The New Design and Numerical Simulation by 3D BPM of New Compact Polarisation Rotator in Anisotropic $LiNbO_3$ Graded Index Waveguide

Andrei Tsarev

Laboratory of Optical Materials and Structures
Institute of Semiconductor Physics, Siberian Branch of Russian Academy of Science
Prospect Lavrenteva, 13, Novosibirsk, 630090, Russia
tsarev@isp.nsc.ru

Abstract: *The new compact polarisation rotator in anisotropic graded index Ti:$LiNbO_3$ waveguide has been proposed and investigated by 3D beam propagation method (BPM) by the software tool BeamPROP from RSoft Design Group, Inc. The polarization conversion from quasi-TE to quasi-TM (and backwards) guided modes at the 8 mm waveguide length has been demonstrated. Device is intended for polarisation diversity of integrated optic elements based on $LiNbO_3$ structures.*

Introduction

Twenty years ago the great number of investigations had been devoted to the studding of anisotropic graded index waveguides in lithium niobate ($LiNbO_3$) substrate. It was shown that optical guided modes are strongly hybrid [1]. Besides at particular angle of propagation (that is not far from the crystallographic ***X*** axis) the guided quasi-TE and quasi-TM modes have the circular polarisation [2, 3] with opposite direction of rotation. Similar types of hybrid modes with the circular polarisation also exist in proper directed 3D channel waveguides based by Ti-diffusion into $LiNbO_3$. Thus the input linear polarisation could be rotated during the light propagation along the anisotropic channel waveguide by means of two hybrid modes that exited in the optical waveguide and that have different effective refractive indexes and opposite direction of rotation of their circular polarisation. This effect of polarisation conversion/rotation in anisotropic graded index waveguides has been studied in this paper for the first time by the full-vectorial 3D beam propagation method (BPM) by the software tool BeamPROP from RSoft Design Group, Inc. [4].

I. Simulated results and discussion

We have examined polarisation rotation at variable orientation of input liner polarisation for different direction q of the strip waveguide related to the crystallographic ***X*** axis of ***Y***-cut $LiNbO_3$. Typical waveguide width w is 8 μm, waveguide height h is 3.5 μm, maximum refractive index increment in the diffused waveguide dN is 0.03, substrate main refractive indexes are N_e = 2.138 and N_o = 2.212. All these parameters corresponds to the case of Ti-diffused $LiNbO_3$ waveguide at optical wavelength 1.55 μm, except that for simplicity we use the same value dN for both extraordinary and ordinary increment of refractive indexes. Graded index distribution of the refractive index across the waveguide depth is typical for diffusion model that is used by RSoft Design Group Inc. in the simulated example for $LiNbO_3$ case [4]. Namely, waveguide refractive index distribution is derived as [4]:

$$n(x,y) = n_0 + \left[\Delta n g(x) f(y)\right]^{\gamma}$$

$$g(x) = \frac{1}{2}\left\{ erf\left[\frac{\left(\frac{w}{2}+x\right)}{h_x}\right] + erf\left[\frac{\left(\frac{w}{2}-x\right)}{h_x}\right]\right\},$$

$$f(y) = e^{\left(-\frac{y^2}{h_y^2}\right)}.$$

In our case we use $h_x = h_y = h$, $g = 1$. Typical refractive index distribution is shown in **Fig**.1.

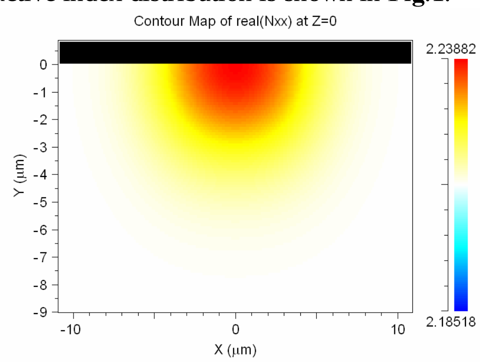
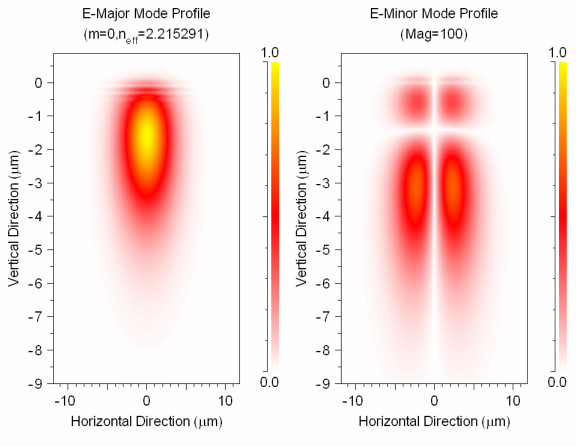


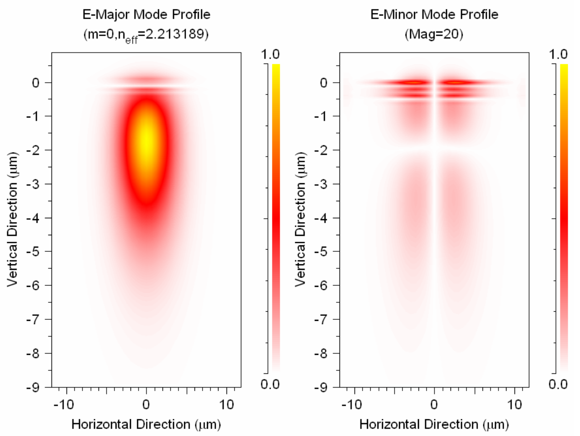
Fig. 1. Simulated distribution of refractive index in channel waveguide. w=8 μm, h=3.5 μm, dN=0.03.

Optical field distribution simulated by BPM for the major and minor components of optical wave are shown in **Fig**. 2 for the case of the waveguide orientation along the crystal axis ***X*** *(q=0).* In order to study effect of polarisation rotation in slanted $(q^{1}0)$

channel anisotropic waveguide we use this optical filed of quasi-TE polarisation as an input filed and then examine by BPM optical wave propagation by determination the overlap integral of the resulted field with the filed distribution of quasi-TE and quasi-TM modes determined for the case *(q=0).*



(a)



(b)

Fig. 2. Simulated distribution of optical filed of guided modes in diffused waveguide presented in **Fig**. 1.
(a) quasi-TE mode, (b) quasi-TM mode. $q=0$.

Typical behaviour of propagation of optical beam along diffused channel waveguide directed at angle 5.7^0 relative to ***X***-axis in ***Y***-cut Ti:$LiNbO_3$ is shown on **Fig**. 3 for the case of incidence of liner polarisation with 45 degree orientation related to the waveguide plate. One can see that incident optical beam is coupled into two hybrid guided modes of circular polarisation. Due to phase delay coursed by a small difference in the refractive index of these modes their superposition produces different polarisation of the resulted filed depending on the propagation length.
The measure of the polarisation rotation is the ratio of quasi-TE and quasi-TM modes. The left part of **Fig**.3 demonstrates propagation of quasi-TE mode. The right part of the **Fig**. 3 demonstrated behaviour of the power amplitude of both quasi-TE and quasi-TM guided modes.

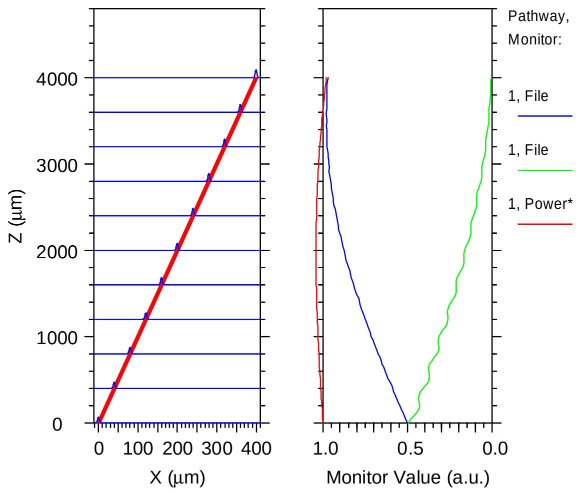
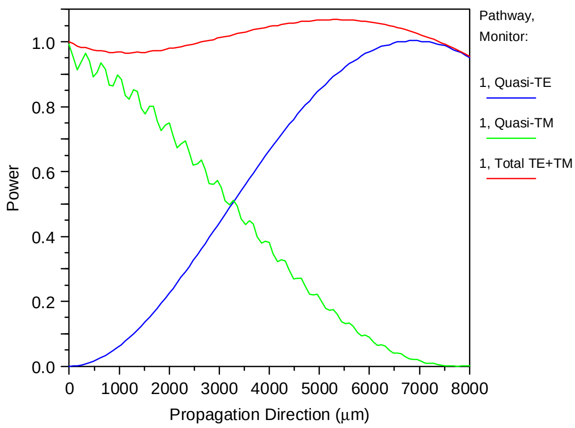
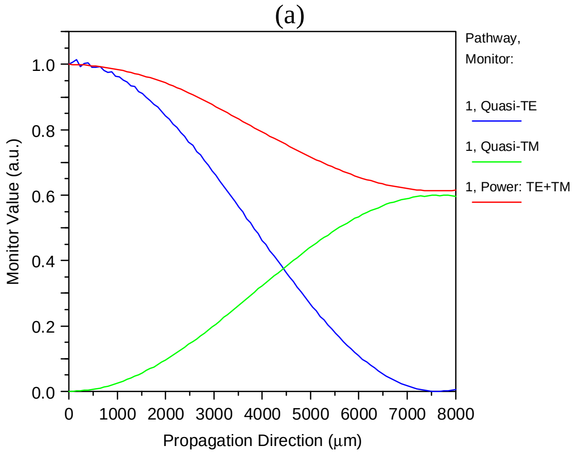


Fig. 3. 3D BPM simulation of polarisation conversion in anisotropic channel waveguide directed at angle $q=5.7^0$. Input polarisations: TE&TM.



(a)



(b)

Fig. 4. 3D BPM simulation of polarisation conversion in anisotropic channel waveguide directed at angle at angle $q=5.7^0$. Input polarisations: (a) TM (b) TE.

It is easily seen that at the distance of 4 mm this anisotropic waveguide produce the 45-degree rotation of incident linear polarisation. By the double increase of the waveguide length this optical element can be used as the 90-degree polarisation rotator and thus could transform incident polarisation from quasi-TE to quasi-TM (see **Fig**. 4a) or from quasi-TM to quasi-TE (see **Fig**. 4b). To measure the actual wait of different polarisation one has to normalize simulated results for quasi-TM and quasi-TE modes to the total power for both polarisations.

Note, that it was impossible to have the constant level of the signals due to simulation problems typical for the full-vectorial 3D beam propagation method that currently has a natural limitation to work only in paraxial approximation. Nevertheless for our particular waveguides with the small contrast this method could be also applied for the slanted waveguides ($q < 7^0$) but by some expense in the nonconstant level of the signals that can be compensated by the simple additional power normalisation procedure.

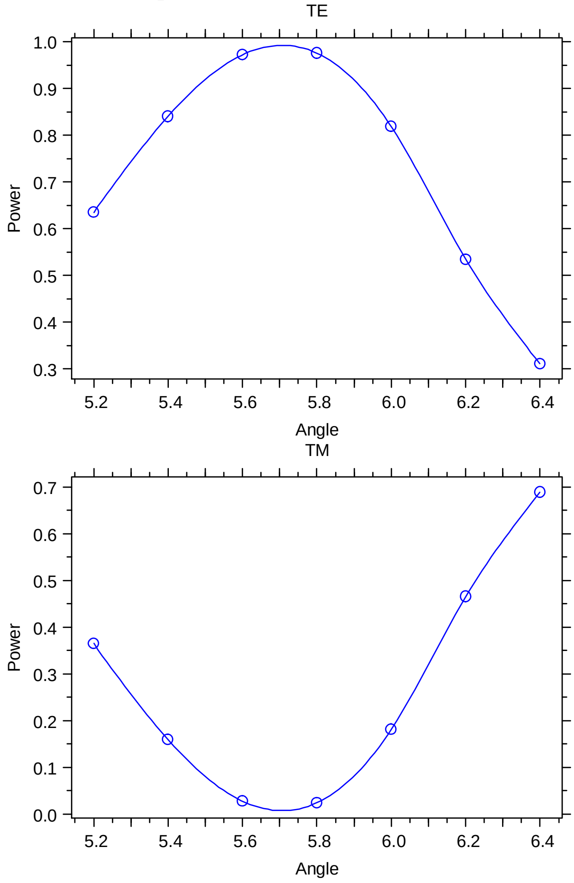
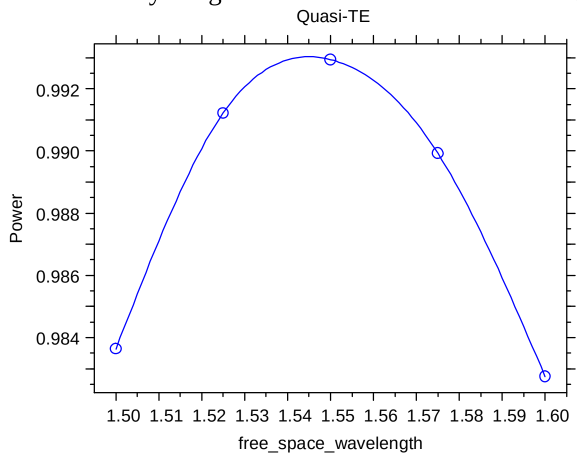


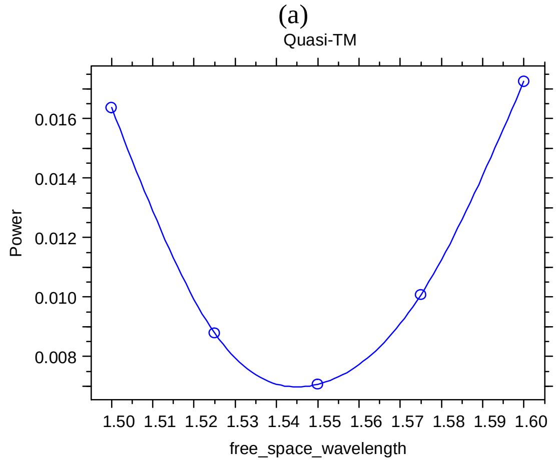
Fig. 5. 3D BPM simulation of polarisation conversion at different angle q relative to ***X***-axis in **Y**-cut Ti:$LiNbO_3$. Input polarisations: (a) TM (b) TE.

The definition of the optimum angle q_0 of the waveguide orientation have bean examined by the power transmittance analyse for quasi-TE and quasi-TM modes pass through the anisotropic waveguide of 4 mm length. This length is near the optimum for the 45-degree rotation thus the input polarisation has also chosen to have the 45-degree orientation. As a result at optimum direction q_0 of the strip waveguide we have the maximum power transmittance for quasi-TE mode and minimum transmittance for quasi-TM mode, respectively. Results of these simulations are presented in **Fig**.5. One can see that the anisotropic strip waveguide in $LiNbO_3$ is working as a good polarisation rotator only within small angle range $\Delta q \sim 0.2^0$ cantered around the angle $q_0 = 5.7^0$ related to the ***X*** axis. For the another waveguide parameters the optimal angle q_0 is differ from this one but the optimum range Δq is of the same order of magnitude. In general the larger difference between the effective refractive indexes for the fundamental quasi-TE and quasi-TM modes (measured along ***X*** axis) and the smaller anisotropy (*No-Ne*) of the crystal than the larger optimum value of the angle q_0.

Proposed optical element has the high extinction ratio (larger then -20 dB) in a wide transmitting band (see **Fig**. 6) that is very important for the practical applications. For example, proposed polarisation rotator can be applied with the well known polarisation splitter [5] for the polarisation diversity of the multiple photonic devices that can be monolithically integrated in lithium niobate substrate.



(a)



(b)

Fig. 6. 3D BPM simulation of polarisation conversion at different optical wavelengths in anisotropic channel waveguide directed at angle $q = 5.7^0$.
Input polarisations: (a) TM (b) TE.

Conclusions

The paper proposes and describes the results of theoretical investigation of the novel integrated optics polarization rotator based on the anisotropic graded index Ti-diffused waveguide in $LiNbO_3$ substrate. The work of the device is based on the hybrid nature of guided modes in 3D anisotropic waveguides. At particular direction of the waveguide relative to crystal axis the two basic fundamental modes could have the circular polarisation with the opposite direction of rotation. Thus linear polarisation has to be rotated during the propagation along the anisotropic channel waveguide by means of two hybrid modes with opposite direction of rotation. This effect of polarisation conversion/rotation in anisotropic graded index waveguides has been studied in this paper for the first time by full-vectorial 3D beam propagation method by the software tool BeamPROP from RSoft Design Group, Inc. [4]. We have examined polarisation rotation at different lunching polarisation for different waveguide orientations and waveguide parameters. It was found that at the particular waveguide direction (around 6 degrees related to ***X*** axis of ***Y***-cut $LiNbO_3$) one can find the condition of total polarisation conversion from quasi-TE to quasi-TM mode (and backwards) at the waveguide length about 8 mm. The half length 4 mm is enough for the 45-degree polarisation rotation. This optical element could find wide applications for the polarisation diversity of photonics devices monolithically integrated in the $LiNbO_3$ substrate.

Acknowledgments

The author thanks Company RSoft Design Group, Inc. [4] that provides user licence and technical support for powerful Rsoft Photonic CAD Suite 6.0 including BeamPROP software for BMP simulations.

References

1 J.Ctyroky, M.Cada, IEEE Journal of Quantum Electronics, vol. 17, p. 1064, 1981.
2 E.M.Zolotov et al, Quantum Electronics (in Russian), vol. **5**, p. 1379, 1978.
3 E.A.Kolosovsky et al, Optics Communications, vol. **43**, p. 21, 1982.
4 www.rsoftdesign.com.
5 L.Bersiner et al, J. Opt. Soc. Am. B, vol.8, p. 422, 1991.