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A New Approach to Designing Polarization Rotating Waveguides

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Implementation of polarization rotating building blocks for photonic integrated circuits remains a challenge. To achieve polarization extinction ratios (PER) above 20 dB in indium phosphide (InP) based waveguides, fabrication tolerances with respect to the waveguide width of around 100 nm or less are required with previous designs [1]. In this work, we present a way of allowing for a respective tolerance of more than 200 nm which substantially eases fabrication using common optical lithography techniques. The design is again based on a slanted sidewall waveguide but a key feature of it is that it does not rely on the waveguide modes being angled by 45° as is commonly required with devices reported recently [1]–[3].

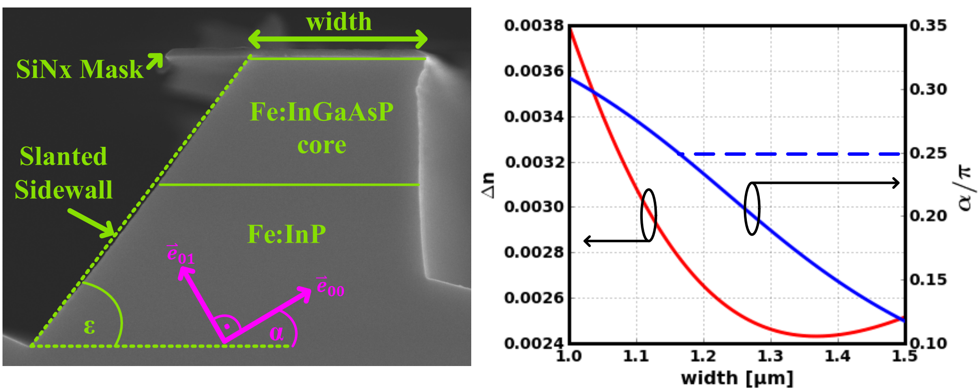

Fig. 7. Left: Cross-section of the slanted sidewall waveguide in this work. The InGaAsP guiding layer has a photoluminescence peak of 1.06 μm. The drawing indicates the tilt α of the modal basis. The slant angle ε is 52° in this work. The waveguide width is defined at the top. Right: Birefringence (red) and modal tilt (blue) versus waveguide width. The slope of these curves becomes smaller for α < π/4, making larger widths significantly more favorable in terms of tolerance.

A slanted sidewall waveguide generally supports a modal basis that is tilted by an angle α with respect to the substrate's plane (see fig. 7). The two modes generally exhibit a birefringence Δn. The Jones matrix of such a waveguide with physical length L and normalized length $\delta = \Delta nL/\lambda$ is given by

$$\underline{J} = \begin{bmatrix} e^{i\pi\delta} sin^2(\alpha) + e^{-i\pi\delta} cos^2(\alpha) & \frac{1}{2}(1 - e^{2i\pi\delta})e^{-i\pi\delta}\sin(2\alpha) \\ \frac{1}{2}(1 - e^{2i\pi\delta})e^{-i\pi\delta}\sin(2\alpha) & e^{i\pi\delta} cos^2(\alpha) + e^{-i\pi\delta} sin^2(\alpha) \end{bmatrix} \qquad (1)$$

The Jones matrix of a series of such waveguides is given by the respective matrix product. In this paper, we limit ourselves to a two-section device, represented by a product of two matrices $\underline{J}_1$ and $\underline{J}_2$. For perfect rotation, the main diagonal of the resulting matrix must vanish while the anti-diagonal must be unity. A simple solution can be found when setting $\alpha_1 = -\alpha_2 = \pi/4$. One then finds $\delta_1 = 0.25$ and $\delta_2 = 0.75$. There are, however, other solutions for various other angles that cannot be found analytically.

Using a FDE mode solver, we derived the dependence of α and Δn on the waveguide width w. The result is shown in fig. 7. It can be seen that the slope of Δn and hence the tolerance is particularly crictical for widths where $\alpha \geq \pi/4$. The slope decreases at larger widths, i.e. smaller α. Using those $\alpha(w)$ and $\delta(w)$ as well as eq. (1), one can compute the Jones matrix of any arbitrary 2-(or more) section device. It should be noted that once $\alpha(w)$ and $\delta(w)$ are known, computing the Jones matrix only takes milliseconds or less. This makes optimization algorithms readily applicable even if they have to evaluate thousands of devices.

Fig. 8 shows maps of the PER for a two-section device in the space of the respective waveguide width of either section, w_1 and w_2.

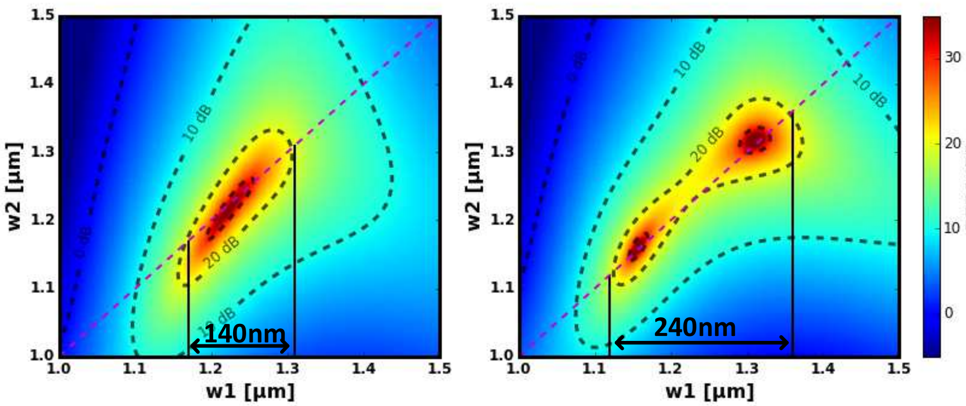

Fig. 8. PER maps versus waveguide widths of a 2-section device. Left: PER map of a device with $\alpha_1 = -\alpha_2 = \pi/4$ and $\delta_1 = 0.25, \delta_2 = 0.75$. Right: PER map for a device with $\alpha_1 = -\alpha_2 = 0.21\pi$ and $\delta_1 = 0.29, \delta_2 = 0.74$. These parameters are obtained from numerical optimization of the Jones matrix' tolerance. The tolerance of either waveguide width is increased from 140 nm to 240 nm. To obtain those numbers, it is assumed that a deviation in width will be equal over both sections (indicated by dashed magenta line).

In summary we have shown a method of designing an integrated polarization rotator which does not rely on the common condition $\alpha = \pi/4$ and therefore enables 100 nm of additional tolerance.

References

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