: 2.20 μm) is introduced. Furthermore the length each taper is modified, resulting in a total length of 262 μm. The length of the 10 μm long input- and the similar 10 μm long output-waveguide are added to the tapered sections lengths. This design results with the TE-mode coupling into the lower waveguide and the TM-mode still being in the upper waveguide.

The advantage of the TM polarization having a lower propagation constant can be used to transform the TM-pass polarizer into a polarization splitter. Since the TM mode has a lower propagation constant, at a certain upper waveguide width this polarization is not anymore guided by the upper waveguide and remains only in the lower waveguide. Whereas the TE-polarization still can be guided by the small width of the upper waveguide. It will be shown how this effect can be used for polarization splitting.

III. SIMULATION RESULTS

Here, we present results of the computations of the commercially available tools Fimmwave and Fimmprop [8]. The modes for each waveguide were calculated with the Film Mode Matching method in Fimmwave. The waveguides are assumed to be perfect waveguides without losses. Fig. 2 shows the output power percentage of the TE- and TM-polarization. For the TM-pass polarizer, an ER of the TE-mode relative to the TM-mode of - 20 dB for a 391 μm long coupler (2x 10 μm for the in- and out-coupler) is obtained. Nevertheless less than -0.1 dB losses for the TM-polarization occur. A relative ER lower than -10 dB is obtained for a bandwidth of ±15 nm.

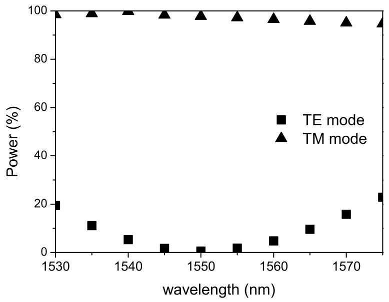

Fig. 2. Output power for the TM-pass polarizer

For the TE-pass polarizer with a length of 262 μm, the ER relation of the TE- to the TM-mode is more than -10 dB. The TE-mode has only losses of -0.2 dB.

IV. CONCLUSION

A TE- and TM-pass polarizer with broad bandwidth and high ER over a short distance of less than 400 μm is shown. With this method only a single growth step is necessary and standard semiconductor processing techniques are needed. Furthermore, the structure and principle of resonant coupling can be used to design a polarization splitter. Finally, the large spot size, lower waveguide enables simplified fiber coupling to PICs.

ACKNOWLEDGMENT

The authors would like to thank Science Foundation Ireland (SFI) to support this work under grant 07/SRC/I1173.

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