DIFFRACTION OF PSEUDO SURFACE ACOUSTIC WAVES IN ANISOTROPIC MEDIA

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Abstract - Technique of numerical calculation and quick and convenient visualization for diffraction of pseudo surface acoustic waves in anisotropic crystals is described. Some examples of two-dimensional distributions of wave energy in some crystals are shown.

Keywords: diffraction, pseudo surface acoustic waves, anisotropic media.

1. INTRODUCTION

All theoretical calculations of surface acoustic waves are performed in accordance with assumption that a wave front is a plane. But real wave sources have finite transversal dimensions and wave beams have finite transversal dimensions too. Therefore a diffraction of a wave beam takes place. If a distance between interdigital transducers (IDT's) is large a power loss because of beam diffraction may be significant. Therefore the problem of diffraction of the surface and pseudo surface acoustic waves (SAW and PSAW) is rather important.

Methods, which used in optics, may be applied to solve this problem. But one has take into account that wave velocity and propagation attenuation in anisotropic medium depend on a propagation direction, moreover pseudo surface acoustic waves exist not for all the directions. If parabolic interpolation of velocity dependence is possible, problem of SAW diffraction may be solved analytically - Ref. 1. In general case numerical calculations are required. Some results of numerical simulation of SAW diffraction were published in Ref. 2.

In this work some results of numerical calculation of PSAW diffraction in piezoelectric crystals are presented. Amplitude of resulting wave in arbitrary point of crystal surface was calculated as a result of superposition of waves, which came in this point from various points of wave source. Attenuation of pseudo acoustic waves and discontinuity of dependencies of wave characteristics on propagation direction were taken into account.

A computer program of diffraction calculations was made in visual programming medium "Borland C++ Builder 4". Dependencies of wave velocity and propagation attenuation on propagation direction, which required for calculation, were obtained by the technique described in Ref. 3. Results of calculations were transferred in worksheet of "Excel" automatically after end of calculation and immediately plotted there as a two-dimensional graphs.

By such manner two-dimensional graphs of power distribution were obtained for the various cuts and propagation directions in various crystals, such as quartz, LGS, $LiNbO_3$, $LiTaO_3$. These graphs descriptive show how different cuts and propagation directions look out from point of view diffraction divergence. These dependencies also contain quantitative information which allows to calculate power propagation attenuation due to diffraction divergence.

2. BASIC FORMULAS

Amplitude of wave A(X,Y) in arbitrary point of plane with coordinates X,Y can be calculated as superposition of waves, coming from different points of a source:

$$A(X,Y) = \int_{-a/2}^{a/2} A_o(Y')K(\alpha)F(\alpha)R^m \, *$$

$$* \exp\left\{ i2\pi \frac{v(0)}{v(\alpha)}[1 + i\delta(\alpha)]R \right\} dY' \qquad (1)$$

Here X' = 0,Y' – coordinates of source points,
$A_o(0,Y')$ – distribution of amplitudes on the source (input IDT),
$R = \sqrt{X^2 + (Y - Y')^2}$ - distance from point of source to point of observation,
$\alpha = arctg \frac{Y - Y'}{X}$ - angle of propagation direction from point of a source to point of observation,
m = 0 for plane waves and m = -0.5 for cylindrical waves;
'm' value may slightly differ from -0.5 for cylindrical waves if anisotropy is taken into account,
F(α) – 'existence function':

$$F(\alpha) = \begin{cases} 1 & \text{if a wave exists for this direction } \alpha \\ 0 & \text{if the wave doesn't exist for this direction } \alpha, \end{cases}$$

$\frac{v(\alpha)}{v(0)}$ - dependence of normalized phase velocity on propagation direction α,
δ(α) – propagation attenuation of a pseudo acoustic wave, which also depends on a propagation direction α (in (1) δ is dimensionless value, not in dB/λ as usually),
a – width of source (aperture),
K(α) – function, which is equal to 1 for α = 0 and decreases if |α| increases, simplest variant is K(α) = cos(α). In Ref. 1 K(α) ~ sin(α)/α is used.

All dimensions are normalized on a wavelength.

One can perform integration of (1) analytically if assume that m = 0 (plane source waves), Ao = const, δ(α) = 0 and dependence of velocity on propagation direction is parabolic:

$$\frac{v(\alpha)}{v(0)} = 1 + \frac{1}{2}\gamma\alpha^2 \qquad (2)$$

In this expression value γ is called as diffraction parameter. Analytic theory shows, that the best value of diffraction parameter is γ = -1. For this parameter diffraction divergence absents, a beam profile doesn't change for any distance from aperture.

Parabolic approximation is valid not always, nevertheless diffraction parameter γ is usually used, if one want to estimate whether this orientation is good from point of view of diffraction or not. Diffraction parameter γ for some concrete orientation may be calculated by means of follow expressions:

$$\gamma = \frac{d\Gamma}{d\Psi}, \qquad (3)$$

where

$$\Gamma = arctg\left(\frac{1}{v}\frac{dv}{d\Psi}\right) \text{ - power flow angle .} \qquad (4)$$

Here ψ – third Euler angle, which defines propagation direction of an acoustic wave in some cut of crystal. A cut of crystal is defined by first and second Euler angles.

For isotropic medium velocity doesn't depend on direction and diffraction parameter γ is equal to zero.

In anisotropic crystals behavior of phase velocity and propagation attenuation very strongly dependent on all three Euler angles. Moreover pseudo acoustic waves exist not for any cut and propagation direction in arbitrary case. For example Figs. 1 and 2 show dependencies of phase velocity and propagation attenuation on the third Euler angle ψ for 42° rotated YX cut $LiTaO_3$ (Euler angles 0°,132°,0°) and 38° rotated YX cut $LiNbO_3$ (Euler angles 0°,128°,0°).

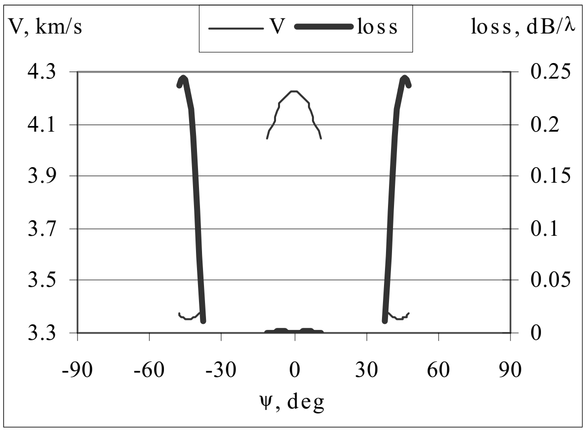

Fig.1. Phase velocity and propagation attenuation on 42YX $LiTaO_3$.

One can see that for these cuts pseudo surface acoustic wave doesn't exist for propagation directions $|\psi|$ from 12° to 37° and from 49° to 90° on $LiTaO_3$ and for $LiNbO_3$ from 6° to 55° (except narrow range of some degrees near 43°).

Obviously, attenuation, due to diffraction divergence, isn't important for those propagation directions, which correspond to large propagation attenuation. Only directions, corresponding to small propagation attenuation of pseudo surface acoustic waves, are interesting from point of view of practical usage and from point of view of diffraction divergence. Such directions in Figs.1, 2 correspond to $\psi = 0$. Maximum of velocity takes place for this direction in Figs. 1 and 2. This means that diffraction parameter γ is negative for this direction (according to (3) and (4)) and diffraction properties may be better, than for isotropic medium. For 42°YX $LiTaO_3$ γ = - 2.7 and γ = -2.161 for 38°YX $LiNbO_3$.

For calculation of integral (1) curves of phase velocity and propagation attenuation were used as numerical tables in range from ψ_o–90° to ψ_o+90° with small step (ψ_o - direction of normal to the input IDT, zero in Figs. 1 and 2). Values corresponding to intermediate points were obtained by linear interpolation.

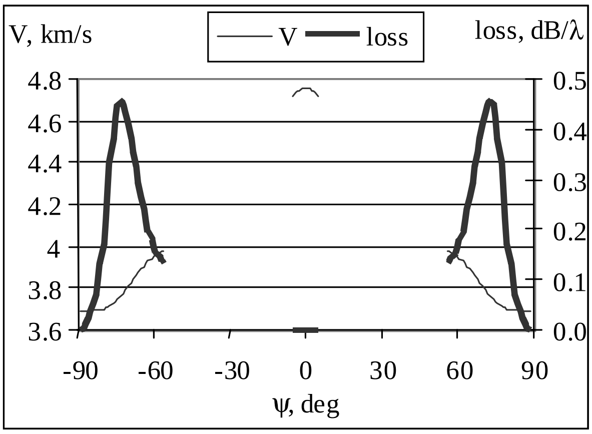

Fig. 2. Phase velocity and propagation attenuation on 38YX $LiNbO_3$.

3. SOME RESULTS OF CALCULATIONS

Cylindrical waves of wave source were used (m = -0.5 in (1)). Some of obtained distributions are shown in Figs. 3-7. In all the cases A_o = const, aperture = 20 wavelengths and Figs. 3-7 show normalized value $|A(X,Y)/A_o|^2$, proportional to a wave energy.

For comparison Fig. 3 shows distribution, corresponding to isotropic medium ($\gamma = 0$).

Figs. 4-7 show energy distributions for pseudo surface acoustic waves corresponding to some known cuts and orientations on some crystals.

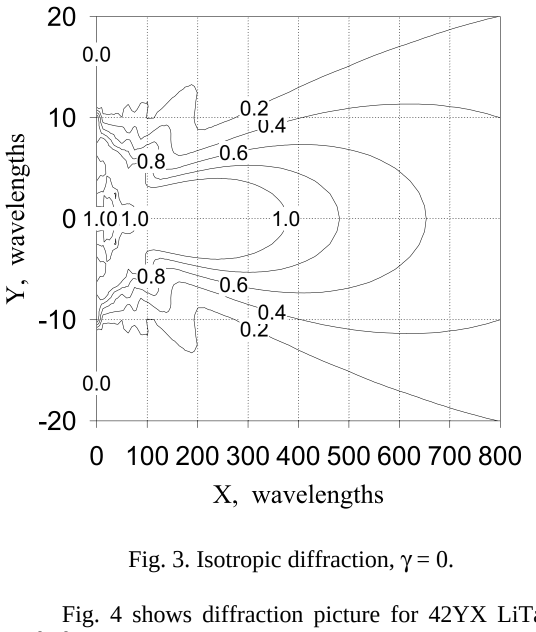

Fig. 3. Isotropic diffraction, $\gamma = 0$.

Fig. 4 shows diffraction picture for 42YX $LiTaO_3$ (0°,132°,0°) and Fig. 5 shows energy distribution for 38YX $LiNbO_3$ (0°,128°,0°).

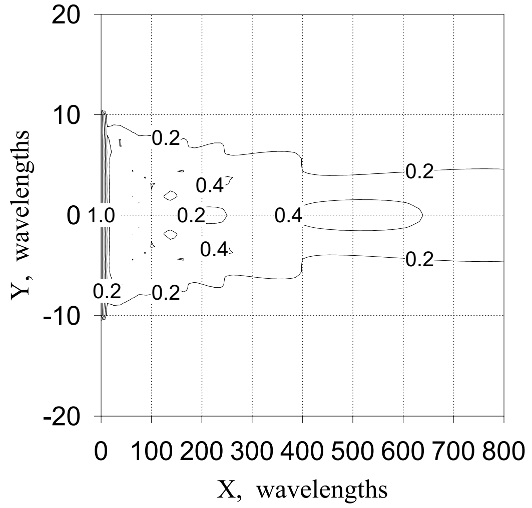

Fig. 4. 42YX $LiTaO_3$

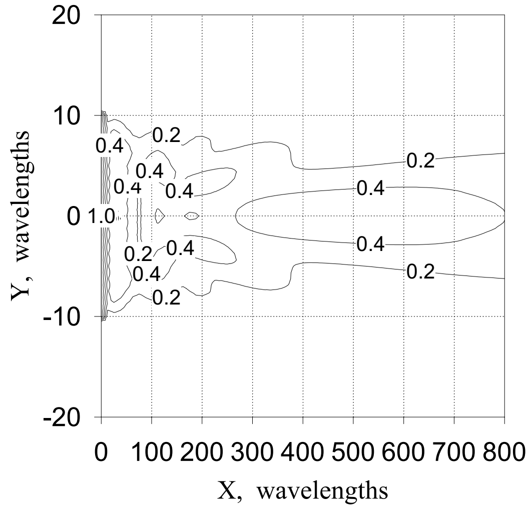

Fig. 5. 38YX $LiNbO_3$.

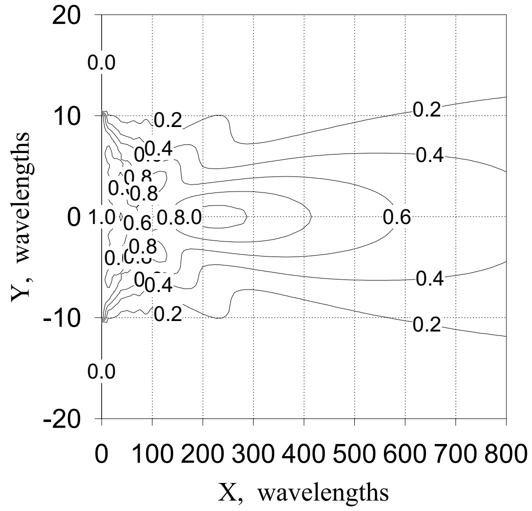

Fig. 6. LST Quartz, $\gamma = -0.584$.

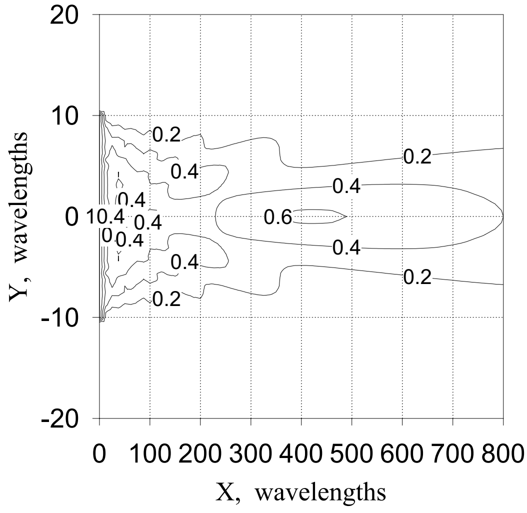

Fig. 7. LGS(0^o,60^o,0^o), $\gamma = -1.855$

These diffraction pictures are significantly better than for isotropic medium (see Fig. 3), because of character of dependence of velocity on a direction - diffraction parameter γ is negative (see Figs. 1 and 2). The second reason of small diffraction divergence is an absence of waves for large angles of diffraction (or large attenuation for these angles). But this second reason causes the more significant decrement of wave energy than for cases when waves exist for any angles - compare Fig. 3 and Figs. 4, 5.

Figs. 6, 7 show diffraction pictures for pseudo surface acoustic waves on LST quartz (0^o,15.7^o,0^o) and LGS (0^o,60^o,0^o) respectively.

Behavior of phase velocity versus direction for these cuts is similar to shown in Figs. 1, 2 and the main features of diffraction pictures are also similar to previous ones (Figs. 4, 5).

CONCLUSION

Described technique of calculation and visualization of two-dimensional energy distributions gives possibility quickly obtain descriptive diffraction pictures for pseudo surface acoustic waves and allows to estimate some cuts and orientations from point of view of diffraction divergence. Moreover quantitative information can be obtained from these distributions for calculation of diffraction losses.

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