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Phase matched magneto optical single mode rib waveguides based on geometrical adjustments

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ABSTRACT

In this work, we demonstrate via numerical simulation the design rules that must be imposed on the geometry of magneto optical rib waveguides to make them behave as single-mode and phase matched rib waveguides.

Using film mode matching method, the results show that operation in both single mode and phase matching is possible under certain circumstances with selected geometries. We simulate the performance of such devices and we determined the waveguide dimensions (height, width, and etching depth) that satisfy single mode and phase matching conditions simultaneously.

1. Introduction

There are a number of candidate materials for the development of integrated magneto-optical waveguide devices such as isolators, modulators and circulators [1–7]. Amongst these are magnetic nanoparticles embedded in a silica gel [1]. They combine the magneto-optical properties of the nanoparticles with the low refractive index and good transparency of the silica matrix. This material has some attractive properties and may offer the possibility to fabricate compact and efficient devices. The technique that has been used to produce monolithic structures of nanoparticle doped silica matrix is the sol–gel process. This latter is a relatively simple and inexpensive method which allows to produce films through an appropriate selection of components. One of the most commonly applied systems in the sol–gel technology is two-component system SiO2:TiO2. By an appropriate selection of components, we can produce films of the refractive index which is within the range from the refractive index of pure silica(1.4) to the refractive index of titania(2.3) [8]. The films of low refractive indexes afford the possibility to produce planar systems which are compatible with telecommunication optical waveguide fibers.

Magneto-optic waveguides are the basic elements for non-reciprocal integrated optics and the phase matching between the fundamental TE and TM modes is an essential condition in magneto-optic waveguides. This condition can be satisfied with selected geometries rib waveguides [9,10].

Another important requirement for optical waveguide devices is the single mode propagation, because almost every kind of active and passive integrated optic device is designed to substate only the fundamental mode of propagation for use with optical fibers, and to identify the upper limit of the single mode operation for a rib waveguide presented in Fig. 1.

Several studies have been carried out to identify the cut-off condition for the second mode [11–14]. As Soref et al. [11] and Pogossian et al. [12] have shown that it is possible to get a single mode propagation condition in a rib waveguide, even if the planar waveguide with the same thickness is multi-modal, they proposed a simple relation between the geometrical parameters of the waveguide:

$$\frac{W}{H} \leq c + \frac{r}{\sqrt{1-r^2}} \tag{1}$$

and

$$r \geq 0.5 \tag{2}$$

c is a dimensionless constant, $c = 0.3$ [11] and $c = 0$ [12]. However, the previous equation was restricted to cases when $0.5 < r < 1.0$.

In this paper, we report a numerical simulation to study the influence of the geometrical parameters for the rib waveguide described above, to achieve a single mode and phase matching conditions in such devices. The two previous conditions are

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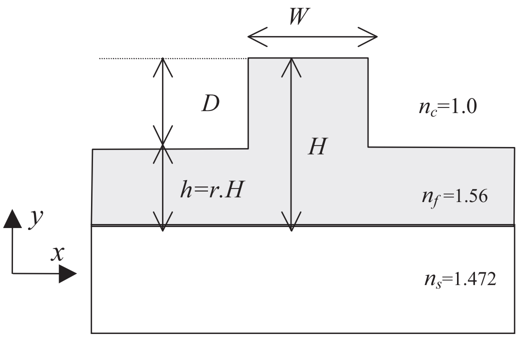

Fig. 1. Cross-section of a rib waveguide, the structural parameters are the height H and the width W, the slab height h and refractive-index n_c, n_s n_f. Where $t=W/H$, H is the rib height, W is the rib width, h is the slab height, r is the ratio of the outer slab layer thickness h to the overall core height $H(r=h/H)$, D is the etching depth.

presented separately, in order to identify waveguide parameters which are able to fulfil the two conditions simultaneously.

2. Device modelling

The simulation was set up with rib waveguides based on magneto optical film waveguides ($n_f=1.56$) corresponding to SiO2/TiO2 film doped with $\gamma-\mathrm{Fe_2O_3}$ waveguides on pyrex ($n_s=1.472$) with an upper cladding of air ($n_c=1$) at a wavelength of 633 nm.

The modelling in this work utilized the full vectorial mode solver based on the film mode matching method [15–17] of photonics CAD tool FIMMWAVE [18] which provides rigorous solutions to the full Maxwell equations. FMM is used to study the influence of geometrical parameters for the waveguide. The waveguide cross-section is considered as a sandwich of slices, each slice corresponds to a planar multi-layer structure. This method involves finding the TE and TM modes of the planar waveguide in each slice [13].

All the modes propagating in the rib waveguide are calculated for both TE and TM polarizations and the corresponding effective index (neff) and propagation constant β are determined. The waveguide phase matching $\Delta\beta$ is the difference of the propagation constant for each polarization.

3. Phase matching condition

The phase matching between the fundamental TE and TM modes is an essential condition in magneto optical rib waveguides. The Faraday rotation is observed in magnetooptic waveguide and causes the mode conversion between TE and TM guided modes, but its efficiency is strongly affected by the difference between their propagation constant $\Delta\beta=\beta_{TE}-\beta_{TM}$. Indeed, the maximum TE–TM mode conversion ratio $R_{\max}$ induced by the Faraday effect is expressed as

$$R=\frac{\theta_F^2}{\theta_F^2+(\Delta\beta/2)^2} \tag{3}$$

θF (°/cm) is the specific Faraday rotation of the material constituting the waveguide, and $\Delta\beta$ (°/cm) is the phase mismatch between TE and TM modes ($\Delta\beta=2\pi\Delta N/\lambda$, ΔN is the modal birefringence) [1].

In order to design a phase matched rib waveguides, the first step was to investigate the polarization characteristics of the rib waveguide due to its geometry.

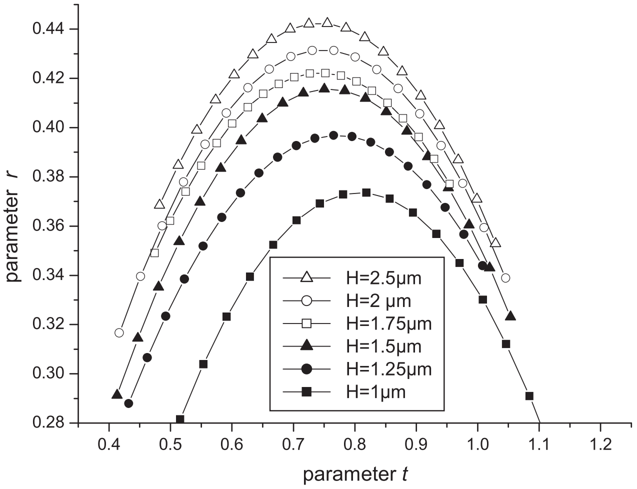

Fig. 2. Parameter r as a function of the parameter t, to achieve phase matching condition for waveguide height H from 1.00 to 2.50 μm.

In this section, we have presented the normalized values t of (W/H ratio) and parameter r, because this provides a clearer indication of the design problem.

The influence of the parameter t on the parameter r corresponding to phase matching condition for several waveguide height values is plotted in Fig. 2.

It shows clearly that the parameter r, corresponding to the phase matching condition, increases (or etch depth D decreases) according to the increase of the waveguide height H. We can observe a maximum of r (corresponding to minimum of etching depth D) for each curve and it occurs for quasi-constant value of t. Indeed t varies from (0.75 to 0.8). In our previous work, we have produced an expression to predict phase matching condition for rib waveguides [9]:

$$D_{\min}=0.07\times10^{-6}+0.711H\ [\mathrm{m}]. \tag{4}$$

This study indicates that it is possible to produce phase matched waveguides for some of the geometries and dimensions when a deeper etch depth is employed $r<0.44$. It is easier to satisfy phase matching condition for waveguides with a height of 2.5, 2.0 and 1.75 μm compared with waveguides with a height of 1.0, 1.25 and 1.50 μm in the context of the technological manufacturing process because it is preferable to increase r (or to decrease the etch depth D).

4. Single mode condition

This section presents the influence of each parameter of the rib waveguide geometry (height, width and etching depth) on single mode condition for $0.3<r<0.6$.

At first, the rib-waveguide height parameter H, etch depth D, and slab height h of the waveguide were fixed constant while increasing the waveguide width to find the single mode–multimode boundary. The iteration of the simulation is repeated with different values of the slab height h to waveguide height ratio parameter r. The process is to increase the waveguide width gradually until second mode propagation, and we determine the maximum waveguide width to reach single mode operation for both polarization TE and TM. The two approaches [11,12] do not extend to study rib waveguide with $r<0.5$, then we have extended these results by extrapolation.