TEMPERATURE STABLE PSEUDO-SURFASE ACOUSTIC WAVES ON LITHIUM TANTALATE

V. I. Cherednick* and M. Y. Dvoesherstov
Nizhny Novgorod State University
Russia, 603950, N. Novgorod, Gagarin av. 23

Abstract – Full contour maps of basic propagation characteristics of pseudo-surface acoustic waves on $LiTaO_3$ are calculated and plotted. Orientations, in which temperature stable pseudo-surface acoustic waves exist, were found. In particular this is a range of Euler angles $\phi = 30^o$, $\theta = 30^o$ - 40^o, $\psi = 116^o$ - 125^o.

I. INTRODUCTION

The Lithium Tantalate is one of the widely used materials for Surface Acoustic Wave (SAW) device designs. Almost all the characteristics of SAW in this crystal are very good. In particular, orientations with rather large electromechanical coupling coefficient (about 1%) and zero Power Flow Angle (PFA) can be found. Moderately high phase velocity of SAW (about 3 km/s) is disadvantageous from point of view of high frequency device applications. But there are some orientations, for which Pseudo-Surface Acoustic Waves (PSAW) with phase velocity about 4 km/s and very low propagation attenuation (10^{-6} – 10^{-4} dB/λ and even lower, where λ is the wavelength) exist.

The single disadvantage of the Lithium Tantalate is its bad temperature stability. There are no orientations, for which SAWs with zero Temperature Coefficient of Delay (TCD) exist. Minimal value of TCD is about 25 ppm/^{o}C and corresponds to a well-known orientation, defined by Euler angles $\phi = 90^o$, $\theta = 90^o$, $\psi = 112^o$. For widely used orientations with PSAWs, such as 36^{o}YX cut and 42^{o}YX cut, TCD is worse by about two times.

In this work, orientations on $LiTaO_3$, in which temperature stable PSAWs exist, were found. For example, this is a range of Euler angles $\phi = 30^o$, $\theta = 30^o$ - 40^o, $\psi = 116^o$ - 125^o (or $\phi = 90^o$, $\theta = 140^o$ – 150^o, $\psi = 55^o$ – 64^o). In this range of orientations PSAWs with small and even zero TCD exist. All the rest of propagation characteristics of PSAWs for these orientations are worse than for known cuts. The electromechanical coupling coefficient is about 0.1%, propagation attenuation – about 0.005 – 0.05 dB/λ, and PFA is about 5^o (plus or minus for $\phi = 90^o$ or $\phi = 30^o$, respectively). But in a case where temperature stability is the most important property of a device, orientations with a zero (or small) TCD can be used for practical device designs, if the distance between IDT's is kept small to minimize propagation attenuation.

II. CONTOUR MAPS

In order to investigate the propagation characteristics of PSAWs calculations in ranges of Euler angles $0^o \le \phi \le 30^o$, $0^o \le \theta \le 180^o$, $0^o \le \psi \le 180^o$ 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. A Campbell and Jones technique [1] and a method of searching for a global minimum of a multi-variable function [2] were used. Material constants for $LiTaO_3$ were taken from work [3] and theirs temperature coefficients – from work [4].

It is well known, that PSAWs exist not for any cuts and orientations. A computer program, which was made in a visual programming medium Borland C++ Builder, has got a visualization of a target function in its work window and gives possibility to watch the existence or non-existence of a solution for every concrete combination of Euler angles. So ranges of Euler angles, over which PSAWs exist, were set rather exactly. All the propagation characteristics – phase velocity, electromechanical coupling coefficient K^2, power flow angle PFA, temperature coefficient of delay TCD, propagation attenuation - were drawn in contour maps, which allow to define any propagation characteristic for any combination of Euler angles easily and quickly.

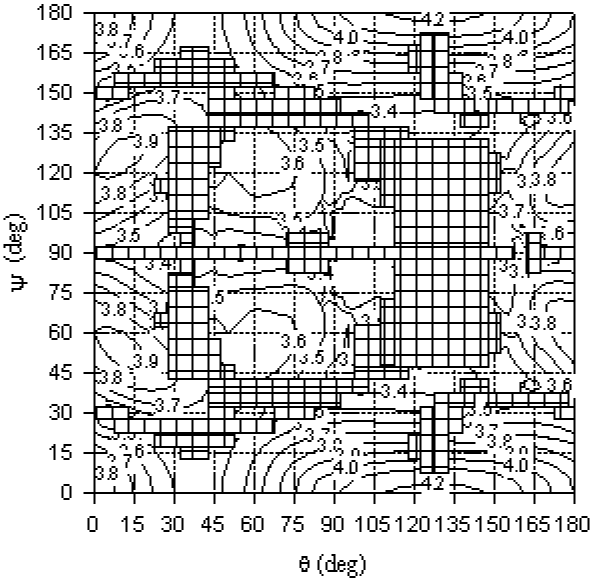

Figure 1: Phase velocity (km/s) on the open surface for $\phi = 0^o$.

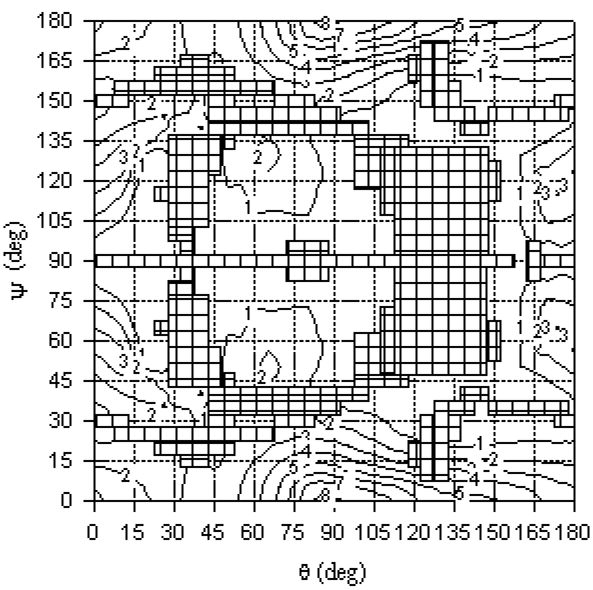

Figure 2: Coupling coefficient (%) for $\phi = 0^o$.

Ranges, in which solutions do not exist, or present surface skimming bulk waves (SSBW), are shaded in contour maps. More detailed presentation of information in contour maps and marking of regions, in which pseudo-surface waves don't exist, differentiate our results from the ones presented in [5]. Not all the contour maps are presented in this work.

Figs. 1 – 2 show contour maps of phase velocity V, and coupling coefficient K^2 for $\phi = 0^o$. Figs. 3 – 6 display contour maps of TCD for $\phi = 0^o$, 10^o, 20^o and 30^o.

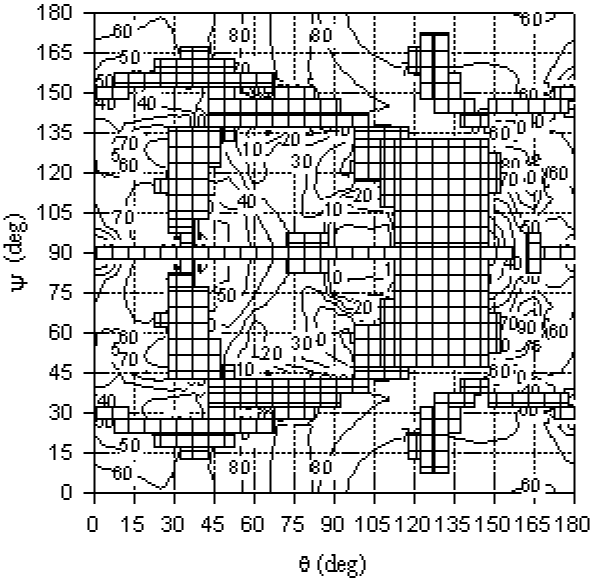

Figure 3: Temperature coefficient of delay (ppm/^{o}C) on open surface for $\phi = 0^o$.

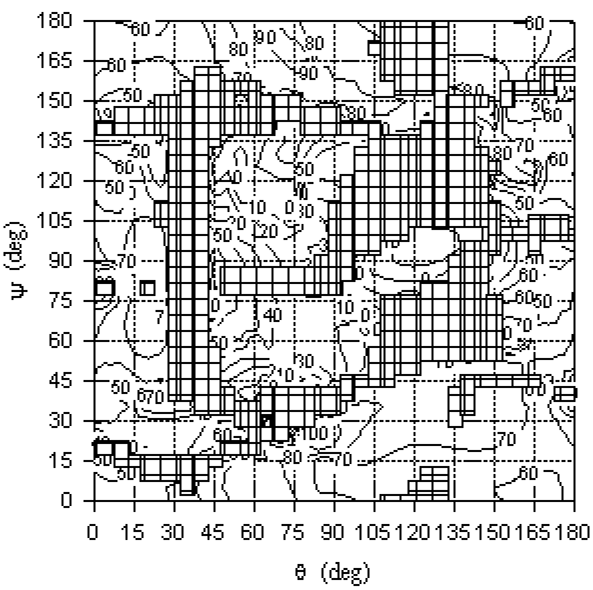

Figure 4: Temperature coefficient of delay (ppm/^{o}C) for $\phi = 10^o$.

One can see in these contour maps that there are areas, in which solution doesn't exist. Moreover, solutions for different regions of Euler angles usually belong to different branches with different properties (velocities, coupling coefficients etc.). These branches may be close each other, may even overlap each other and therefore contour lines may be non-smooth in some regions of Euler angles because it is impossible to plot two and more branches simultaneously in two-dimensional graphics (there is no such possibility in graphical software).

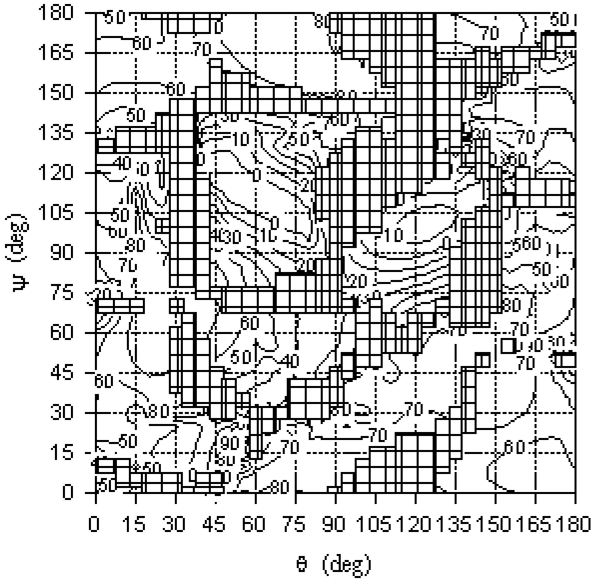

Figure 5: Temperature coefficient of delay (ppm/^{o}C) for $\phi = 20^o$.

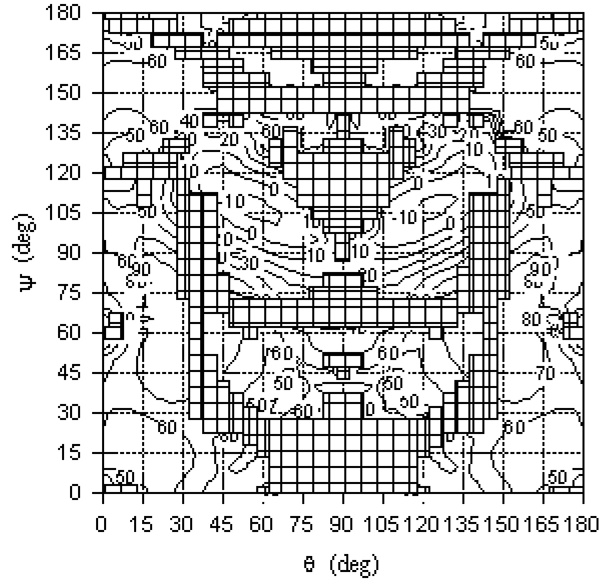

Figure 6: Temperature coefficient of delay (ppm/^{o}C) for $\phi = 30^o$.

Fortunately, such regions correspond to propagation characteristics, which are not interesting for practical applications (large propagation attenuation, small coupling coefficient, etc.).

III. TEMPERATURE STABLE ORIENTATIONS

Contour maps contain full information about all the basic propagation characteristics of pseudo-surface acoustic waves on $LiTaO_3$. In particular, contour maps show, that orientations, for which all the propagation characteristics of pseudo-surface acoustic waves are equal to their optimal values simultaneously, do not exist. Orientations in the vicinity of (0^o, 126^o –128^o, 0^o) are the most attractive from point of view of all the basic parameters, excepting TCD. Namely, the phase velocity is close to its maximal value, propagation attenuation is very small, the coupling coefficient is rather large and the power flow angle is zero for this area. Therefore, cuts in this area are widely used in SAW devices in particular the most common ones, such as, 36^oYX-$LiTaO_3$ (0^o,126^o, 0^o or 0^o, -54^o, 0^o) and 42^oYX-$LiTaO_3$ (0^o, 132^o, 0^o or 0^o, -48^o, 0^o) orientations.

A single disadvantage of these cuts is their bad temperature stability. TCD is between 60 ppm/^{o}C and 70 ppm/^{o}C as one can see in Fig. 3. Contour maps also show that there is no other orientation in which a combination of these characteristics is better than for (0^o, 126^o – 128^o, 0^o).

Figs. 3 – 6 show that there are Euler angle areas, where TCD is small or even zero (there are zero lines of TCD in these Figs). Unfortunately zero lines of TCD do not coincide with lines of large K^2, large velocity, zero PFA, and small attenuation simultaneously. One of the best combination of all the basic propagation characteristics with zero (or small) TCD can be found for $\phi = 30^o$ (see Fig. 6).

This is an area of the 2nd and the 3rd Euler angles about $35^o \le \theta \le 45^o$, $116^o \le \psi \le 126^o$. TCD and propagation attenuation for this area are presented in Figs. 7 - 8. Calculations for these contour maps were performed with 0.5^o step for both θ and ψ. Contour maps show that all the PSAW propagation characteristics in this area are worse than for 36^oYX-$LiTaO_3$ and for 42^oYX $LiTaO_3$ excepting TCD (velocity and K^2 are smaller, propagation attenuation is larger, and the PFA is non-zero).

Only in a case when the temperature stability of the SAW device is the most important characteristic and distances between IDTs are not large, orientations in this area may be more preferable than 36^oYX-$LiTaO_3$ or 42^oYX-$LiTaO_3$.

Some concrete orientations, which may be interesting from point of view of high temperature stability, are presented in a Table 1.

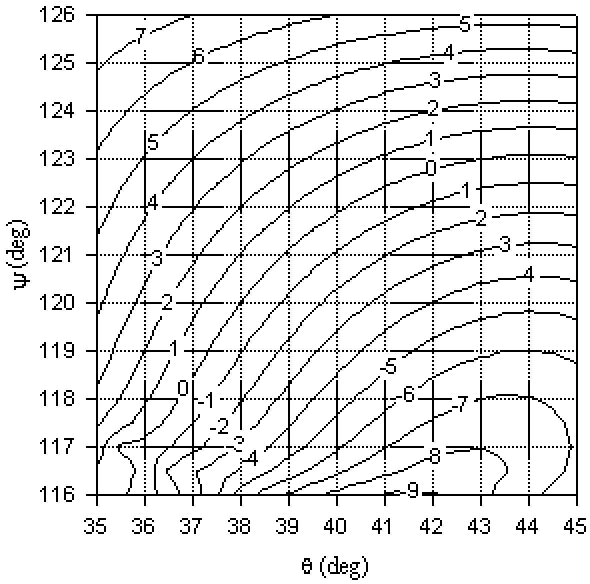

Figure 7: TCD (ppm/^{o}C) for $\phi = 30^o$, $35^o \leq \theta \leq 45^o$, $116^o \leq \psi \leq 126^o$.

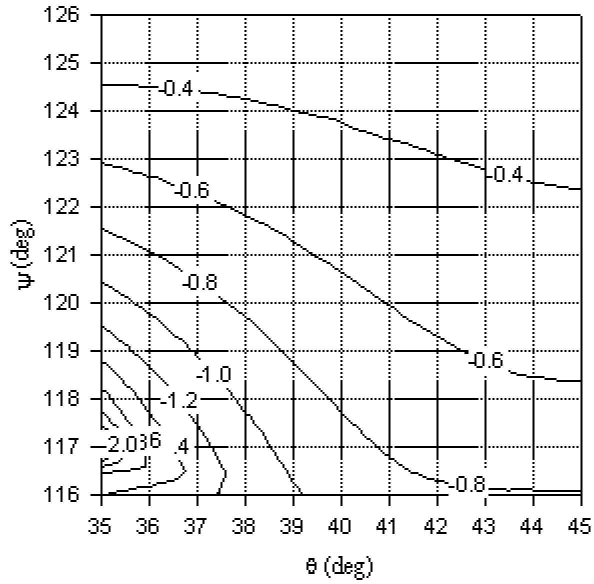

Figure 8: Propagation attenuation (lg(dB/λ)) for $\phi = 30^o$, $35^o \leq \theta \leq 45^o$, $116^o \leq \psi \leq 126^o$.

Table 1. Some orientations on $LiTaO_3$ corresponding to PSAWs with high temperature stability.

φ (deg)	θ (deg)	ψ (deg)	V_s (km/s)	V_o (km/s)	Att_o (dB/λ)	K^2 (%)	pfa(deg)	tcd(ppm/^{o}C)
10	45	123	3.72382	3.726479	0.00245095	0.143	1.589	3.5994
30	33	119	3.69063	3.692611	0.01140635	0.107	-5.708	7.4699
30	35	117	3.70572	3.706978	0.00252693	0.068	-3.749	1.372
30	36	117.5	3.7046	3.706495	0.03591342	0.102	-4.904	0.58429

IV. CONCLUSION

Full contour maps of basic PSAW propagation characteristics are calculated and drawn. Areas, where PSAWs do not exist, are marked. Areas of orientations with small and even zero TCD are shown. Some of such areas are calculated and plotted in a more detailed fashion. Some orientations with small TCD and relatively good combinations of others characteristics are presented.

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*V.I.Cherednick e-mail: odissey@sandy.ru