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Demonstration of an ultra-short polarization converter in InGaAsP/InP membrane

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***Abstract*—An ultra-short (< 10 µm length) polarization converter is demonstrated in an indium phosphide based membrane. Measurements show very high polarization conversion efficiency (97 %) with low excess losses (~ 1 dB).**

Keywords: Indium phosphide; integrated optics; polarization converter; triangular waveguide.

I. INTRODUCTION

Membrane photonics platforms have been developed in the past few years to lower the power consumption of photonic chips and increase the density of components they can integrate [1]. However, the typical high-index contrast realized in these platforms results in a strong difference between the propagation properties of the TE and TM polarized modes. In order to avoid problems due to, among others, polarization-dependent dispersion and losses, it is essential to supply these platforms with polarization handling capabilities.

The basic component to control the polarization in photonic integrated circuits is the polarization converter, which enables the conversion of TE polarized light into TM, and vice versa. Recently, several interesting membrane polarization rotators have been demonstrated on the SOI platform. However, they are either relatively long [2], or rely on very tight fabrication accuracy [3].

In this paper, we not only demonstrate the first polarization converter in an InP membrane (a material of special interest since gain materials can be integrated inside to fabricate active devices [1]), we also show that it can be made as short and show performances similar to the best converters made on SOI [2-3], while being potentially more tolerant.

II. THEORY

The design of the polarization converter presented here has been described in detail elsewhere [4]. The device relies on the beating between the two eigenmodes of chemically etched triangular waveguides (see Fig.1). The input polarization state is projected on these eigenmodes and after propagating over the designed distance in two oppositely-loaded triangular waveguides, the new polarization state obtained is rotated by 90° with respect to the input state.

As compared to the design of [4], a rectangular waveguide of length x is added between the two triangular waveguides for characterization purposes (cf. section IV).

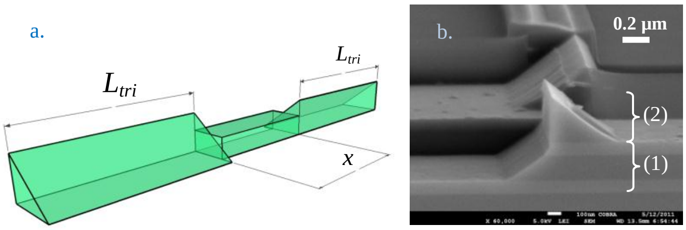

Figure 1. (a.) Schematic and (b.) SEM picture (before bonding) of the presented polarization converter

III. FABRICATION

Like other devices realized previously on the IMOS (Indium phosphide membrane on silicon) platform, the polarization converter presented here is first fabricated using standard lithography, dry-etching and wet-etching steps on a III-V epitaxial layer-stack, before being bonded on a carrier wafer and released from the initial substrate [1].

As shown in Fig. 1b, the layers grown on the InP substrate before the fabrication starts can be separated into a stack (1) (InGaAs-100 nm / InP-200 nm / InGaAs-100 nm), which will be used to protect the membrane during substrate removal, and a stack (2) (InP-250 nm / InGaAsP-20 nm / InP-130 nm), which forms the membrane itself and will contain the devices.

As mentioned in the fabrication plan of [4], the 20 nm-thin InGaAsP layer of the membrane is used to define very accurately two different membrane thicknesses, without damaging the material. After depositing a 50 nm-thick SiN_x layer on the sample by plasma-enhanced chemical vapor deposition (PECVD), an e-beam lithography step, with ZEP520 resist, is used to open this layer in the areas where the membrane should be only 250 nm-thick (e.g. for the input and output rectangular waveguides of the polarization converter). The sample is then etched chemically first in solution (A) $1HCl: 4H_3PO_4$ and subsequently in solution (B) $1H_2SO_4: 1H_2O_2: 10H_2O$, to selectively remove the (InP-130 nm / InGaAsP-20 nm) layers from the areas open in the SiN_x layer.

In the following step, the rectangular waveguides and the straight sidewalls of the triangular waveguides of the future polarization converter are defined simultaneously. The previous SiN_x layer is removed using buffered hydrofluoric acid (BHF) and a new 50 nm-thick SiN_x layer is deposited. A second e-beam lithography is carried out to open trenches in the SiN_x layer around all the future devices. These trenches are then etched into the III-V membrane layers using the SiN_x

layer as a mask in a reactive ion etching (RIE) CH_4–H_2 process. In order to create the slopes of the triangular waveguides at the end of the fabrication, it is important to align the future polarization converters along the right crystallographic direction (i.e. parallel to the primary flat if working with a (100) InP substrate).

The last part of the polarization converters' patterning consists in the fabrication of the sloped sidewalls of the triangular waveguides. Once again, the previous SiN_x layer is removed and a new SiN_x layer is deposited. A final e-beam lithography is used to open locally the areas of the future triangular waveguides in the SiN_x layer. This time the dry-etching time of the SiN_x layer has to be controlled so that the SiN_x is removed from the horizontal areas but not from the vertical sidewalls defined previously (this is rendered possible by the relatively good conformality of the SiN_x PECVD deposition and the strong verticality of the SiN_x RIE process used). Finally, the stack (2) is etched chemically in the regions open in the SiN_x layer, using the solutions (A) and (B) mentioned previously. Since the etching produced by these solution stops on the (112) plane of InP, a 35° slope running from the top of the SiN_x covered sidewall to the first InGaAs etch-stop layer below is obtained (see the background of the SEM picture in Fig.1b).

After the triangular waveguides have been defined, the SiN_x layer is removed, and a 300 nm-thick SiO_2 cladding layer is deposited on top of the whole chip. Meanwhile, a 1.5 µm-thick layer of SiO_2 is deposited on a silicon carrier wafer. The InP chip is then bonded upside-down on the silicon carrier wafer using a 100 nm-thick BCB (Benzo-cyclo-butene) layer as a glue. In the final step, the substrate and the stack (1) are removed by selective wet-etching, using solution (A) and (B).

IV. MEASUREMENTS

The most efficient way to couple light into and out of membrane photonics chips is through the use of grating couplers [1]. However, these diffractive structures are optimized for exciting the TE-polarized mode in the chip, and due to their highly polarization-dependent behavior, in practice they act as TM-filters with 50-dB extinction ratio… This means that when grating couplers are used, polarization converters cannot be characterized by rotating the input polarization and measuring the polarization state of the output light. In order to verify the polarization conversion behavior of the presented device, an alternative technique, relying on the variation of the length parameter x (see Fig.1a), is used.

The rectangular waveguide of length x introduced between the two triangular waveguides of the polarization converter can sustain the standard TE and TM modes. As described in [4], for a TE-polarized input light, the polarization state after propagating through the first triangular section is a complex superposition of the TE and TM modes that we can call $\boldsymbol{P}_{intermediate}$. Since the TE and TM modes propagate at different speed in the rectangular waveguide, a phase-shift is created between them that linearly increases with x. This in turn will modify the designed behavior of the polarization converter and cause the polarization state of the light leaving the device after propagating through the second triangular waveguide to contain some TE component instead of the fully TM polarized state predicted by design when $x = 0$. However, when x is a multiple of $L_{2\pi} = 2\pi / (\beta_{TE} - \beta_{TM})$, (where $\beta_{TE,TM}$ are the propagation constants of the standard TE and TM modes) the phase-shift created by the propagation through the rectangular waveguide is a multiple of 2π, which means that the polarization state at the input of the second triangular waveguide is exactly $\boldsymbol{P}_{intermediate}$. For these values of x, the device functions as a polarization converter.

A set of 16 devices was printed, where each device consists of two oppositely-loaded triangular waveguides of length L_{tri} = 2.3 µm with a rectangular section of length x in between (x was varied from 4 to 11.5 µm). The TE-TE transmission of each device at $\lambda = 1.55$ µm was measured separately and plotted as a function of the length x of the rectangular section (see Fig. 2). As expected from the wave nature of light, the linear relation between the phase-shift created in the rectangular section and its length x is translated into a *cosine*^{2} variation of the TE-TE transmission versus x. The curve obtained is used to determine that the polarization conversion efficiency (PCE) of this family of devices is close to 97 %, while the excess losses (as shown by the devices x = 4 µm and 10 µm) can be as low as 1 dB.

Another set of devices identical to the previous one but with L_{tri} = 2.6 µm is analyzed in the same way and shows a polarization conversion efficiency of 92 %, with equally low excess losses, which shows that the tolerance on the triangular waveguide length is rather relaxed.

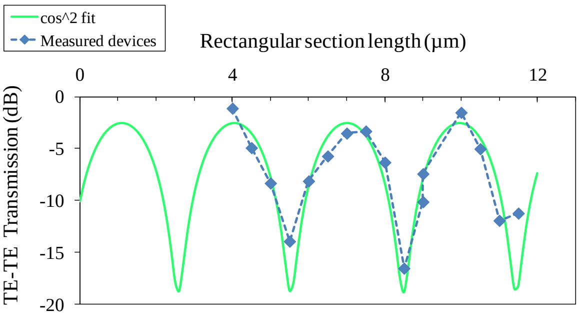

Figure 2. Demonstration of the device's polarization conversion behavior

V. CONCLUSION

An ultra-short polarization converter in InGaAsP/InP membrane is fabricated and characterized. Measurements show very high polarization conversion efficiency (97 %) with low excess losses (~ 1 dB). Further experiments are needed to estimate the spectral behavior of the device.

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