Impact of domain depth on SAW generation by acoustic superlattice transducer in 128° YX-cut lithium niobate

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***Abstract*—Surface acoustic wave (SAW) generation on 128° YX acoustic superlattice has been investigated by considering the finite-depth of the domain created by the UV direct-domain writing. We found that bound and localized SAW will be generated when the domain depth of the ASL structure, underlying the transducer, is smaller and bigger than the lattice period, respectively. Efficient bound SAW can be achieved, provided the domain depth is 30% of the lattice period.**

Keywords—lithium niobate; surface acoustic wave, domain inversion

I. Introduction

Recently, a piezoelectric superlattice configured as a semi-infinite or surface-terminated $LiNbO_3$ substrate —*acoustic superlattice* (ASL)— has been used, in conjunction with uniform coplanar electrodes, to realize a new kind of SAW transducer [1]. The ASL is an artificial structure, based on periodic domain inversion on a single-crystal $LiNbO_3$ substrate [1], [2], [3], offering an alternative to SAW generation compared to a standard interdigital transducer (IDT) [4]; the method has been demonstrated experimentally [1], [5]. Characterization of the transducer by means of radio frequency (RF) and acousto-optical measurements has enabled direct observation of the excited SAW displacement [5], [6], [7]. The use of such transducer in a monolithic integrated SAW-based acousto-optic filter has recently been reported [6], [7]; coplanar electrode configurations indeed allow for the placement of an optical waveguide on the electrodes' gap, thus better optical loss compared to that obtained from a similar device with the IDT [6]. In our recent studies it was shown that ASL transducer exhibits SAW band gap, resulting in localization of the SAW generated on the ASL [8]. This may therefore open up new possibilities for SAW manipulation by means of tailoring the band gap through engineering the ASL structure, similar to phononic and photonic crystal-based devices [9], [10].

As mentioned previously, main building block of ASL transducer is PPLN. To date, PPLN is fabricated using electric field poling at room temperature [11]. While this technique has been considered as a reliable process and has been used for many practical PPLN-based devices [11], but works better on a crystal with a polar face such as Z-cut $LiNbO_3$ [12], and will become impractical [13] on crystal with inclined polarization axis such as 128° YX-cut. This therefore limits the practical use of ASL transducer as in many other SAW applications beside the optical ones [6], 128° YX-cut is preferable and is commonly used for instance in microfluidic [14] due to its largest coupling constant (5.3%) [15]. Different fabrication techniques such as Ti diffusion and heat treatment [16] have been proposed to achieve domain inversion on different cuts. High temperature requirement up to 1100°C makes the mentioned processes difficult to control in particular when a domain at a length scale of sub-to-few microns is desired.

Recently, ferroelectric direct-domain writing using a continuous wave ultraviolet (UV) laser has been proposed for domain engineering lithium niobate where domain patterning on non-polar crystals X- and Y-cut has been demonstrated [17]. A significant advantage of this technique is that local domain inversion can be achieved at room temperature by directly scanning the UV laser across the crystal surface, thus better control of domain patterning to obtain complex structure. However, these engineered domains can be quite shallow. Here, we analyze SAW generation on 128° YX-cut $LiNbO_3$ studying in particular the impact of domain depth.

II. Model and Methods

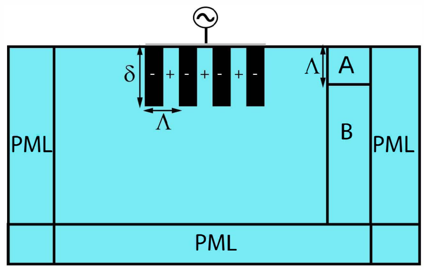

Figure 1. Model structure used for transmission computations of finite-depth ASL structure.

In modeling the structure, finite element method was employed. The finite-depth ASL structure being considered is derived from periodic domain inversion of 128° YX-cut $LiNbO_3$ substrate where the domain walls were taken to be perpendicular to crystallographic X axis and distributed periodically along the *x*-axis of SAW propagation. We defined the normalized parameter $\tau=\delta/\Lambda$, representing the domain depth, with a constant lattice period ▪ and a variable domain depth δ[see Fig. 1]. Stress free bound condition (BC) was imposed on the surface expect at the periodic domain surface where Dirichlet BC, V_{rf}=1 V, was imposed. The remaining boundaries were terminated with Perfectly Matched Layers (PMLs).

The domain depth τ was varied from 0 (unpoled substrate) to 4 and for each value of τ, the transmission *T* was calculated. The transmission *T* was determined from the ratio between acoustic energy that passes through region A and the total acoustic energy, leaving the transducer. Throughout the modeling, the acoustic frequency was fixed at the SAW resonance, given by $f=V_{SAW}/\Lambda$ where V_{SAW} = 3980 m/s, corresponding to SAW velocity on 128° YX $LiNbO_3$ [15].

III. Results and Discussion

Figure 2 presents the modeling results, showing that when the domain depth is close to zero (below 10% of the lattice period), the calculated transmission is almost zero. This is as expected because in this case the electro-acoustic coupling is very small; it is zero when τ=0. Any acoustics being generated by the transducer, having such depth will be mostly bulk acoustics. However, when the domain depth is increased above 10% of the period, the transmission goes up sharply and is well above 50%; more than half of generated acoustic energy passes region A. It reaches maximum (almost 90%) when the depth is 30% of the period (τ≈0.3). However, if the depth is further increased, the transmission is decreasing exponentially and is reaching almost zero when the domain is much larger than the period (τ>>1).

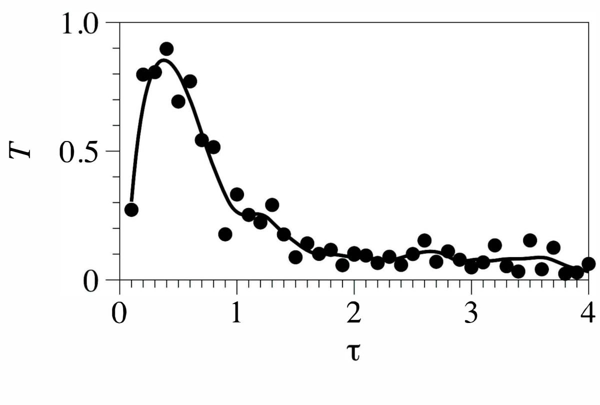

Figure 2. Out-going surface bound acoustic energy (T) vs normalized domain depth

The above results indicate that a bound SAW is achieved when τ≈0.3. This is confirmed by the calculated displacement profile as shown in Fig. 3(a). Figure 3(b) shows that the generated SAW is more localized within the periodic domain as a standing wave when the depth is far beyond the lattice period Λ (τ>>1). This behavior is probably as a consequence of the existence of the SAW band gap, exhibited by the ASL structure as studied previously [8]. Such band gap becomes strong when the domain is much larger than the period, so that the frequency resonance will lie within the upper stop band edges and the group velocity is almost 0, indicating the standing wave. However, the gap becomes much weaker, thus phase and group velocity almost equal when the depth is shallower or below the period. Hence travelling SAW is generated.

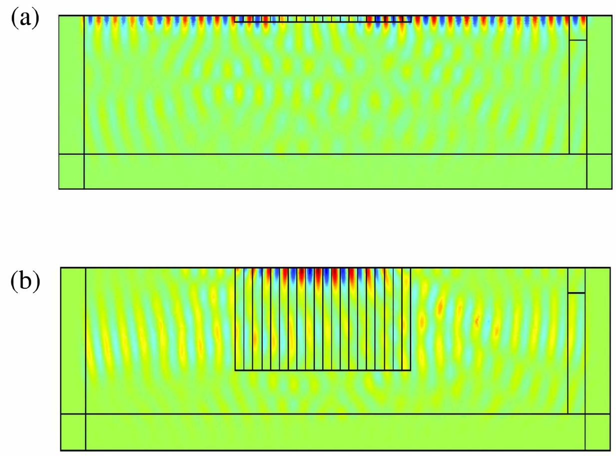

Figure 3. Displacement profiles with: (a) τ=0.3 and (b) τ=4.

IV. Conclusion

We have investigated the impact of the domain depth on the SAW generation on 128° YX ASL structure, realized by the UV domain writing. We found that bound and localized SAW will be generated when the domain depth is smaller and bigger than the lattice period, respectively. Generation of bound SAW will be efficient, provided the domain depth is 30% of the lattice period. This behavior of SAW generation seems to be related to the presence of the SAW band gap, exhibited by the ASL in accordance to the previous studies [8].

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