Polarization converter in layer stacks of low contrast of refractive index for photonic integrated circuits

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We report on design of a polarization converter for the InGaAsP-InP system. The polarization converter has a sloping sidewall made by wet chemical etching. Polarization conversion is higher than 95 % and loss is lower than 0.5 dB for the following parameters of the converter: width of top, $1.24 \pm 0.06\,\mu m$*; length,* $275 \pm 32\,\mu m$*; deviation of layer thicknesses of the converter stack, more than* $\pm 10\,\%$*; wavelength range, 1.5-1.6 µm. This design of the converter is suitable for photonic integrated circuits based on layer stacks of low contrast of refractive index.*

Introduction

Dual-polarization quadrature phase shift keying transceivers are promising for data transfer rates of 100 Gb/s [1]. The transceivers often use components on $LiNbO_3$ to produce two orthogonal states of polarization. When we talk about an integrated transceiver for photonic integrated circuits, $LiNbO_3$ becomes useless because we cannot integrate lasers and detectors into the circuit on $LiNbO_3$. InGaAsP-InP photonic circuits can have integrated lasers and detectors, and polarization converters can be used to produce two orthogonal states of polarization in a circuit.

This paper reports on design of a polarization converter suitable for photonic integrated circuits whose waveguiding and cladding layers have a low contrast of refractive index.

Design of polarization converter

We design a polarization converter for the InGaAsP-InP material system. The refractive index contrast between the guiding InGaAsP layer and the InP cladding layer is low (about 0.1).

To convert polarization from one state to another, we need to tilt the fundamental modes of the converter relatively to the fundamental modes of a waveguide in the photonic circuit. This tilt appears when the shape of the converter is asymmetric. There are several ways to obtain the asymmetry. However, when we talk about design of a polarization converter, we need to think of how good the polarization conversion is, what the optical loss is, how tolerant the converter is in terms of the fabrication technology, and if the converter's fabrication is compatible with the standard integration technology of photonic circuits. So the way of making the converter asymmetric should be compatible with the integration technology. And the shape that meets all of the requirements is a shape with a sloping sidewall made by wet chemical etching [2]. Figure 1a shows the shape, and Fig. 1b shows the top view on the converter with input and output waveguides.

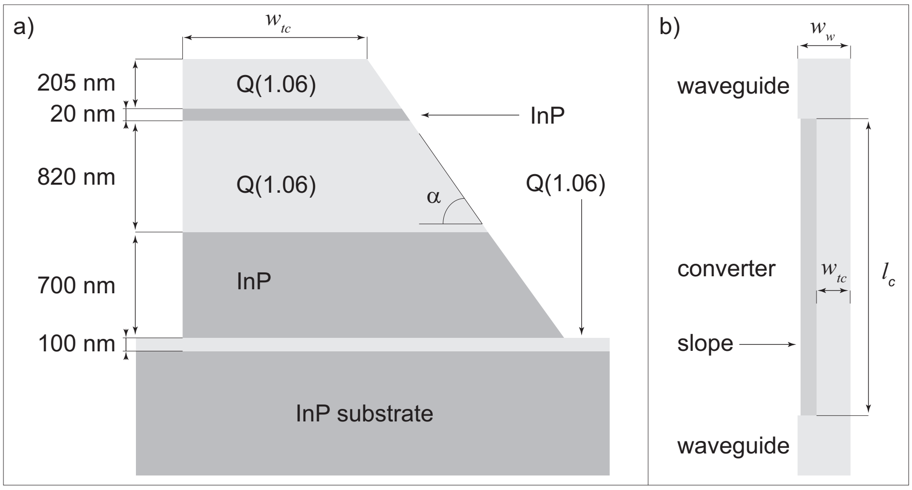

Figure 1: (a) Cross section of converter used to calculate modes of converter. (b) Top view on converter. w_{tc}, width of top; Q(1.06), $In_{0.87}Ga_{0.13}As_{0.27}P_{0.73}$ used as guiding layer; w_w, width of input and output waveguides; $\alpha = 55^\circ$, angle of sloping sidewall made by Br_2-CH_3OH wet etching .

Simulations

To characterize a polarization converter, we need to know its polarization conversion and optical loss; we use Fimmwave/Fimmprop software to do the simulations. The idea behind the simulations is as follows. The finite element method engine of Fimmwave calculates the modes in a cross section of the converter. The modes are then propagated in the Fimmprop package, where we built a polarization converter device, to simulate polarization conversion and optical loss. All of the simulations except for the simulation of the wavelength response are done at a wavelength $\lambda = 1.55\,\mu$m.

Figure 1a shows the cross section of the polarization converter as we set it in the calculation window of Fimmwave. For now, we need to find the size of the calculation window and resolution of the finite element mode solver of Fimmwave.

The size of the calculation window should be large enough to have the electric field of the modes at the borders of the window close to zero. We find a square calculation window $8 \times 8\,\mu\text{m}^2$ to be suitable. At this window size, the resolution of the finite element solver has to be high enough so that a further increase in the resolution does not influence the propagation constants of the modes. The suitable resolution is 140×140 elements.

Next we find a geometry of the converter that supports the modes with a tilt angle of 45°: only at this angle proper polarization conversion is possible. There are two parameters influencing the mode tilt: the width of top w_{tc} and the angle of the sloping sidewall α. Angle α equals 55° and is always constant because the Br_2-CH_3OH etching is selective to crystallographic planes of InGaAsP and InP. Fimmwave calculates the modes in the converter as a function of the width of top, and we choose the widths of top that allow the modes to have a 45° tilt. The range of acceptable widths of top is 1.232-1.240 μm. We choose a value of 1.236 μm. At this width, the propagation constants of the modes are $\beta_1 = 12.905286$ and $\beta_2 = 12.893857$. So we can calculate the length of the converter as $l_c = \pi/(\beta_1 - \beta_2)$, where l_c is the length of the converter; it equals 275 μm.

Knowing the width of top and the length of the converter, we can build a Fimmprop

device. The Fimmprop device consists of an input waveguide, the converter, and an output waveguide. The input and output waveguides are the same and have the same layer stack as the converter does. First, we find the optimal width of the input-output waveguides and their offset from the center of the converter. The width and the offset should give the lowest loss. The simulation shows that the lowest loss occurs when the straight sidewall of the converter is in line with a sidewall of the waveguides (see Fig. 1b), and the optimal width of the input-output waveguides w_w is 1.69 μm.
The converter should have good tolerances to variation of the width of top, of layer thicknesses of the converter stack, and we need to know the wavelength response of the converter. The parameters that we judge the converter's performance by are efficiency of polarization conversion, or simply conversion, and transmission, or loss. For the transverse electric (TE) mode as an input to the converter, we define the conversion and the transmission as

$$C = \frac{P_{TM}}{P_{TM}+P_{TE}}, \tag{1}$$

$$T = 10 \cdot \log(P_{TM}+P_{TE}), \tag{2}$$

where C is conversion, T, transmission, P_{TM}, power of the transverse magnetic (TM) mode at the exit of the output waveguide of the converter, P_{TE}, power of the TE mode at the exit of the output waveguide of the converter.
The minimal conversion that our converter should give is 95 %, and minimum transmission is 90 %, or almost -0.5 dB.
Figure 2a shows the polarization conversion as a function of the width of top. The converter and the input-output waveguides have the same critical steps of fabrication. For the simulation, this means that if the width of top of the converter deviates from the ideal by a certain number, the width of the waveguides should deviate by the same number. To have 95 % of conversion, the width of top should be $1.236 \pm 0.06\,\mu$m. Transmission stays above -0.5 dB for all values of the width of top.
To find the tolerance to variations in the layer thicknesses, we vary the layer thicknesses in a range from -10 to 10 %; the same percentage applies to all layers of the stack. After running the simulation, we get the results in Fig. 2b. We obtain 95 % conversion and acceptable transmission over the whole range of the thickness variation.
Simulation of the tolerance to variation of the length shows a value of $275 \pm 32\,\mu$m for a conversion of 95 %, and transmission higher than -0.5 dB.
Simulations of the wavelength response need wavelength dependences of the refractive indexes of InGaAsP and InP. We took these values from [3]; in a range of 1.5-1.6 μm, they are described by the formulas:

$$n_Q = 1 + \frac{8.065}{1-(0.51\mu\text{m}/\lambda)^2}, \tag{3}$$

$$n_{InP} = 1 + \frac{8.877}{1-(0.43\mu\text{m}/\lambda)^2}, \tag{4}$$

where n_Q is the refractive index of $In_{0.87}Ga_{0.13}As_{0.27}P_{0.73}$, n_{InP}, the refractive index of InP, and λ, wavelength. With these equations, we can simulate the conversion and trans-

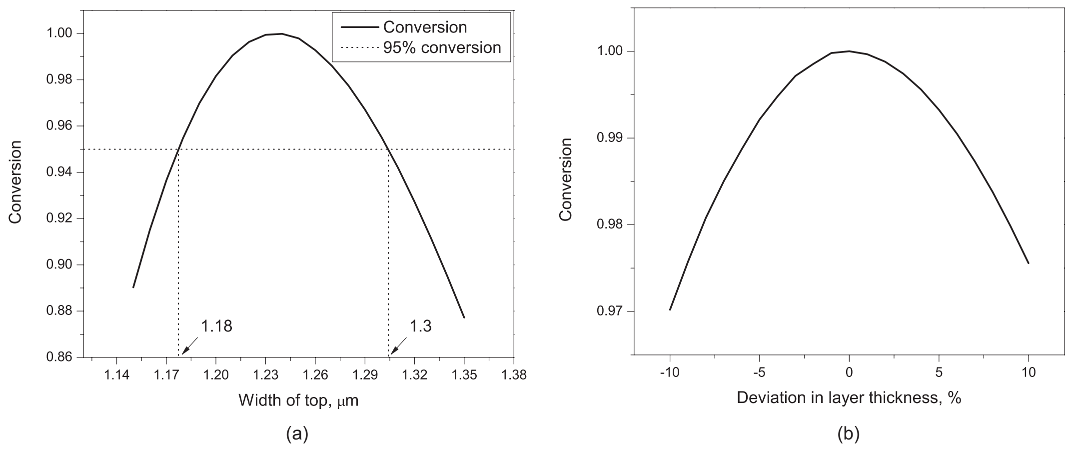

Figure 2: (a) Conversion of converter as function of width of top. Dotted horizontal line shows conversion limit of 95 %. (b) Conversion as a function of deviation in layer thicknesses of converter's stack.

mission as functions of wavelength. The transmission is higher than -0.5 dB, and the conversion is higher than 95 % over 1.5-1.6 μm range of wavelengths.

Conclusions

We reported on a design of a polarization converter for photonic integrated circuits on a layer stack of a low refractive index contrast between the guiding and the cladding layers. The most reproducible shape has a sloping sidewall made by the wet chemical etching with Br_2-CH_3OH. To have 95 % polarization conversion and 90 % transmission (or 0.5-dB loss), the converter may have the width of top $1.236 \pm 0.06\,\mu$m, length $275 \pm 32\,\mu$m, deviation of the layer thicknesses of the stack ± 10 % in a wavelength range of 1.5-1.6 μm.

Acknowledgments

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