Design of Spectrometers and Polarization Splitters Using Adiabatically Connected Slab Waveguides

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***Abstract*— The design of fully integrated prism spectrometers and polarization splitters in adiabatically connected slab waveguides with two different thicknesses, using principles of geometrical optics, is presented. In addition, the design of mirrors to connect these devices to input and output waveguides is discussed. The proposed structures will be fabricated, using two wet-etching steps, in a Si3N4 layer in-between a buffer and cladding SiO2 layer.**

Keywords- prism spectrometers; polarization splitters; adiabatically connected slab waveguides; waveguide mirrors

I. Introduction

In the early years (70's) of Integrated Optics (IO), slab waveguide (WG) based devices, such as thin film lenses, prisms, reflectors and polarization splitters were extensively investigated [1]. The design of these components is extremely easy since the propagation of light waves in these slabs can be described by geometrical optics in 2D, using the effective refractive index (N) of the fundamental slab modes [2]. Furthermore, slab WG fabrication is not a complicated process. In spite of these advantages, only a small number of integrated devices, which combines more than one of these components to have an IO device, have been implemented [3-5].

In this paper, we describe the design of fully integrated prism spectrometers and polarization splitters in adiabatically connected slab WGs (having two different thicknesses), using principles of geometrical optics. For light transport ridge WGs will be used. The operating wavelength will be around λ = 850 nm. Both the slab and ridge WGs will be implemented in a LPCVD Si_3N_4 layer which is deposited on a buffer SiO_2 layer (grown on a Si substrate) and covered with a cladding SiO_2 layer. The fabrication process that will produce these devices consists of two wet etching step. One is for defining the ridge WGs (20 nm ridge height) and one is for defining the thin slab WG regions (etching down to 40 nm) in the Si_3N_4 layer. The interfaces between the thin and thick slab regions are chosen to be adiabatic in order to decrease conversion to scattering modes and reflection losses at the prism interfaces and the interfaces of the trench used for the polarization splitter [1].

The rest of this paper is organized as follows. First, we will introduce the prism spectrometer and followed by an explanation of the design of this device, in section II. In section III we will consider the design of a fully integrated polarization splitter device. The paper ends with conclusions (section IV).

II. Prism Spectrometer

A schematic picture of the considered prism spectrometer device is shown in figure 1. It is composed of an input WG, a collimation mirror, a prism slab, a focusing mirror and output WGs corresponding to different wavelengths.

The working principle of the proposed spectrometer, to be operated with TE polarized light, can be described as follows. The single-mode input WG is carrying the multi wavelength light, which diverges in the thick slab and is collimated after reflection from the collimation mirror, which is a total internal reflection (TIR) mirror for slab modes defined at the interface between thick (high N) and thin (low N) slab WGs. After that, the collimated light beam enters the prism slab where it is angularly dispersed with respect to the wavelength. The output beams are coupled into different output waveguides, which correspond to different wavelengths, by the focusing mirror.

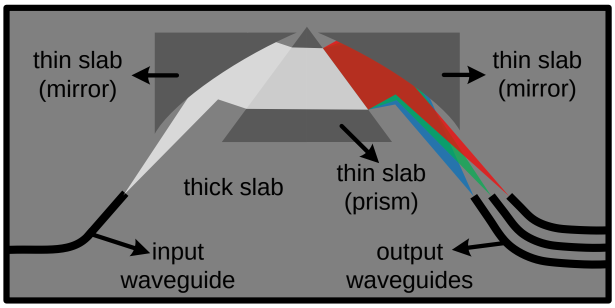

Figure 1. Schematic of the considered prism spectrometer. The light and dark grey area correspond to thick (160 nm) and thin (40 nm) Si_3N_4 slabs, respectively. Ridge waveguides are indicated by black lines.

A. Prism Design

The geometrical structure of a generic slab waveguide based prism spectrometer is shown in figure 2-a. In this figure, η is the prism angle, σ_1 is incidence angle, b is the prism base length and w_i is the input beam width. The effective indices of the thin and thick slabs are denoted by N_1 and N_2, respectively, and we define $D = N_2 / N_1$. Assuming an approximate flat intensity profile at the input of the prism, the resolving power ($\mathcal{R}$) of this spectrometer can be written as

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$$\mathcal{R} = bD' \quad (1)$$

with $D' = \partial D / \partial \lambda$. Unlike in conventional bulk prism spectrometers, the refractive index dispersion, which generates the angular dispersion, is here mainly provided by the thick slab surrounding the prism. For given materials D' depends only on the two thicknesses of the two slabs. Varying these, in order to optimize D' we arrive at a thickness of 40 nm for the thinner slab, as a safe lower limit to prevent leakage to the Si substrate. Next D' is maximized to a value of 1.21 x 10^{-4} /nm by choosing a thickness of 160 nm for the thicker layer, for which that layer still supports one TE mode.

For the layout of the spectrometer it is of particular importance to take into account mirror aberrations owing to the fact that the output mirror is designed for the central wavelength (850 nm) and introduces extra focal spot broadening for wavelengths nearby. It turns out that these aberrations are at minimum if the prism is operated at minimum deviation. More design aspects for the layout of the spectrometer will be presented during the conference.

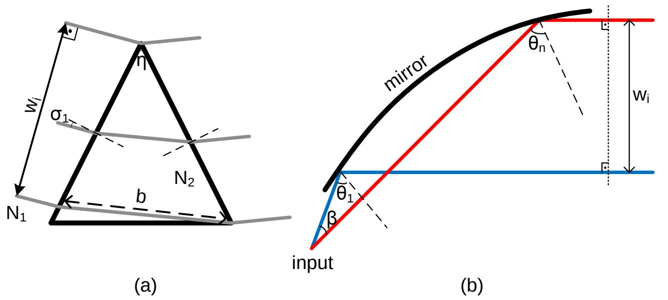

Figure 2. Schematic of (a) a generic prism spectrometer and (b) parabolic collimation mirror.

B. Mirror Design

Both of the mirrors used in the spectrometer device are parabolic mirrors that can be designed by using Fermat's Principle. Figure 2-b shows the schematic of a parabolic collimation/focusing mirror. The mirror geometry can be extracted by choosing the following parameters; the largest angle of incidence (θ_1), input beam width (w_i) and input divergence angle (β). Usually w_i is defined by given $\mathcal{R}$; β should be chosen such that it is compatible with the numerical aperture of the WG modes and it gives an acceptable geometrical aberration (broadening of the focal spot should be smaller than the diffraction limited spot size) in the focusing mirror. Meanwhile θ_1 should be chosen such that it is above the critical angle for TIR. The phase shifts induced on TIR depend on the angle of incidence, which should be taken into account on designing. We calculated the phase shifts for different angles of incidence by assuming an imaginary ridge waveguide with tapered edges, as used for the mirrors. In order to find the phase shift resulting from TIR, we first calculated the modal index of the ridge WGs and then we used these values in the transverse resonance condition equation defined for an equivalent 1-D WG to deduce the (angle dependent) phase shift on reflection (of the fundamental slab modes) at the slanted side walls. The computational results show, among others, that the extra aberrations can be minimized by increasing θ_1.

We generated a sample layout for a prism spectrometer which has a theoretical resolution of 5 nm at 850 nm wavelength. In this sample device, which has a total size of 15 mm x 5 mm, η, w_i, β and θ_1 are given by 130°, 470 µm, 5° and 72.5° respectively.

III. Polarization Splitter

A schematic of the considered polarization splitter device is shown in figure 3. In this device, there is an elliptical focusing mirror which focuses un-polarized light that is launched from the input WG to two output WGs which are corresponding to different polarizations. The polarization splitter slab shown in the figure is similar to the thin film polarizer described in [1], but here we use a trench with non-parallel sidewalls in order to minimize geometrical aberrations in the output. The size of the complete device, which is designed to work at 850 nm wavelength, is 10 mm x 2 mm.

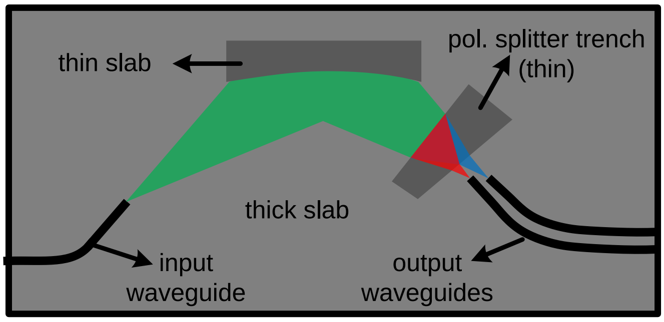

Figure 3. Schematic of the considered polarization splitter.

IV. Conclusions

We described the design of fully integrated prism spectrometers and polarization splitters which are considered to be fabricated in Si3N4 slab waveguides connected adiabatically. As a follow-up, we will fabricate the devices and measure their performances.

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