Integrated optical polarizer based on the cross strip interferometer configuration

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A bimodal segment of specific length and thickness between two single mode sections of a planar waveguide can serve as a simple interferometer. The configuration can be realized by etching a wide strip from a dielectric film and forcing a — vertically guided, laterally unguided — beam of light to traverse the strip perpendicularly. A TE-pass polarizer designed on the basis of this concept achieves more that 30dB polarization discrimination with a total length of only 5 micrometers, for air covered Silicon-Oxide/Nitride waveguides at a wavelength of 650 nanometers.

Introduction

Owing to the birefringent properties of almost all dielectric guiding structures, a large variety of concepts have been developed for polarization discrimination in integrated optics. Most proposals for guided wave polarizers rely on trying to exclusively attenuate one of the basic TE or TM fields, where the damping mechanisms are manifold, including isotropic absorption [1], dichroism [2], or strong birefringence [3]. In turn, polarization splitters are usually interferometric devices. Several different types have been investigated, e.g. Mach-Zehnder structures [4] or directional couplers [5].

Figure 1 introduces the geometry of an alternative proposal for a simple interferometric polarizer. Following some remarks on the interferometer properties of the "cross strip" in the next section, the second part of this paper sketches the polarizer design. More details, in particular concerning the rigorous simulation of the device, can be found in [6]. Ref. [7] reports on a concept for a integrated isolator which employs the same cross strip configuration.

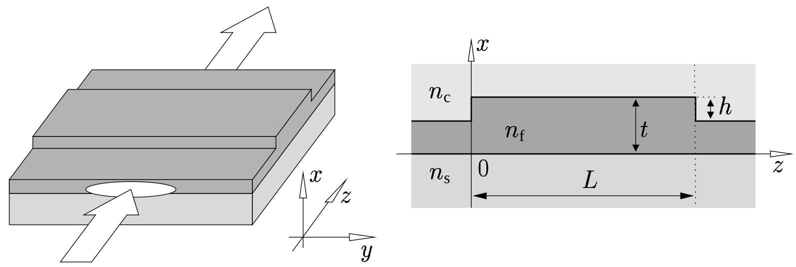

Figure 1: The planar waveguide geometry. x and y are the cross section coordinate axes, with the x-direction normal to the film plane. Light propagates along the z-direction, perpendicularly to a wide strip that has been etched into the guiding film. n_s, n_f, and n_c are the refractive indices of the substrate, the film, and the cover; t, h, and L denote the total film thickness, the etching depth, and the strip width (the length of the thick segment), respectively.

Cross strip interferometer

For fixed vacuum wavelength λ, all parameters introduced in the caption of Figure 1 shall be selected such that for both TE and TM polarization the etched input and output regions $z < 0$, $z > L$ of the device constitute single mode waveguides, while the strip region in between supports two guided modes.

A rough simulation of the light propagation in terms of a 1-D overlap model requires only a few ingredients. ψ denotes the guided mode profile of the input and output segments. ϕ_0, ϕ_1 and β_0, β_1 are the fundamental and first order mode of the coupling section and the corresponding propagation constants. The modes are meant to be normalized with respect to a proper scalar product $(\,.\, , \,.\,)$. See Ref. [6] for a specification of the abstract notation. Assuming that a normalized input field passes a thick segment of length L, by equating transverse components at the two waveguide junctions, projecting on the involved fields, and using the orthogonality properties for guided modes, one arrives at the following expression for the relative power transmission:

$$\mathcal{P}(L) = w_0^2 + w_1^2 + 2w_0 w_1 \cos(\beta_0 - \beta_1)L\,. \tag{1}$$

The squared mode overlaps $w_j = (\psi, \phi_j)^2$ are real for suitably chosen basic mode profiles.

The transmitted power varies strictly harmonically with respect to the length L of the strip segment, with a half beat length or coupling length $L_c = \pi/(\beta_0 - \beta_1)$. Obviously the maximum respectively minimum throughput is given by the sum $(w_0 + w_1)^2$ or the difference $(w_0 - w_1)^2$ of the overlaps. Hence one can expect interferometric behaviour of the device — i.e. alternatively almost complete or no power transmission — if the geometric parameters can be adjusted such that the overlaps are equal, while at the same time their sum is as large as possible. For the polarizer application, the condition $w_0 = w_1$, implying the complete suppression of the power transmission, is essential. We have found, that proper adjustment is indeed possible for a specific range of total thicknesses t by selecting a suitable etching depth h. Figure 2 shows examples for the involved mode profiles and their superpositions.

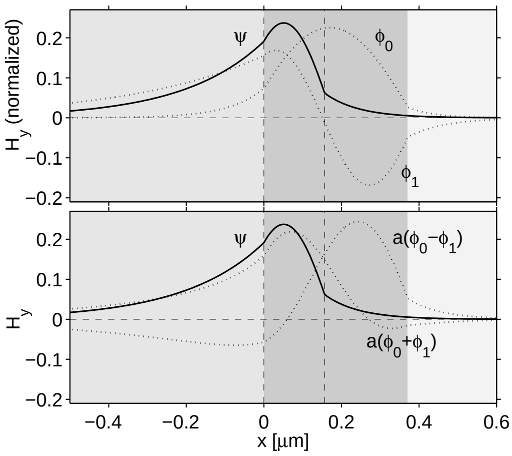

Figure 2: Basic magnetic field component H_y of the TM modes for the structure defined by Table 1, with $t = 0.371\,\mu m$ and $h = 0.214\,\mu m$. Top: The mode ψ of the lower core, and the profiles ϕ_0, ϕ_1 of the strip region. Bottom: With suitable amplitudes $a = \sqrt{w_j} = 0.694$, the modes of the thicker waveguide form a field that matches the output mode well (+), or that is orthogonal to the output profile (−). Shading indicates the permittivity of the thick segment, while the vertical lines mark the boundaries of the input/output core.

For a properly adjusted geometry a symmetric superposition of ϕ_0 and ϕ_1 can be reasonably close to the input and output mode ψ. Therefore little power is lost, if this field excites the strip region at $z = 0$, or if the symmetric superposition arrives at the output junction in $z = L$. At the same time, the antisymmetric superposition of ϕ_0 and ϕ_1, with absolute values of the amplitudes as before, but with an additional phase difference of π, is orthogonal to ψ. Hence the output mode does not receive any power, if this superposition excites the lower region at $z = L$. In that case the power is partly reflected, but mostly radiated away, a smaller part into the cover, a larger fraction into the higher index substrate.

Polarizer design

A TE-pass-polarizer, i.e. a device that transmits as much as possible of the TE input power while it blocks the TM throughput, has to be assessed in terms of the polarization discrimination or extinction ratio $\mathrm{ER} = 10\log_{10}\mathcal{P}^{\mathrm{TE}}/\mathcal{P}^{\mathrm{TM}}$ and the insertion loss $\mathrm{LO} = -10\log_{10}\mathcal{P}^{\mathrm{TE}}$, where $\mathcal{P}^{\mathrm{TE}}$ and $\mathcal{P}^{\mathrm{TM}}$ are the relative TE and TM power transmissions.

Given the material parameters and the wavelength, a proper total thickness t and strip width L are to be identified first. Eq. (1) predicts periodic variations of $\mathcal{P}^{\mathrm{TE}}$ and $\mathcal{P}^{\mathrm{TM}}$ with different beat lengths $L_{\mathrm{c}}^{\mathrm{TE}}$ and $L_{\mathrm{c}}^{\mathrm{TM}}$. Polarizer performance requires a (short) configuration, where L is an even multiple of $L_{\mathrm{c}}^{\mathrm{TE}}$ and simultaneously an odd multiple of $L_{\mathrm{c}}^{\mathrm{TM}}$. For a difference of one in the multiplicities, these conditions fix the optimum polarizer length as $L_{\mathrm{p}} = L_{\mathrm{c}}^{\mathrm{TE}}L_{\mathrm{c}}^{\mathrm{TM}}/(L_{\mathrm{c}}^{\mathrm{TE}} - L_{\mathrm{c}}^{\mathrm{TM}})$. By varying t over the range where the strip segment supports two guides modes for both polarizations, evaluating L_{p} and checking for an even integer $L_{\mathrm{p}}/L_{\mathrm{c}}^{\mathrm{TE}}$, one can indeed find a suitable geometry. The parameters of Table 1 lead to $L = L_{\mathrm{p}} = 4L_{\mathrm{c}}^{\mathrm{TE}} = 5L_{\mathrm{c}}^{\mathrm{TM}}$. Then the search for a suitable etching depth h, where the condition of $w_0 = w_1$ for destructive interference is met for TM waves, completes the design. Note that for the present nonsymmetric waveguides (n_{c} is considerably smaller than n_{s}) the condition can be satisfied *exactly* by properly selecting the etching depth. This is possible for all admissible thicknesses $0.34\,\mu\mathrm{m} \le t \le 0.56\,\mu\mathrm{m}$, where the strip region is bimodal for TM fields.

Table 1 summarizes the parameters of the resulting polarizer proposal. For the tuned device, a rigorous mode expansion simulation as described in [6] predicts relative power throughputs of $\mathcal{P}^{\mathrm{TE}} = 94\%$ and $\mathcal{P}^{\mathrm{TM}} = 0.01\%$. This amounts to a polarization discrimination of about $\mathrm{ER} = 40\,\mathrm{dB}$ and an insertion loss $\mathrm{LO} = 0.3\,\mathrm{dB}$. Relative guided powers of 0.04% (TE) and 5.7% (TM) are reflected. Plots of the corresponding fields in Figure 3 illustrate the behaviour of the interferometer.

	t	h	L	λ	n_{s}	n_{f}	n_{c}
q	$0.420\,\mu$m	$0.240\,\mu$m	$4.910\,\mu$m	650 nm	1.465	2.01	1.0
Δq	4 nm	15 nm	50 nm	24 nm	0.011	0.015	0.05

Table 1: Structural parameters for a planar polarizer as sketched in Figure 1. The tolerances Δq indicate that the polarizer should still achieve an extinction ratio higher than 20 dB and suffer from losses below 1 dB, if a single parameter deviates from the optimum value q by not more than $\pm\Delta q$.

While the present design is basically a planar configuration, an extension to channel waveguides will be a subject of future research. Defining a laterally weakly confining waveguide along the light path, e.g. by suitable annealing or by etching a shallow rib, seems to be unlikely to disturb the properties of the interferometer.

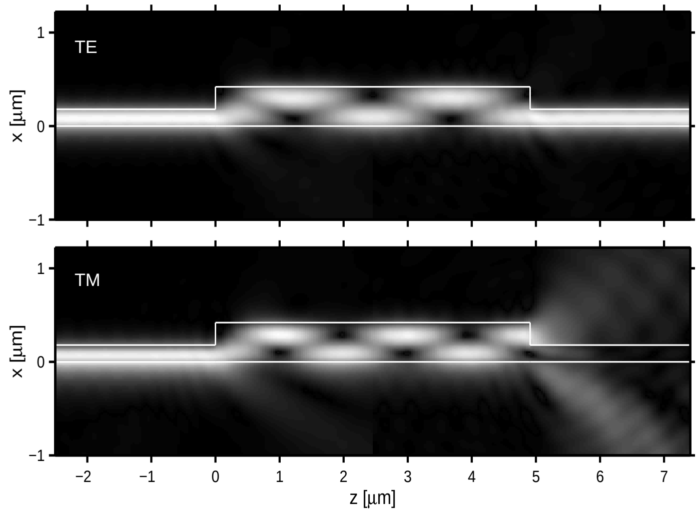

Figure 3: Simulation of the light propagation through the cross strip defined by Table 1, for TE (top) and TM polarized input (bottom). For TM polarization, the output junction scatters almost the entire power into the surrounding, while TE polarized waves pass the device smoothly.

Conclusions

A simple dielectric strip of specific dimensions can show good polarizer performance. The proposal may help to overcome some of the drawbacks of the concepts mentioned in the introduction: It requires neither exotic materials nor complicated processing steps. The design is adaptable to a certain range of material and wavelength parameters. Together with reasonable levels of polarization discrimination and insertion loss and an extremely short length, the cross strip geometry should be a promising candidate for including polarizer functionality into a larger integrated optical circuit.

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