Passive polarization rotator in anisotropic $LiNbO_3$ graded-index waveguide

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Abstract: *The new passive polarization rotator in the near-Z-axis anisotropic graded index Ti:$LiNbO_3$ channel waveguide has been investigated by 3D beam propagation method (BPM). The polarization conversion from quasi-TE to quasi-TM guided modes (and backwards) along the 8 mm long waveguide with an index contrast 0.015 has been numerically demonstrated.*

1. Introduction

A great number of investigations are devoted for studying the anisotropic graded index waveguides in lithium niobate ($LiNbO_3$.). It was shown that optical guided modes are strongly hybrid [1]. By means of artificial anisotropy induced by external electric-field the polarization conversion had been demonstrated in ***Z***-axis directed channel waveguides [2]. It was shown that at near-***Z***-axis propagation direction the hybrid quasi-TE and quasi-TM guided modes could have a circular polarization [3-6] with opposite directions of rotation. Nevertheless it is very interesting to construct the polarization rotator also in passive $LiNbO_3$ structures. It is possible [5, 6] as the input linear polarization could be rotated during the light propagation along the anisotropic channel waveguide by means of two hybrid modes that have different effective indexes and opposite directions of rotation for their circular polarizations. This effect of polarization conversion/rotation in anisotropic graded index channel waveguides has been studied in this paper for the first time by full-vectorial 3D beam propagation method (BPM) [7].

2. Simulated results and discussion

The polarization rotation has been examined for different input linear polarizations and directions θ of the channel waveguide related to the crystallographic ***Z***-axis on ***Y***-cut $LiNbO_3$. The waveguide width is w = 13 μm, waveguide height is h = 2.4 μm, maximum refractive index contrast in the diffused waveguide is Δn = 0.015, substrate main refractive indices are N_e = 2.138 and N_o = 2.212. All these parameters are relevant to a Ti-diffused $LiNbO_3$ waveguide simulated example [7] at the optical wavelength 1.55 μm. However, for simplicity we use the same value Δn for both extraordinary and ordinary increases of refractive indices.

In order to study the effect of polarization rotation in the near-***Z***-axis channel anisotropic waveguides $(\theta \neq 0)$, we use the optical fields of quasi-TE or quasi-TM polarizations as input, then examining by BPM the optical wave propagation through the anisotropic waveguide by determination of the overlap integral of the resulted field with the distribution of quasi-TE and quasi-TM modes determined for $\theta = 0$.

Typical behaviour of optical waves propagated along the diffused channel waveguides directed at angle 5.27° is shown in Fig. 1 for the case of incidence of quasi-TE fundamental mode. The left part of Fig. 1 shows propagation of quasi-TE mode along the waveguide. The right part of the Fig. 1 presents power amplitudes of the both quasi-TE and quasi-TM guided modes.

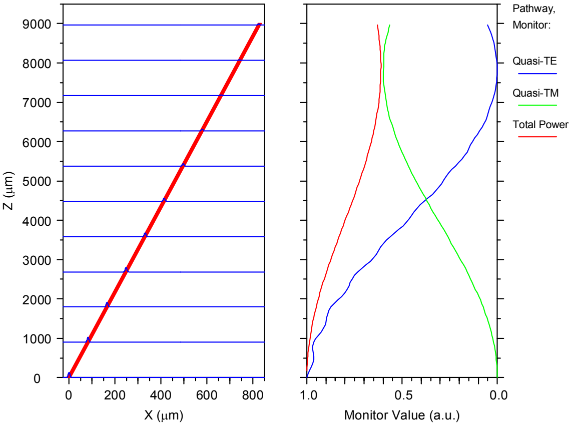
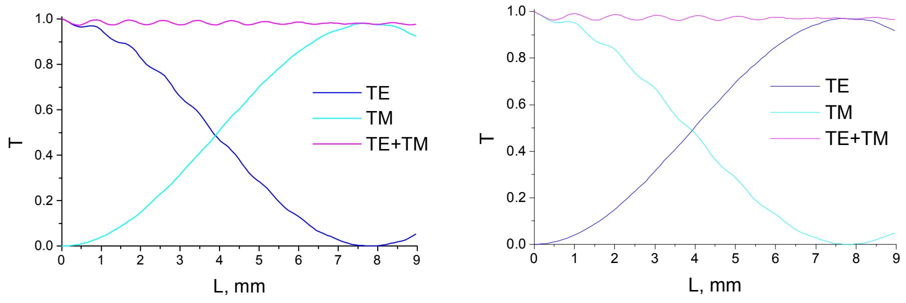


Fig. 1. 3D BPM simulation of polarization conversion in the near-***Z***-axis anisotropic channel waveguide directed at angle θ = 5.27°. Input polarizations: quasi-TE.

One can see that the incident quasi-TE fundamental mode has to change the polarization to quasi-TM mode, while propagating along the waveguide. This effect of polarization rotation/conversion in an anisotropic channel waveguide could be explained in the following way [5, 6]. The incident optical beam excites two hybrid guided modes of circular polarization. Because of the phase delay due to the difference of effective refractive index of these modes, their superposition produces different polarization of the resulting field at the waveguide end, depending on the propagation length L.

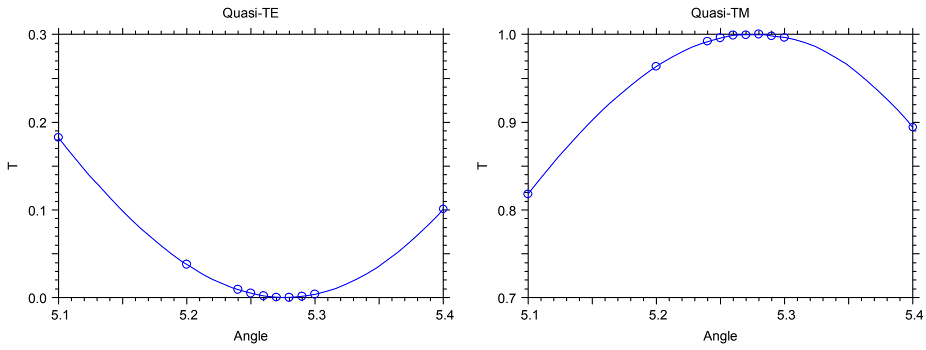
It is worth noting that it has been impossible to achieve a constant level of the total power due to simulation problems, typical for the full-vectorial 3D BPM that currently works only under paraxial approximation [7]. Nevertheless, for our particular waveguides with the small index contrast, this method could be also applied for the near-***Z***-axis waveguides ($\theta < 7°$) but at the expenses of the non constant level of the total power. However, this effect can be corrected by a simple power normalization procedure by means of the correction coefficient K_C to the monitor values for quasi-TM and quasi-TE modes. Results of this power normalization are presented in Fig.2. It is easily seen that, at optimal length L_0 = 7.8 mm, this anisotropic channel waveguide produces a 90° rotation of the incident linear polarization from quasi-TE to quasi-TM (see Fig. 2a) or from quasi-TM to quasi-TE (see Fig. 2b).

The influence of waveguide orientation in the vicinity of the optimum angle θ_0 has been investigated by the power transmittance analysis for quasi-TE and quasi-TM modes passing through the 7.8 mm long anisotropic channel waveguide. This length is close to the optimum for the 90-degree rotation, thus the input polarization has been chosen to have the quasi-TE orientation. As a result, at optimum direction θ_0 of the channel waveguide we have the maximum power transmittance for quasi-TM and the minimum transmittance for quasi-TE mode, respectively. Results of these simulations are presented in Fig. 3.



(a) (b)

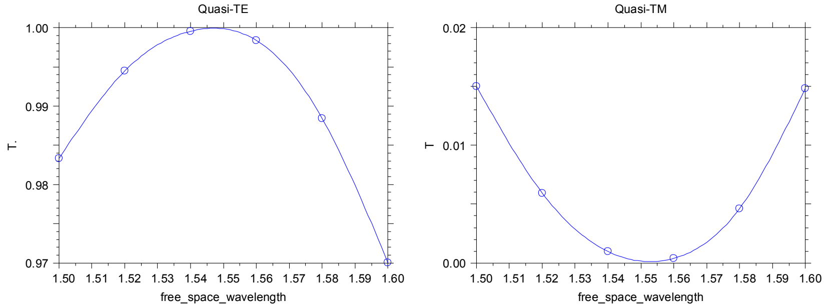
Fig. 2. Normalized results of 3D BPM simulation of power transmittance T in the near-$\boldsymbol{Z}$-axis anisotropic channel waveguide directed at angle $\theta = 5.27°$. $K_C = 1.636$.
Input polarizations: (a) quasi-TE; (b) quasi-TM.



(a) (b)

Fig. 3. 3D BPM simulation of polarization conversion from quasi-TE to quasi-TM mode at different angle θ relative to $\boldsymbol{Z}$-axis in $\boldsymbol{Y}$-cut Ti:LiNbO3. $L_0 = 7.8$ mm. (a) quasi-TE; (b) quasi-TM.

One can see that the anisotropic channel waveguide in $LiNbO_3$ is working as the good polarization rotator only within a small angle range, $\Delta\theta \sim 0.1°$, centered around the angle $\theta_0 = 5.27°$ related to $\boldsymbol{Z}$-axis. For another waveguide parameters, the optimal angle θ_0 is different from this one but the optimum range $\Delta\theta$ is of the same order of magnitude. In general, the larger difference between the effective indices of fundamental quasi-TE and quasi-TM modes (measured along $\boldsymbol{Z}$-axis), then the larger optimum value of the angle θ_0 and the smaller length of the total polarization conversion.
The proposed optical element for the polarization conversion has the high extinction ratio (larger than -20 dB) in a wide transmitting band ~ 80 nm (see Fig. 4) that is very important for practical applications. For example, this polarization rotator/converter can be applied with the polarization splitter for the polarization diversity of the multiple photonic devices that can be monolithically integrated in lithium niobate substrate.



(a) (b)

Fig. 4. 3D BPM simulation of polarization conversion from quasi-TM to quasi-TE mode at different optical wavelengths in the near-***Z***-axis anisotropic channel waveguide directed at angle $\theta = 5.27°$. $L_0 = 7.8$ mm. (a) quasi-TE; (b) quasi-TM.

3. Conclusions

This paper describes the results of theoretical investigation of the novel passive (without external electric filed) integrated optics polarization rotator/converter based on the near-Z-axis anisotropic graded index Ti-diffused channel waveguide in $LiNbO_3$. The device operation is based on the hybrid nature of guided modes in 3D anisotropic waveguide. The effect of polarization conversion/rotation has been studied by the full-vectorial 3D beam propagation method. It has been found that at particular waveguide direction (about 5° related to ***Z***-axis of ***Y***-cut $LiNbO_3$), the condition of total polarization conversion from quasi-TE to quasi-TM mode (and backward) can be obtained by using a waveguide with index increase 0.015 and total length about 8 mm. This optical element could find the wide applications for the polarization diversity of photonic devices monolithically integrated in the $LiNbO_3$ substrate.

Acknowledgments

The authors thank Company RSoft Design Group, Inc. for providing user license for Rsoft Photonic CAD Suite 8.0 including BeamPROP software [7] for BPM simulations.

References

[1] J. Ctyroky, M. Cada, "Generalized WKB method for the analysis of light propagation in inhomogeneous anisotropic optical waveguides," IEEE J. Quantum Electron. vol. 17, pp. 1064–1070, 1981.

[2] T. Kawazoe, K. Satoh, I. Hayashi, and H. Mori, "Fabrication of integrated-optic polarization controller using Z-propagating Ti-$LiNbO_3$ waveguides," J. Lightwave Technol., vol. 10, pp. 51–56, 1992.

[3] E.M. Zolotov, V.A. Kiselev, V.M. Pelekhaty, A.M. Prokhorov, V.A. Chernykh, E.A. Sherbakov, "A Study of Anisotropic Optical Diffuse Waveguides in LiNbO3," Quantum Electron. (Rus) vol. 5, pp. 1379-1381, 1978.

[4] E.A. Kolosovsky, D.V. Petrov, A.V. Tsarev, I.B. Yakovkin, "An exact method for analyzing light propagation in anisotropic inhomogeneous optical waveguide," Opt. Commun. vol. 43, pp. 21-25, 1982.

[5] J. Ctyroky, "Analysis of polarization effects in near-Z-axis Ti:$LiNbO_3$ devices," J. Opt. Commun., vol. 14, pp. 32-38, 1993.

[6] Andrei V. Tsarev, New compact polarization rotator in anisotropic LiNbO3 graded-index waveguide, Optics Express, vol. 16, pp.1653-1658, 2008.

[7] BeamPROP from RSoft Design Group, Inc , http://www.rsoftdesign.com.