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TOWARDS BROADBAND LATERAL BAW EXCITATION IN A LOW-VELOCITY ANISOTROPIC SUBSTRATE

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ABSTRACT

We investigate a novel transducer structure that combines the thin plate lithium niobate (LN) and interdigital transducer (IDT) technologies. We simulated an anisotropic LN-on-TeO_2 structure with an IDT atop, in which shear horizontal (SH) bulk acoustic wave (BAW) excitation was considered. X-cut LN plate is bonded to the substrate, and the IDT electrodes are aligned with $Z + 41°$ direction of pure SH displacement. The transducer was aligned with (110) plane of the TeO_2 substrate having the SH BAW velocity in the range from 0.62 to 0.80 km/s depending on the cut angle α. Frequency dependencies of the resulting BAW polarization in the substrate were retrieved and analyzed. With a fixed-pitch IDT, SH BAW excitation can be achieved in the relative bandwidth of $\sim 20\%$ at various central frequencies depending on the LN plate thickness. At the boundaries of the excitation band, we observed transformation of the BAW mode from SH to longitudinal polarization. Owing to periodic IDT structure, the beam steering effect is observed for the excited SH BAW in TeO_2 that helps to extend the bandwidth of light-to-ultrasound coupling in photonic applications.

Keywords: *acousto-optics, beam steering, interdigital transducer, anisotropic multilayer structure*

1. INTRODUCTION

Broadband excitation of bulk acoustic waves (BAWs) is of great demand in various applications including acousto-optics and photonic integrated circuits. The golden standard of BAW transducers up to 1 GHz is thin plate lithium niobate (LN), which allows for longitudinal/shear mode excitation in solids with high electromechanical coupling. Interdigital transducer (IDT) technology is an effective method for surface and hybrid wave launching, but its applications in BAW domain are still limited. Commonly, leakage of acoustic waves into bulk modes is considered as a drawback and a source of undesired losses in high-frequency ultrasonic devices. To eliminate leakage, high-velocity substrates or membrane structures are commonly used in sufrace acoustic wave devices.

We analyze the possibility of applying IDT techniques for purposeful shear horizontal (SH) BAW excitation in a low-velocity TeO_2 crystal substrate (Fig. 1). Periodical out-of-phase excitation of ultrasound enables the effect of beam steering in the substrate crystal, which can be used to extend the phase-matching band of acousto-optic deflectors and tunable filters [1]. Radiation pattern of a periodically poled transducer depends on the ultrasound frequency that results in effective wavefront tilt and readjustment of acousto-optic phase matching. In this report, we numerically analyze excitation bandwidth and acoustic modal structure created by the said transducer.

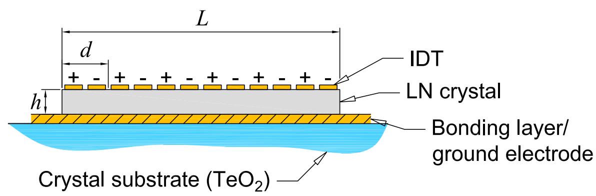

Figure 1. Piezoelectric transducer with an IDT atop of anisotropic LN-on-TeO_2 structure.

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2. METHODS

The proposed transducer structure combines the thin plate LN and IDT technologies. We simulated an anisotropic LN-on-TeO_2 structure with an IDT atop, in which SH BAW excitation was considered (panel A in Fig. 2). X-cut LN plate is bonded to the substrate, and the IDT electrodes are aligned with $Z + 41°$ direction of pure SH displacement. The transducer was aligned with (110) plane of the TeO_2 substrate having the SH BAW velocity in the range from 0.62 to 0.80 km/s depending on the cut angle α.

The transducer's performance was modelled with a semi-analytical SDA-FEM-SDA method developed for arbitrary anisotropic multilayered structures excited by an IDT: plane wave decomposition (spectral domain analysis, SDA) is used in homogeneous layers and finite-elements-method (FEM) is used in the electrode layer [2]. Periodic boundary conditions are applied. Frequency dependencies of the resulting BAW polarization in the substrate were retrieved and analyzed.

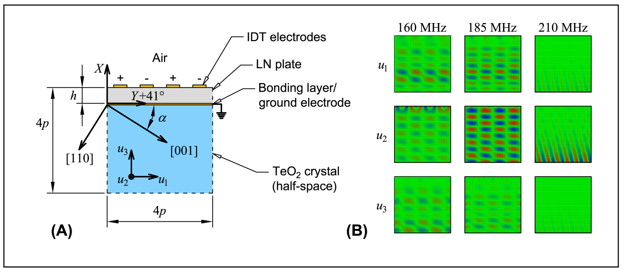

Figure 2. Numerical modelling of the piezoelectric transducer: (A) elementary cell for SDA-FEM-SDA modelling; (B) BAW structure (u_1, u_2 and u_3 mode amplitudes) at various frequencies.

3. RESULTS AND DISCUSSION

The transducer structure (Fig. 1) has several independent parameters, each of them affecting the performance and mode structure of the BAW fields in the substrate. In our simulations, the thickness and the fill factor of the IDT electrodes were fixed. The LN plate orientation corresponded to a standard homogeneous SH BAW transducer (see Fig. 2, A).

The TeO_2 substrate cut angle was $\alpha = 6°$ in $(1\bar{1}0)$ plane, which is a typical crystal orientation for acousto-optic deflectors and filters using slow SH BAW. The optimal IDT pitch $d = 58$ μm was derived from acousto-optic phase matching conditions for a broadband tunable filter design [1].

Admittance of the transducer was computed for different LN plate thickness values. With a fixed-pitch IDT, SH BAW excitation can be achieved in the relative bandwidth of $\sim 20\%$ at various central frequencies depending on the LN plate thickness h. At the boundaries of the excitation band, we observed transformation of the BAW mode from SH to longitudinal polarization. Simulated displacement maps are shown in Fig. 2 (B) for the IDT pitch of $2p = 58$ μm and LN thickness of $h = 5.6$ μm. The SH mode corresponds to u_2 component of the acoustic displacement vector. Owing to periodic IDT structure, the beam steering effect is observed for the excited BAW in TeO_2 that helps to extend the bandwidth of light-to-ultrasound coupling in photonic applications.

From the modelling results we concluded that the optimal LN thickness of h is much smaller than that for a homogeneous SH BAW transducer at the same resonance frequency. That proves a different mechanism of BAW excitation with an IDT: a plate mode is excited in the top layer of the substrate, which is converted into a non-homogeneous BAW mode owing to effective leakage to the low-velocity substrate.

4. CONCLUSIONS

Numerical modelling demonstrated that IDT-on-LN transducer structures are capable of effective excitation of SH BAW in TeO_2 crystal for acousto-optic applications. Resonance frequency can be adjusted by choosing a proper LN plate thickness h provided the IDT pitch d is fixed. Extension of the excitation bandwidth can be achieved using s stair-step LN plate with several segments corresponding to different resonance frequencies.

5. REFERENCES

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