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Acousto-Optic Modulators Driven by Longitudinal Leaky Surface Acoustic Waves on $LiNbO_3$ Thin-Plate Bonded Structures

$LiNbO_3$薄板接合構造上の縦型リーキー弾性表面波を用いた音響光学変調素子

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1. Introduction

A light wave that is guided to the propagation region of a surface acoustic wave (SAW) is Bragg-diffracted by an acousto-optic (AO) effect and undergoes an optical frequency shift caused by the SAW. To increase the frequency shift, the authors previously fabricated an AO modulator (AOM) using a longitudinal leaky SAW (LLSAW) that has 1.5–2-fold higher phase velocity than Rayleigh-type SAWs (R-SAWs) on an X-cut 36°Y-propagating $LiNbO_3$ (X36°Y-LN) substrate with a high electro-mechanical coupling factor K^2 for an LLSAW and evaluated its diffraction properties [1]. However, the driving voltage required for optical diffraction by the LLSAW was higher than those when using R-SAWs because the LLSAW lost energy through the radiation of bulk waves into the substrate. On the other hand, our group also found that the propagation properties of LLSAWs could be improved by using a structure consisting of an LN thin plate bonded to a high-velocity substrate such as quartz or sapphire (Al_2O_3) [2]. In this study, to lower the driving voltage of an AOM using an LLSAW, AOMs were fabricated on LN thin plates bonded to quartz or Al_2O_3 substrates, and their diffraction properties were evaluated.

2. Design of AOM

Figure 1 shows the configuration of the AOMs fabricated in this study. Samples of bonded structures in which an X36°Y-LN thin plate with a thickness h of 2.0 or 3.0 μm bonded to AT-cut quartz (AT-quartz) or c-plane Al_2O_3 (c-Al_2O_3) substrates were prepared. The propagation direction of the AT-quartz was set to 45°X propagation to obtain a larger K^2. In the fabrication of the optical waveguide of each AOM, to avoid peeling at the bonded interface, a proton exchange (PE) method was used, which allowed a lower-temperature process than the conventional Ti diffusion method [1]. To determine the depth of optical waveguide, the attenuation of LLSAWs, and the optical mode dispersion of an optical guided wave (OGW) were calculated.

Figure 2 shows the calculated attenuation of LLSAWs with a SAW wavelength Λ of 20 μm and optical mode dispersion with an OGW wavelength λ of 0.633 μm as a function of the PE depth d for PE:LN/LN/quartz and PE:LN/LN/Al_2O_3 structures. An OGW with single-mode propagation was obtained in the range of d of 0.48–1.55 μm. The minimum attenuation of the LLSAWs was obtained at d of 0.40 μm for LN/quartz and 1.0 μm for LN/Al_2O_3. From the above calculated results, d was set to 1.2 μm for LN/Al_2O_3. On the other hand, for LN/quartz, d was set to 0.65 μm because the OGW was not guided at d of 0.40 μm.

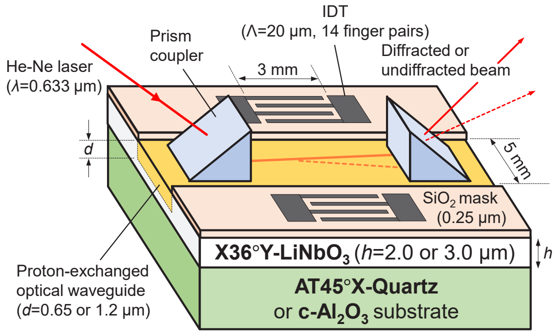

Fig. 1 Configuration of the AOMs on LN thin-plate bonded structures.

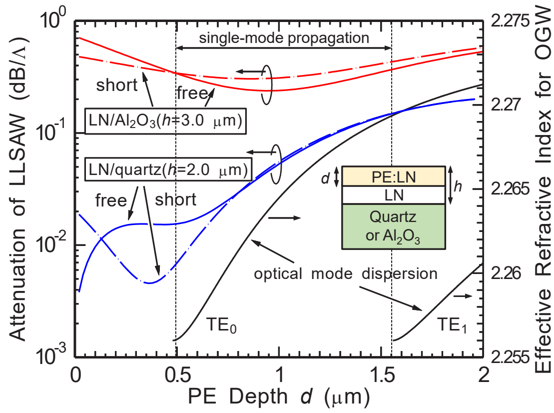

Fig. 2 Calculated attenuation of LLSAWs and optical mode dispersion of an OGW for PE:LN/LN/quartz and PE:LN/LN/Al_2O_3 structures. Λ=20 μm, λ=0.633 μm.

Moreover, the particle displacements of LLSAWs on LN/quartz without a PE layer and with d of 0.65 μm were calculated using a finite element method (FEM) system. As shown in **Figs. 3(a) and 3(b)**, the particle displacement for d of 0.65 μm was more concentrated to the surface than that without the PE layer owing to the lower phase velocity of the PE layer than that of the LN bulk. In addition, the

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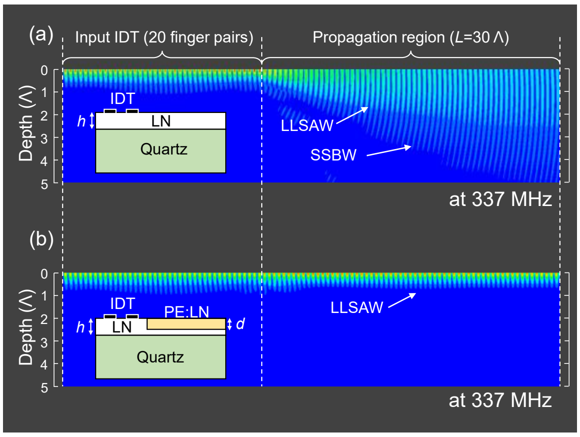

Fig. 3 Calculated particle displacements of LLSAWs on LN/quartz (h=2.0 μm): (a) without PE layer, (b) d=0.65 μm. Λ=20 μm, free surface.

propagation of a longitudinal surface-skimming bulk wave (SSBW) was markedly suppressed because the phase velocity in the SAW propagation region with a PE layer was lower than that without one.

3. Evaluation of Diffraction Properties

The process of fabricating the AOMs was as follows. First, as an optical waveguide mask with a width of 5 mm, a 2500-Å-thick SiO_2 thin film was deposited on LN/quartz or LN/Al_2O_3 samples. Then, the samples were immersed in benzoic acid at 240 °C to fabricate a PE optical waveguide with a depth d of 0.65 or 1.2 μm. Then, interdigital transducers (IDTs) with a period Λ of 20 μm, an overlap length of 3 mm, and a propagation length L of 300 Λ were fabricated on a SiO_2 mask using a 2500-Å-thick Al thin film.

Figure 4 shows the measured frequency responses between the input and output IDTs for the LLSAWs on the AOM samples and the LN/quartz sample without a PE process. The minimum insertion loss *MIL* for LLSAW on the LN/quartz was smaller than that on the LN/Al_2O_3 because the attenuation of the LLSAW on LN/quartz was lower than that on LN/Al_2O_3. In addition, *MIL* for LN/quartz was less than that without PE process owing to the suppressed propagation of the SSBW.

To excite a TE-mode light beam, a He-Ne laser (λ=0.633 μm) was guided into a PE optical waveguide using rutile prism couplers. An RF burst signal was applied to the input IDT and LLSAWs on LN/quartz or LN/Al_2O_3 were excited by adjusting the frequency of the input RF signal to 347 or 403 MHz. The intensity of the undiffracted light was measured using a photomultiplier and the diffraction efficiency was determined from the decrease in the intensity.

Figure 5 shows the measured diffraction efficiency as a function of the RF input voltage. The measured results were fitted using the $\sin^2$-curve solution of coupled-mode equations [3], as shown in Fig. 5. The maximum diffraction efficiency in the TE_0 mode and the driving voltage required by the LLSAWs were 91% and 5.1 V for LN/quartz and

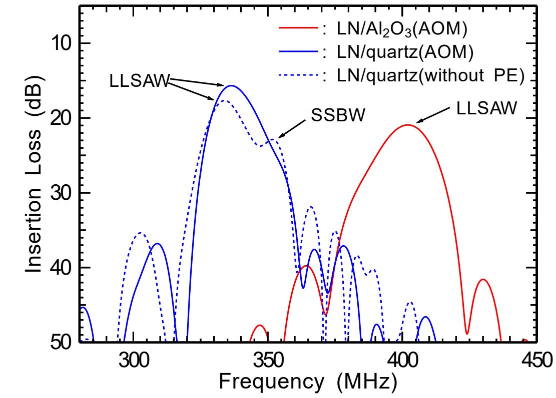

Fig. 4 Measured frequency responses between the input and output IDTs for the AOM samples and the LN/quartz sample without a PE process.

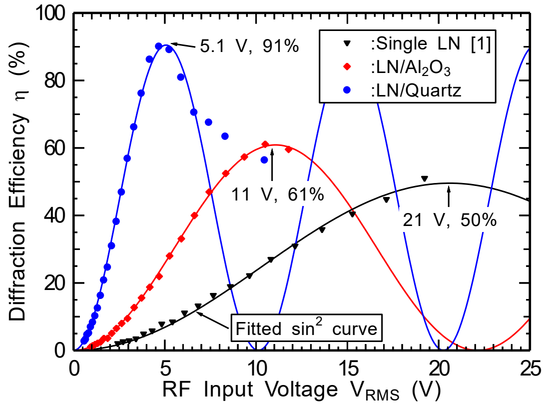

Fig. 5 Measured diffraction efficiency for the LLSAWs. Λ=20 μm, λ=0.633 μm.

60% and 11 V for LN/Al_2O_3, respectively. The diffraction properties of the LLSAWs on the bonded structures were improved compared with those of a single LN [1].

4. Conclusions

In this study, to obtain an AOM using an LLSAW with a lower driving voltage, AOMs with LN/quartz or LN/Al_2O_3 structures were fabricated and their diffraction properties were evaluated. The diffraction properties of the LLSAWs on the bonded structures were improved compared with those of a single LN. Moreover, it was theoretically and experimentally revealed that the attenuation of LLSAWs on bonded structures was decreased owing to the PE process.

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