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Polarization Control by Leaky SAW in Reverse-Proton-Exchanged $LiNbO_3$ Optical Waveguide

漏洩弾性表面波による逆プロトン交換 $LiNbO_3$ 光導波路の偏波制御

Sho Sato[‡] and Shoji Kakio (Univ. of Yamanashi)
佐藤　翔[‡]，垣尾 省司 (山梨大院・医工)

1. Introduction

Acoustooptic (AO) devices using the AO effect between an optical guided wave in an optical waveguide and a surface acoustic wave (SAW) have been investigated for a long time. The authors have realized a waveguide-type AO modulator (AOM) driven by an SAW using coplanar AO coupling, that is, Bragg diffraction, in which laser lights of the three primary colors, red, green, and blue (RGB), can be modulated by the same modulator.[1,2] For application in the field for laser displays, a simple simultaneous modulation system for RGB laser lights has been proposed and constructed using the AOM module.[2] However, it is difficult to realize an extinction ratio higher than 24 dB, which is required for practical use, because part of the incident guided optical wave inherently leaks to the diffracted port.

To obtain a higher extinction ratio, the utilization of collinear AO coupling, that is, TE-TM mode conversion, is suitable because the coupling can be achieved in a straight channel waveguide. However, it is difficult to obtain a rapid response because the length of the AO interaction region is of 10 mm order.

In this study, to obtain a high extinction ratio and rapid response for an AO interaction in a straight channel waveguide, polarization control of the optical guided wave in a new configuration using a reverse-proton-exchange (RPE) $LiNbO_3$ optical waveguide and a leaky SAW (LSAW) was investigated for RGB laser lights.

2. Configuration and Fabrication of Sample

Figure 1 shows the configuration of the polarization controller based on a straight channel optical waveguide fabricated on Y-cut $LiNbO_3$. The propagation direction of the optical guided wave is set to be parallel to the optical axis (Z-axis) so that the propagation constant vectors $\boldsymbol{\beta}_{TE}$ and $\boldsymbol{\beta}_{TM}$ of the TE and TM modes, respectively, are close to each other ($\boldsymbol{\beta}_{TE} \fallingdotseq \boldsymbol{\beta}_{TM}$). The LSAW propagates perpendicular to the channel waveguide from the interdigital transducer (IDT). In this configuration, the polarization of the incident light can be controlled by the LSAW, which causes the perturbation of off-diagonal elements of the dielectric tensor without adding the LSAW wavenumber vector $\boldsymbol{K}$. A rapid response can also be obtained. Furthermore, an LSAW with a high electromechanical coupling factor on Y-cut X-propagating $LiNbO_3$ can be utilized. Only light with the controlled polarization is filtered from the light output by an analyzer.

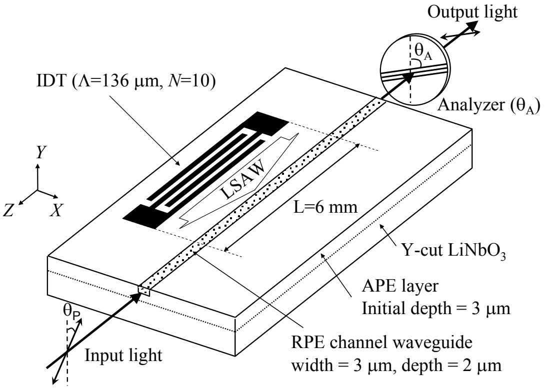

Fig. 1 Configuration of polarization controller.

To fabricate the optical waveguide, we adopted the RPE process, which increases only the ordinary refractive index. The fabrication process of the polarization controller is as follows. First, an annealed PE (APE) planar waveguide with a depth of 3.0 μm was formed on the whole surface of a Y-cut $LiNbO_3$ substrate by immersing the substrate in a solution of benzoic acid (Li 1.0 mol%) at 240˚C for 7 h 45 min and annealing for 40 min at 400˚C. For the fabrication of RPE channel waveguides, RF-sputtered SiO_2 masks with a thickness of 0.25 μm and a mask width of 3 μm were formed by a lift-off technique. Next, an RPE channel waveguide with a depth of 2.0 μm was formed by immersing the APE sample in an equimolar mixture of $LiNO_3$-$NaNO_3$-KNO_3 at 350˚C for 8 h. The change in the ordinary refractive index in the RPE waveguide was measured to be 0.02. The above conditions were chosen so that the RPE channel waveguide maintains a single-mode guided wave in the depth direction for RGB laser lights. Finally, after polishing the end face, IDTs with a period of 136 μm, 10 finger pairs, and an overlap length of 6 mm were fabricated using an Al film. The sample length was 23 mm.

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g10me014@yamanashi.ac.jp

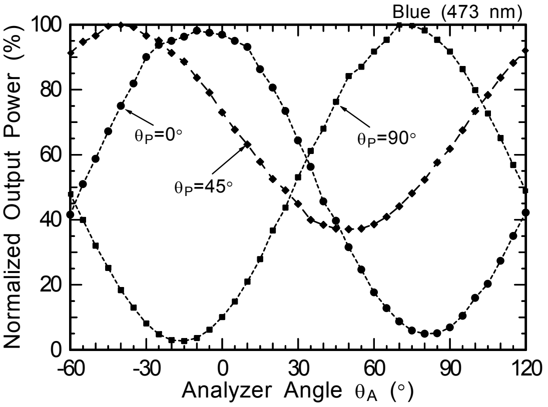

Fig. 2 Measured output power vs analyzer angle without LSAW as a parameter of polarization angle.

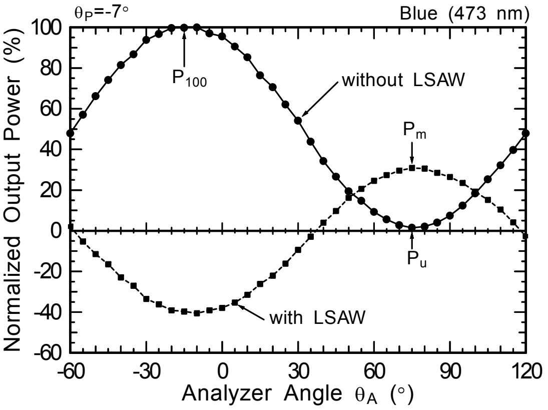

Fig. 3 Measured output power vs analyzer angle with and without LSAW.

3. Polarization Properties in RPE Waveguide

To evaluate the inherent change in polarization owing to a disturbance in the RPE waveguide, the output power was measured as a function of the analyzer angle θ_A using the polarization angle θ_P of the incident linearly polarized wave as a parameter. A laser beam was coupled to the input and output end faces of the RPE waveguide through an objective lens with a magnification of x40. The output power through the analyzer was measured by a photodetector.

Figure 2 shows the output powers for θ_P=0°, 45°, and 90°, which were normalized by the maximum value for each case, when a blue laser with an optical wavelength λ of 473 nm was used. It was observed that for θ_P=0° and 90°, the incident linearly polarized waves were rotated by -10° and -15°, respectively, while linearity almost remained in the propagation length of 23 mm. On the other hand, when θ_P was 45°, a minimum normalized output power of approximately 40% was retained. This means that the incident linearly polarized wave became elliptically polarized. However, appropriate pairs of θ_P and θ_A for each laser light, in which the minimum normalized output power was less than 1.5%, were confirmed and were used as conditions in the experiment on polarization control by the LSAW reported in the next section.

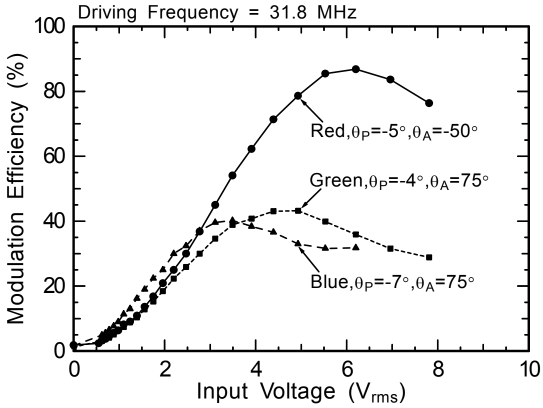

Fig. 4 Measured modulation efficiency.

4. Polarization Control by LSAW

Figure 3 shows the normalized output power with and without an input voltage to the IDT as functions of θ_A for λ=473 nm. When θ_P and θ_A were -7° and 75°, respectively, a modulated output power P_m of 30% and an unmodulated output power P_u of 1.5% were observed. Therefore, 30% of the power of the incident linearly polarized wave was rotated by -90° in addition to the inherent rotation of -15° due to the perturbation of the LSAW.

Figure 4 shows the modulation efficiency as functions of the input voltage for RGB laser lights. The driving frequency was fixed at 31.8 MHz for all wavelengths. The maximum modulation efficiencies for optical wavelengths of 633, 532, and 473 nm were 86, 43, and 40%, respectively. Higher efficiency was obtained at a longer wavelength. The extinction ratio was determined as P_u divided by the maximum modulated power. The extinction ratio of 16.8-13.8 dB was slightly improved from the previous values of 11-13 dB for the Bragg diffraction type AOM.[2]

Furthermore, to obtain a rapid response, an IDT with a period of 20 μm, three finger pairs, and an overlap length of 16 mm was fabricated. The response time for modulation control was measured to be approximately 22 ns. The response time of polarization control is considered to be almost equal to the time required for the propagation of the LSAW through an IDT of width 60 μm.

5. Conclusions

Polarization control in an RPE $LiNbO_3$ optical waveguide fabricated on Y-X $LiNbO_3$ by an LSAW was investigated for RGB laser lights. Maximum modulation efficiencies of 40-86% and an extinction ratio of 16.8-13.8 dB were obtained. The measured response time of 22 ns was almost equal to the time required for the propagation of the LSAW through the IDT width.

References

1. S. Kakio, *et al.*: Jpn. J. Appl. Phys. **48** (2009) 07GE02.
2. S. Kakio, *et al.*: Jpn. J. Appl. Phys. **49** (2010) 07HD18.