Electro-Optic Polarization Controller With Ti:PPLN Channel Waveguides

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Abstract—**An electro-optic polarization controller consisting of a PPLN based polarization converter followed by a phase-shifter is reported. The integrated device is fabricated in Z-cut $LiNbO_3$ with X-propagation. Design and characterization of the single components are discussed and polarization transformation is demonstrated.**

Keywords: integrated optics, polarization conversion, PPLN

I. INTRODUCTION

Controlling the state of polarization (SOP) is a key task in various applications. Especially in communications systems polarization control is essential for polarization multiplexing or to mitigate polarization mode dispersion (PMD). In recent years several different schemes for polarization control have been investigated. Among them integrated optical approaches offer the potential to enable fast electro-optic polarization control with low drive voltages.

In $LiNbO_3$ polarization controllers have been realized using X-cut material with Z-[1] or with Y-propagation [2]. These devices consist of a structure composed of electro-optic mode converter and phase-shifter. Endless, reset-free polarization control has been demonstrated. Although a good performance has been obtained, the devices have also some drawbacks. The Y-propagating structure requires interleaved transducer electrodes on top of the waveguide which might induce additional propagation losses. Devices with Z-propagation can hardly be integrated with other devices as most functions cannot be obtained in this orientation. Therefore, we have realized a polarization controller in Z-cut $LiNbO_3$ capable to be integrated with other electro-optic or nonlinear optical components. Benefiting from a periodically poled substrate, the electrode configuration is much simpler than that of previously demonstrated devices in X-cut $LiNbO_3$.

In this contribution we report the first realization of a polarization controller composed of a polarization converter in periodically poled $LiNbO_3$ (PPLN) - which has recently been demonstrated in [3] - and a phase-shifter.

II. PRINCIPLE OF OPERATION

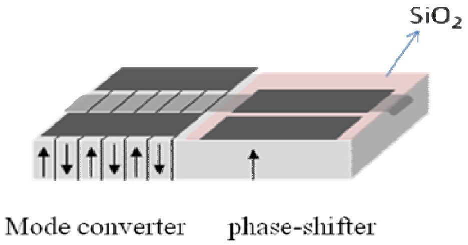

Fig. 1. Schematic drawing of the polarization controller.

The integrated optical polarization controller as shown in Fig. 1 consists of an electrooptic polarization converter followed by a phase-shifter in Z-cut, X-propagating $LiNbO_3$. The converter itself consists of a Ti-diffused waveguide in a periodically poled region [3]. An electrical field is generated in the waveguide via a control voltage applied to lumped type electrodes deposited on top of the sample on both sides of the waveguide. A polarization conversion, i.e. TE→TM or vice versa, can be induced via the r_{51} coefficient of the electro-optic tensor by the Y-component of the electric field. The poling period Λ must be chosen to provide phase-matching for the desired wavelength λ according to $\Lambda=\lambda/(n_{TM}-n_{TE})$, where n_{TM} and n_{TE} are the effective indices of the TM and TE mode, respectively. The conversion efficiency as function of the applied voltage varies according a $\sin^2$-characteristics. In terms of polarization transformation the conversion can be interpreted as a rotation around the S_2 axis on the Poincare-sphere [4].

In the phase shifter a voltage can be applied to vary the birefringence in the waveguide, and, hence, the relative phase between the TE- and TM-waves at the output of the guide. This corresponds to a rotation of the SOP around the S_1 axis on the Poincare sphere.

The cascading of the converter and phase-shifter enables the transformation from almost any input SOP to any desired output SOP via two control voltages. Only for certain input SOPs (for instance circular polarization) the polarization transformation is limited. To overcome this drawback and to provide full flexibility in the polarization transformation another phase-shifter in front of the converter can be implemented.

III. DEVICE FABRICATION

Optical waveguides were fabricated in Z-cut $LiNbO_3$ by an indiffusion of 7 µm wide and 96 nm thick titanium stripes. Diffusion was carried out for 8.5 h at 1060 °C. This fabrication process leads to single mode waveguides in both polarizations in the 1550 nm range. Waveguide losses are typically about 0.1 dB/cm.

Subsequently, a 15 mm long region out of the 35 mm long sample was periodically poled with a poling period of 22 µm. The unpoled phase-shifter region was covered with a 400 nm thick SiO_2 layer. Electrodes for the converter and the phase-shifter were fabricated by depositing 15 mm long titanium films with a gap of 15 µm directly on the $LiNbO_3$ surface and on the SiO_2 film, respectively.

Finally, the polished end-faces of the waveguides were AR coated and the sample was mounted on a copper holder which can be temperature stabilized to about 0.1 °C.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

At first polarization converter and phase-shifter were studied separately. A tunable external cavity laser (ECL) was used to investigate the spectral characteristics of the polarization converter. TE-polarized light was launched into the waveguide and the TE- and TM-polarized powers at the output were recorded. In Fig. 2 such spectral characteristics are shown. A converter voltage of U_c=10 V lead to a complete conversion at the phase-match wavelength λ=1587.2 nm with a spectral width of 2 nm. The measured curve coincides well with the theoretically predicted one, which is also given in the diagram. At the phase-matchwavelength the converted power was measured as function of the applied voltage (Fig. 2, bottom). The predicted $\sin^2$-behaviour could be observed. A small offset on the horizontal axis, i.e. a conversion at U_c=0 V, was observed. This offset can be attributed to local electric fields already present in the crystal without any applied voltage.

The phase-shifter was characterized using a linear input polarization at 45°. The voltage required to obtain a relative phase-shift of π was determined from the observed beating at the output to be $U_{p,\pi}$=15 V.

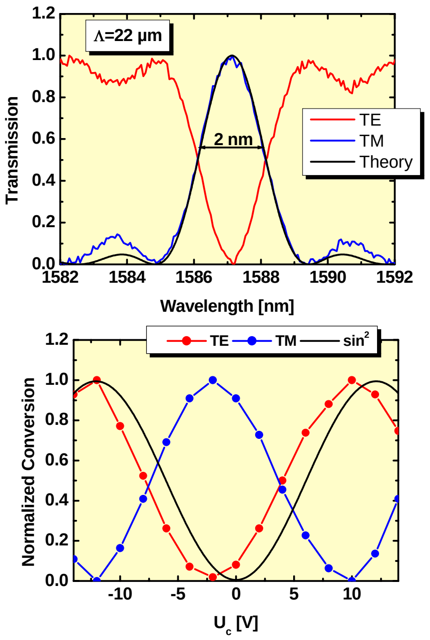

Fig. 2: Top: Measured and calculated spectral characteristics of the electro-optic polarization converter. Bottom: Conversion efficiency at phase-matching as function of the applied voltage.

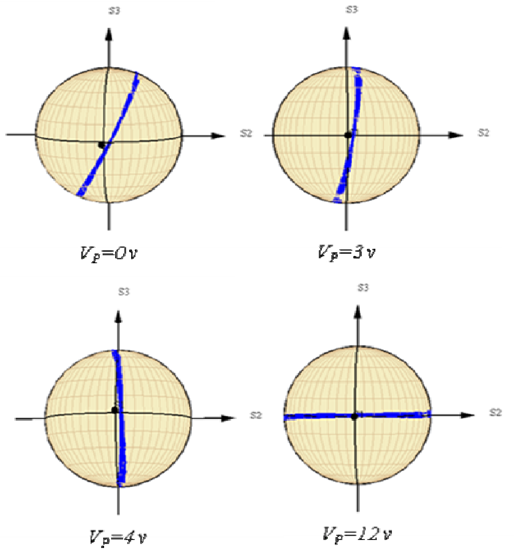

Fig. 3: Measured polarization transformation of the device

To demonstrate the applicability of the combined converter and phase-shifter as polarization controller a TE polarized wave was coupled into the waveguide. A static voltage was applied to the phase-shifter and a ramp voltage (- 15 V … 15V) to the converter electrodes. The output SOP was monitored using a commercial polarimeter.

In Fig. 3 traces on the Poincare sphere are shown for several phase-shifter voltages. Closed circles on the Poincare-sphere were observed. Their orientation depends on the phase-shifter voltage. By a proper choice of the converter voltage U_c and the phase-shifter voltage U_p any desired SOP can be obtained at the output.

V. CONCLUSIONS

We have demonstrated a new electro-optic waveguide device, which can be used as a polarization controller consisting of a TE↔TM mode converter followed by a phase shifter. Such devices will find applications where fast electro-optic polarization control is required as for instance polarization multiplexing and PMD compensation in communication systems or polarization state preparation in quantum communications.

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