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$LiTaO_3$ Electro-Optic Polarization Modulator Utilizing Periodically Poled Structure

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***Abstract*— New electro-optic polarization modulators utilizing periodically poled z-cut $LiTaO_3$ were demonstrated experimentally for the first time as far as the authors know. They lead to high-speed (>10GHz) polarization control devices operating in wide wavelength ranges.**

I. INTRODUCTION

A high-speed optical polarization modulator/converter is an important device in many opto-/quantum electronic systems. Several electro-optic (EO) optical polarization modulators/converters have been proposed and implemented [1]-[3]. $LiNbO_3$ and $LiTaO_3$ have a large Pockels coefficient of r_{42} applicable for polarization modulation/conversion in high frequency ranges. A key point for an efficient polarization control is the phase matching between two orthogonally polarized modes, and several specific comb-like electrode structures were adopted for the phase matching [1], [3]. However, these electrodes with a complicated structure are not suitable for the operation in microwave frequency ranges. Another approach using a Pockels coefficient of r_{61} (r_{22}) is applicable with no comb-like electrode structure, but its Pockels coefficient value is about 1/10 of r_{42}.

In this report, a new optical polarization modulator using a periodically poled structure is proposed, and its operation is demonstrated experimentally. Utilizing the quasi-phase matching technique with a periodically poled structure, an efficient polarization control is possible by using standard coplanar electrodes with no comb-like structure. This modulator should lead to novel high-speed polarization control devices.

II. EO POLARIZATION MODULATOR WITH A PERIODICALLY POLED STRUCTURE

Figure 1 shows the structure of the EO polarization modulator we have proposed. It consists of a single-mode channel waveguide and coplanar electrodes fabricated on a z-cut $LiTaO_3$ crystal substrate. A light propagation direction is set to the *x*-axis of the $LiTaO_3$ crystal and a modulation electric field is applied along to the *y*-axis as shown in the Fig. 1 (b). With this configuration, coupling between TE and TM modes is induced through a Pockels coefficient of r_{42}. Compared with the *z*-axis propagating polarization modulator by using a Pockels coefficient of r_{61} (r_{22}), a lower operational voltage is expected since r_{42} is about 10 times larger than r_{61}. A periodically poled structure is designed for the quasi-phase matching between the TE and TM modes.

Figure 2 shows the calculated wavelength dependences of the *x*-propagating polarization modulators with periodic poling by using z-cut $LiTaO_3$ or z-cut $LiNbO_3$, where we assumed an operational wavelength of ~630nm and an electrode length of 10mm. $LiNbO_3$ has a large material birefringence ($|n_o - n_e|$~0.086), therefore, the poling period required for the quasi-phase matching is $2L$~7μm for the wavelength of ~630nm. On the other hand, $LiTaO_3$ has a small birefringence ($|n_o - n_e|$~0.004), and the poling period for the quasi-phase matching is $2L$~180μm for ~630nm. Therefore, the wavelength bandwidth in the $LiTaO_3$ device is over 20 times wider compared to $LiNbO_3$.

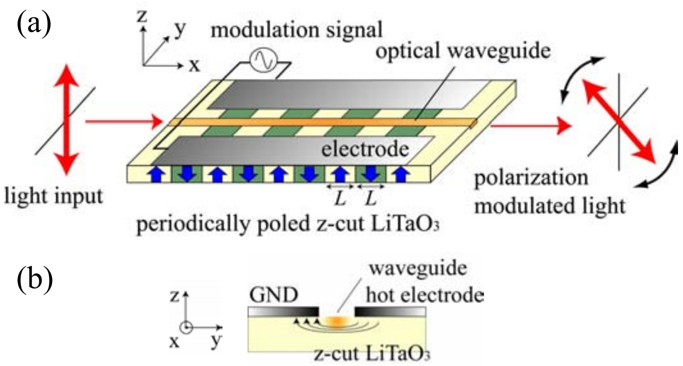

Fig. 1. Basic structure of the EO polarization modulator with periodically poled structure

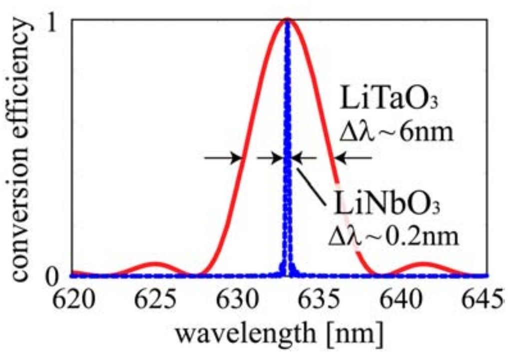

Fig. 2. Calculated wavelength dependence of EO polarization modulators with periodic poling.

III. Device Fabrication and Experiment

In order to construct the proposed polarization modulator, it is necessary to fabricate an optical waveguide supporting TE and TM modes with the periodically poled structure in a z-cut $LiTaO_3$ substrate. The APE method is applicable for waveguide fabrication in a periodically poled $LiTaO_3$ substrate [4], however, the APE waveguide supports a single polarization mode only. Ti diffused waveguides are widely used for $LiNbO_3$ devices, however, the high temperature diffusion process over the Curie point of $LiTaO_3$ (~600 degrees Centigrade) is necessary. Therefore, we adopted the Ni diffusion method with a relatively low diffusion temperature of ~580 degrees Centigrade [5].

Firstly, the periodically poled structure was fabricated into a z-cut $LiTaO_3$ crystal by using the pulse voltage applying method. The poling period, $2L$, was set to ~180μm for the phase matching between the TE and TM modes at ~630nm. Next, a ~20mm long *x*-propagating optical waveguide was fabricated by thermal diffusion (70h, 580 degrees Centigrade) of a 35nm thick Ni stripe into the surface of the periodically poled $LiTaO_3$ crystal. The Ni width of 5μm was determined so as to be a single-mode both for TE and TM modes around the operation wavelength of ~630nm. Finally, 10mm long Al coplanar electrodes were formed on the surface of the $LiTaO_3$. The spacing of the two electrodes was set at 10μm.

The polarization modulation operation of the fabricated device was tested. Figure 3 (a) shows the output intensity change from the device through an analyzer plate when a sinusoidal voltage of 400Hz was applied to the electrodes. The polarization change according to the applied voltage was clearly observed. The required voltage for the complete TE-TM conversion was about 35V for the device with the periodic polarization reversal of $2L$=188μm, which was several times larger than the calculated voltage. We believe that it would be reduced by using optimized design and fabrication conditions. Figure 3 (b) shows the measured TE-TM conversion efficiency for the lightwave wavelength. The wavelength bandwidth was in good agreement with the calculated value.

IV. Conclusions

The optical polarization modulator utilizing periodically poled $LiTaO_3$ was proposed and its basic operation was demonstrated. By adopting a travelling-wave electrode structure to the proposed device, a fast polarization modulator operated in quasi-millimeter-wave/millimeter-wave ranges can be obtained.

Acknowledgement

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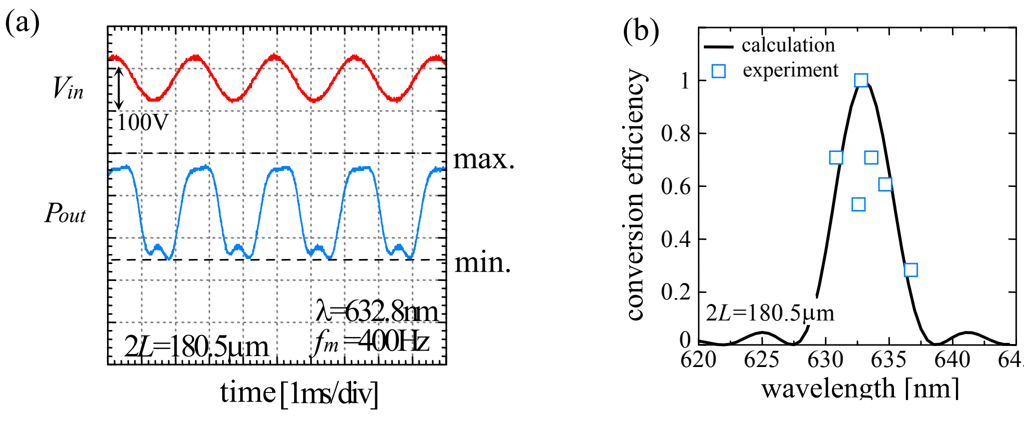

Fig. 3. Measured output characteristics (a) and the wavelength dependence of the polarization conversion (b).