Quasi-Longitudinal Pseudo-Surface Acoustic Waves on Lithium Tantalate

V.I. Cherednick
Chemical department
State University
Nizhny Novgorod, Russia
odissey@sandy.ru

M.Yu. Dvoesherstov
Radio-physical department
State University
Nizhny Novgorod, Russia
dvoesh@rf.unn.ru

K.Bhattacharjee
Clarisay
Dallas, USA

Abstract—**Calculations of quasi-longitudinal pseudo-surface acoustic waves for all the Euler angles on Lithium Tantalate are performed. The first Euler angle was changed in range from 0^o to 30^o with 10^o step, the second and the third angles were changed in range from 0^o to 180^o with 5^o step. It was found that quasi-longitudinal pseudo-surface acoustic waves exist in many ranges of Euler angles. All these ranges are shown in two-dimensional contour maps. Ranges of Euler angles, corresponding to relatively good propagation characteristics, are shown in detail.**

Keywords - pseudo-surface acoustic waves; ranges of existence; propagation characteristics

I. INTRODUCTION

Lithium Tantalate is one of the widely used materials for surface acoustic wave devices. In particular, orientations with Euler angles 90^o, 90^o, 112^o and also 36^{o}YX and 42^{o}YX are well known. The first orientation corresponds to surface acoustic wave and the second and the third ones correspond to pseudo-surface acoustic waves with very small propagation attenuation. For high frequency devices in GHz range, orientations corresponding to high phase velocity are needed. From this point of view, pseudo-surface acoustic waves with phase velocities about 4 km/s are more preferable than surface acoustic waves (velocities about 3 km/s). But on Lithium Tantalate as on other crystals, waves with higher velocities exist. These are quasi-longitudinal pseudo-surface acoustic waves with velocities about 6 km/s and even higher. Other terminologies used by different authors for these waves are – high velocity pseudo-surface acoustic waves (HVPSAWs), second leaky surface waves, quasi-longitudinal leaky surface acoustic waves and so on. Some orientations for such waves on Lithium Tantalate are known, for example, orientations in X cut. Some calculated orientations are presented in particular in works [1] – [2] and some results of experimental investigations of orientation 90^o, 90^o, 31^o are presented in work [3].

In this work, calculations of quasi-longitudinal pseudo-surface acoustic waves for all the Euler angles were performed. Ranges in which such waves exist were found. It is shown, that propagation characteristics of these waves are not suitable for practical usage in almost all ranges of existence (large propagation attenuation, low electromechanical coupling coefficient). But in some separate small regions propagation characteristics are relatively good. These orientations are presented in this work.

II. RANGES OF EXISTENCE

In order to investigate the propagation characteristics of HVPSAWs calculations in ranges of Euler angles $0^o \leq \phi \leq 30^o$, $0^o \leq \theta \leq 180^o$, $0^o \leq \psi \leq 180^o$ were performed. These ranges contain full information because of symmetry properties of a $LiTaO_3$ crystal (3m symmetry group). Calculations were done with 10^o step for the first Euler angle ϕ and with 5^o step for the second angle θ and the third angle ψ. The Campbell and Jones technique [4] and a method of searching for a global minimum of a multi-variable function [5] were used. Material constants for $LiTaO_3$ were taken from work [6] and temperature coefficients from [7] and [8] were used.

It is well known, that HVPSAWs exist only in some regions of cuts and orientations and do not exist in others. A computer program, which was made in a visual programming medium, Borland C++ Builder, provides visualization of a target function in its work window and gives possibility to watch the existence or nonexistence of a solution for every concrete combination of Euler angles. So ranges of Euler angles, over which HVPSAWs exist, were set rather exactly. Regions of existence of these waves are shown in contour maps in Figs. 1 – 4 for Euler angles ϕ = 0^o, 10^o, 20^o and 30^o respectively. Ranges, in which solutions do not exist, or present surface skimming bulk waves (SSBW), are shaded by red inclined lines in these contour maps.

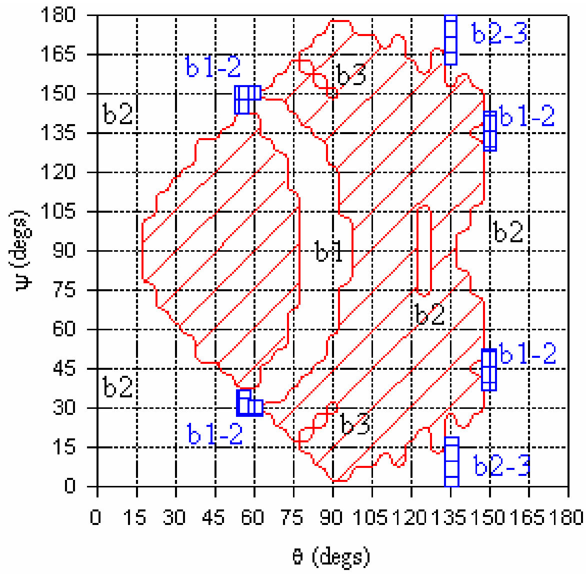

Figure 1: Ranges of existence and nonexistence of HVPSAWs for $\phi = 0^o$.

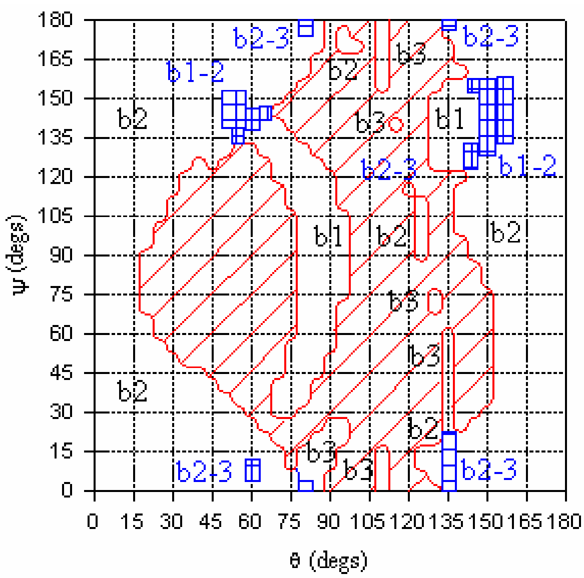

Figure 2: Ranges of existence and nonexistence of HVPSAWs for $\phi = 10^o$.

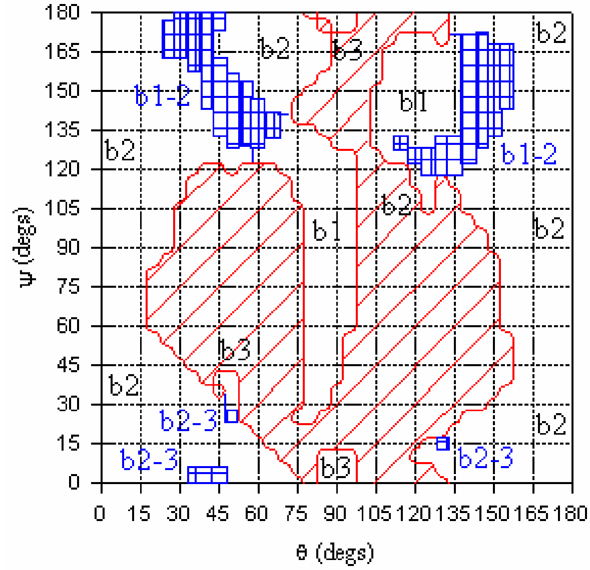

Figure 3: Ranges of existence and nonexistence of HVPSAWs for $\phi = 20^o$.

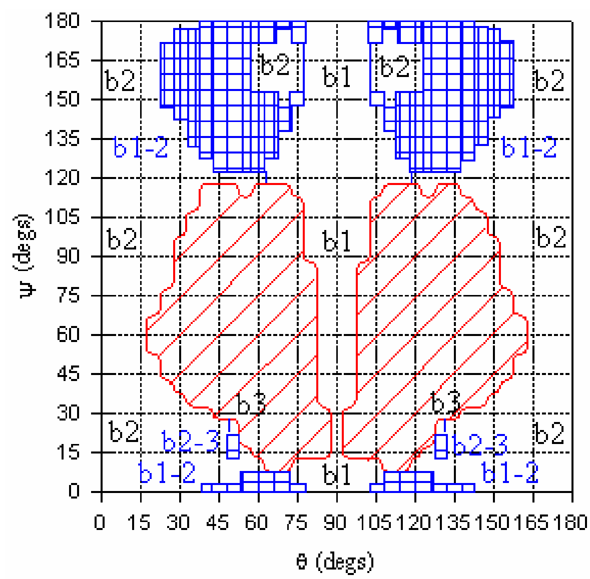

Figure 4: Ranges of existence and nonexistence of HVPSAWs for $\phi = 30^o$.

Three branches of solutions were found. The first branch corresponds to interval of velocities from about 5.5 km/s to 6.5 km/s, the second branch presents solutions with velocities from about 6.6 km/s to 8.6 km/s. The third branch contains some exotic solutions with velocities from about 8.7 km/s up to about 21 km/s. Ranges, corresponding to these branches, are marked by “b1”, “b2” and “b3” in Figs. 1 – 4. There are some orientations, in which two different branches exist simultaneously. Such orientations are shaded by blue horizontal and vertical lines and are marked by “b1-2” (branches 1 and 2) and “b2-3” (branches 2 and 3) in Figs. 1 – 4.

Additional short blue lines show borders between two branches in places where they do not overlap with each other. Existence of different branches makes it impossible to draw contour maps of propagation characteristics, because two-dimensional contour maps cannot show two and more different branches simultaneously. Two-dimensional presentation is possible only for one branch.

III. Some Results

The most promising for practical use is the first branch because of relatively low propagation attenuation δ and rather high electromechanical coupling coefficient K^2. In particular, quite good propagation characteristics can be obtained in region of Euler angles $\phi = 30^o$, $\theta = 75^o – 105^o$, $\psi = 120^o – 150^o$ (or 90^o, 75^o - 105^o, 30^o – 60^o) – see Fig. 4. Propagation characteristics in this region are shown in Figs. 5 – 9.

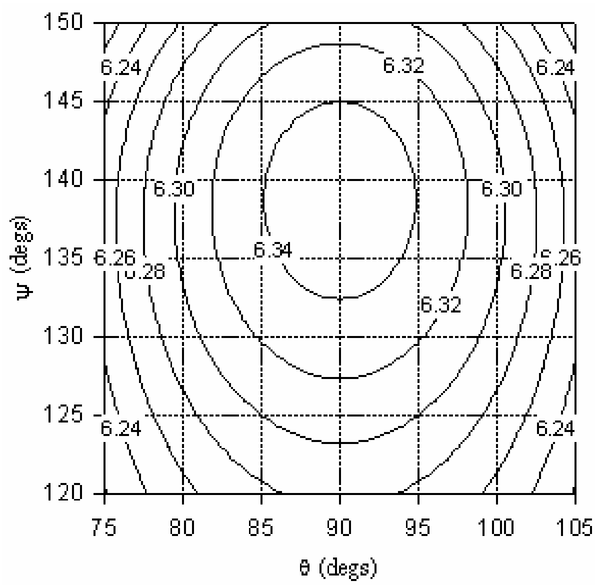

Figure 5 Contour map of phase velocity V_o (km/s) on open surface.

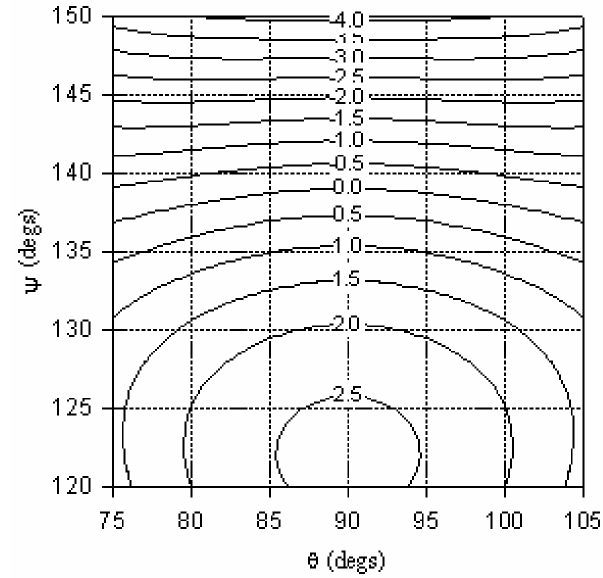

Figure 7. Contour map of power flow angle pfa on open surface (degs).

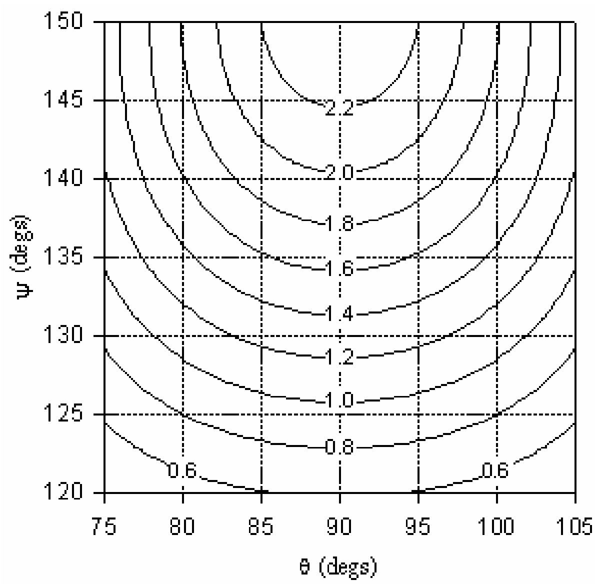

Figure 6. Contour map of K^2 (%).

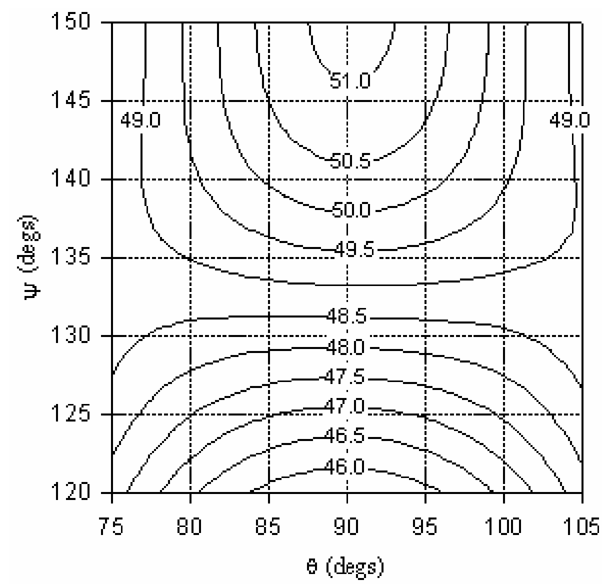

Figure 8. Contour map of temperature coefficient of delay tcd on open surface (ppm/^{o}C).

These contour maps show, that the maximum of velocity and zero pfa in this region correspond to orientations near about 30^o, 90^o, 138^o, but the maximum of K^2 and low propagation attenuation correspond to orientation near 30^o, 90^o, 149^o (or 90^o, 90^o, 31^o). This orientation was investigated experimentally in [3].

Other region, corresponding to rather good propagation characteristics, is about $\phi = 20^o$, $\theta = 105^o - 120^o$, $\psi = 135^o - 150^o$ (see Fig. 3).

In particular, for orientation (20^o, 105^o, 150^o) V_o = 6.2993 km/s, K^2 = 2.32 %, pfa = -4.52^o, $\delta_o = 4 \cdot 10^{-5}$ dB/λ, tcd = 51.1 ppm/^{o}C.

The second branch corresponds to higher velocities and higher K^2 (about 9% - 12%), than the first branch, but propagation attenuation is very large in this branch for almost all the orientations (about 1-2 dB/λ), therefore almost all these waves are not suitable for practical use. But for orientations near (10^o, 120^o, 115^o) propagation attenuation drops significantly in this branch. In particular, for orientation (10^o, 120^o, 112^o) V_o = 7.3936 km/s, K^2 = 6.06%, pfa = 2.67^o, δ_o = $2 \cdot 10^{-3}$ dB/λ, tcd = 65.2 ppm/^{o}C.

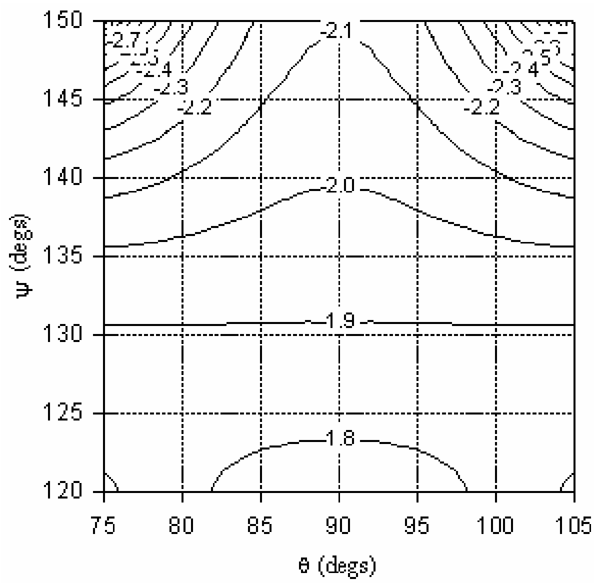

Figure 9. Contour map of propagation attenuation on open surface [lg(δ_o in dB/λ)].

The value of tcd in the first branch is not good (about 50 ppm/^{o}C), but in the second branch some orientations can be found in which tcd is rather small. But such orientations correspond to large propagation attenuation. For example, orientation (20^o, 75^o, 0^o) corresponds to the following propagation characteristics: V_o = 7.9296 km/s, K^2 = 2.91%, pfa = -1.5^o, δ_o = 0.44 dB/λ, tcd = 3.4 ppm/^{o}C. This result for tcd corresponds to Smith's temperature coefficients [7]. Other coefficients may give different results. For example, according to Taziev's coefficients [8] tcd = 35.8 ppm/^{o}C for this orientation. It is interesting to note that for almost all the other orientations both the coefficients mentioned give close results, but for this orientation these results differ significantly.

The third branch gives solutions with extremely high velocities and very large K^2 (up to 20%), but all the other propagation characteristics (pfa, tcd and propagation attenuation) are very poor. Besides not all solutions of this branch are quasi-longitudinal waves. Transverse component of the displacement (shear or normal) predominates in some of them. It is doubtful that waves representing these exotic solutions exist in nature.

Finally it should be noted that for all three branches rather wide ranges of solutions exist, for which, velocity on short-circuited surface is larger than that on free surface.

IV. CONCLUSION

Calculations of quasi-longitudinal pseudo-surface acoustic waves on $LiTaO_3$ are performed for all possible cuts and orientations. All the ranges of existence and nonexistence of these waves are shown on the two-dimensional contour maps. Three branches of solution were found. Some concrete orientations, corresponding to relatively good propagation characteristics, are presented.

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