Properties of LL SAW on YZ-Cut LiNbO$_3$: Modeling and Experiment

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Longitudinal leaky (LL) waves on YZ-LiNbO$_3$ substrates [1, 2] feature many properties which are unusual for SAW and remain unexplained. Recent demonstration [3] of wideband low-loss filters operating on LL waves in the 2.5–5 GHz frequency range, manufactured with optical lithography, makes these waves of primary practical importance. Filters based on LL waves may become competitors against the FBAR technology, all operating practically in the same frequency range. Synchronous test resonators employing the LL SAW mode have been fabricated on the YZ-cut LiNbO$_3$ substrate to study the dependence of resonator behavior on the metallisation ratio, aperture, finger thickness and the number of fingers in the IDT. Experimental data accumulated at different frequencies (2.5, 2.8, and 5.2 GHz) are presented and compared with simulations. In all the cases, high Q factors are achieved with “magic” relative Al thickness value of about $h/\lambda=7.8\%$ to $8.0\%$. For experimental resonators operating in the 2.8 GHz frequency range, Q factors at resonance of 340 and relative resonance-antiresonance distance of 4.2% have been measured. The corresponding figures for resonators in the 5.2 GHz frequency range are 180 and 5.2%, respectively. The Q factor decreases with increasing aperture and, unexpectedly, also with increased length of the IDT. We present here systematic FEM/BEM modeling results for dependence of LL wave characteristics on the electrode geometry. For better agreement between the simulation and measurement, additional lumped elements are added to the resonator equivalent circuit and their electrical parameter values are obtained through a fitting procedure. We assume that the waves are not guided by the structure and that different kinds of side radiation may influence the resonator Q factors.


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IMAGING OF ACOUSTIC FIELDS GENERATED IN A LONGITUDINAL LEAKY SAW RESONATOR

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We have utilized a scanning laser-interferometric probe [1] to map the spatial distribution of the acoustic field inside a one-port synchronous leaky longitudinal SAW (LLSAW) resonator. This marks the first visualization of LLSAWs within such a structure. The measurement is feasible since LLSAWs possess a small vertical displacement component, which is detectable with the interferometer. Interest in these waves exists since LLSAWs feature high velocity (>6100 m/s) on YZ-LiNbO₃ substrate and hence enable fabrication of bandpass filters operating in the 2.5 - 5 GHz range with conventional optical lithography [2]. Measurements at frequencies within and above the stopband for a 1.6 GHz LLSAW resonator fabricated on YZ-cut LiNbO₃ were performed. The resonator comprises a long IDT with N=151 fingers and a relatively narrow aperture of W=16 wavelengths and synchronously placed reflectors on both ends of the IDT consisting of 37 short-circuited electrodes. We found that below the resonance the longitudinal profile did not feature a beating pattern typically observed for Leaky SAW resonators. Above the resonance frequency, strong attenuation of the LLSAWs was observed on top of the reflector gratings. The transversal profile within the IDT featured interesting behaviour as strong mode shapes possessing 2, 3, 4, 5, etc. maxima appeared as the drive frequency was increased. Furthermore, oblique beams were observed to radiate from the sides of the resonator. These beams were identified as Rayleigh waves. The energy-flow angles of the Rayleigh beams were obtained as functions of frequency and have been compared with simulated values.

The lecture briefly reviews some basic achievements in theoretical studies on SAW propagation in anisotropic media. Emphasis will be given to the following issues. Lothe-Barnett's existence theorems for SAWs on half-infinite non-piezoelectric and piezoelectric media. Orientation sectors of the co-existence of two SAWs on piezoelectric substrates. Orientation sectors of the non-existence of SAWs on piezoelectric substrates. Leaky SAWs, their relation to "supersonic" SAW and fast exceptional bulk waves. The existence of "supersonic" SAW propagating faster than the slowest bulk wave. The existence and properties of non-attenuating localized waves propagating faster than both the quasi transverse bulk waves in the substrate; requirements on crystallographic symmetry and material constants, examples. Theorems on the existence of localized waves on the interface between two elastic media; Stoneley waves in non-piezoelectric and piezoelectric media of arbitrary anisotropy, "gap" waves. Specific features of Stoneley waves on twist boundaries in crystals.

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5F-4  2:30 p.m.

EFFECT OF SURFACE-BULK HYBRID MODE ON STRIP ADMITTANCE IN 42°YX AND 48°YX CUTS OF LITAO₃ WITH AL GRATING

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In resonator structures using rotated YX-cuts of LiTaO₃, leaky SAW strongly interacts with the surface skimming bulk wave and forms the surface-bulk hybrid mode (SBH). As a result, additional resonance of strip admittance occurs at the frequency close to the upper edge of the Bragg stopband. The amplitude of this resonance depends on crystal orientation, geometrical parameters of the grating and detuning of applied voltage from synchronous resonance condition. An approximation is suggested for SBH effect on strip admittance of the grating with arbitrary electrode thickness h/p, metalization ratio a/p and detuning factor dS=p/λ-0.5 (λ is periodicity of applied voltage, p is the period of the grating). Using this approximation, the main parameters of SBH mode, that is resonance frequency, effective electromechanical coupling K₉ and propagation loss at resonance L₉, have been extracted from numerically found strip admittance Y(f,p/L) in 42°YX and 48°YX cuts of LiTaO₃ with Al grating. All parameters are plotted as functions of detuning factor, at different h/p and a/p, and show good agreement with SBH behavior observed experimentally. Effective coupling K₉ grows with detuning and reaches maximum value at dS=0.003-0.005. For example, with a/p=0.5 and h/2p=0.05 (optimal thickness for 42°YX cut), this maximum is fairly low, about 0.2%, but it increases dramatically when Al thickness becomes less than 4%. Attenuation of SBH mode is much stronger in
48°YX than in 42°YX cut. As a result, with the same Al thickness and metalization ratio, the effect of SBH on strip admittance is less apparent in 48°YX. Furthermore, if Al thickness is optimized for this cut (h/2p=0.1), the spurious SBH resonance becomes negligible, though it grows with increasing a/p. The found dependences of SBH parameters on detuning factor have been used for fast simulation of finite-length resonator structures and compared with accurate numerical simulation and experimental data.

5F-5 2:45 p.m.

A TWO-DIMENSIONAL ANALYSIS OF THE SURFACE ACOUSTIC WAVE VELOCITY IN FINITE ANISOTROPIC SOLIDS

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The two-dimensional theory for surface acoustic waves analysis in finite solids by Wang and Hashimoto (2003 IEEE International Ultrasonics Symposium, Hawaii) is extended to anisotropic materials through the introduction of complex exponentially decaying parameters and subsequent manipulations of expansion functions including the combination of trigonometric and exponential functions. Following the usual procedure for dimension reduction with three components in the basis function and complete coupling of three mechanical displacements due to anisotropy, we now have nine two-dimensional equations for the surface acoustic wave propagation in a finite anisotropic solid, resembling the higher-order Mindlin plate equations for bulk acoustic waves. Similar to the isotropic case, we also found that these equations give the identical phase velocity in limiting case where the depth of the solid is infinite. With these equations and the corresponding decaying parameters that are material specific and can be extracted through the half-space solutions, we calculated the phase velocity of straight-crested surface acoustic waves in a finite anisotropic solid to demonstrate the applications of these two-dimensional equations and the solution technique. Similar to plate theories, this two-dimensional theory can be used in the surface acoustic wave device modeling for both analytical and numerical solutions with the advantage of simplifying the physical model and reducing the computational difficulty, thus posing great potential in aiding the increasingly complicated but important modeling and analytical efforts.

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