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Calculation of thermostable directions and the influence of bias electric field on the propagation of the Lamb and SH waves in langasite single crystal plates

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Abstract— **Paper is presented the results of computer simulation. Effect of the dc electric field influence on the propagation of Lamb and SH waves and its temperature coefficients of delay in piezoelectric langasite crystal plate for a lot of cuts and directions have been calculated. There were found the cuts possessing the thermostability and sufficient electromechanical coupling.**

Keywords- thermostability; Lamb wave; SH-wave; dc electric field influence

I. INTRODUCTION

Thermostability is one of the more important conditions which are expected for modern acoustoelectronic devices (resonators, narrow band filters, delay lines etc.). Langasite single crystals (LGS, $La_3Ga_5Si0_{14}$) and its isomorphs are of great importance for acoustoelectronic devices producing because of the combination of practically important properties such as thermostability, small attenuation of acoustic waves and a good electromechanical coupling in comparison with quartz [1, 2]. Application of piezoelectric crystals having the acoustic modes with low temperature coefficients and a small level of the elastic and other kinds of nonlinearities should be a good practice. So there are such devices as resonators using bulk (BAW) or surface (SAW) acoustic waves [3-8]. In addition langasite crystals possess a good chemical stability and a lack of any phase transitions up to melt point (1470 °C). Last circumstance gives a possibility of high temperature devices fabrication [9-13]. On other hand, the possibility to control and change the electromechanical properties of piezoelectric crystal by external influences such as an electric field or mechanical pressure gives us a potential to produce the controlling devices for example, the different types of acoustoelectronic sensors. As a rule, the best results for acoustoelectronic sensors can be obtained if it will be found an optimum combination of three factors: sensitivity, thermostability and good electromechanical coupling. For example, a general approach to the analysis of the acceleration sensitivity of SAW resonators has done in the paper [14] on the basis of the perturbation theory of acoustic wave's propagation under the influence of finite bias fields, given by H.F. Tiersten [15]. Some applications of this theory for purposes of experimental investigations of the complete set of nonlinear electromechanical properties of sillenite and langasite piezoelectric crystals have made by authors [16, 17]. The influence of the dc electric field, mechanical stress and temperature variation on BAW and SAW propagation in langasite single crystals has been considered in [18, 19]. Calculation of the dc electric field influence on the Lamb and surface horizontal (SH) waves propagation in $Bi_{12}GeO_{20}$ piezoelectric crystal has made earlier [20]. In present paper the anisotropy of zero-order Lamb wave parameters under the action of dc electric field and the thermostable cuts and directions of these waves in langasite crystals have been investigated.

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II. SEARCH OF THERMOSTABLE CUTS AND INVESTIGATION OF ANISOTROPY OF DC ELECTRIC FIELD INFLUENCE ON LANGASITE PIEZOELECTRIC PLATE WAVES PARAMETERS

Computer simulation of anisotropy of dc electric field influence on the Lamb and SH waves parameters of LGS piezoelectric plate has made on the basis of the theory and dispersive equations, given earlier [20-22]. Calculation of such wave parameters as phase velocities v_i and v_{im} for the free and metalized surface respectively, the square of electromechanical coupling coefficient (EMCC)

$$K^2 = 2\frac{v_i - v_{im}}{v_i}, \qquad (1)$$

controlling coefficients of phase velocities by the action of dc electric field E

$$\alpha_{v_i} = \frac{1}{v_i(0)}\left(\frac{\Delta v_i}{\Delta E}\right)_{\Delta E \to 0} \qquad (2)$$

and temperature coefficients of delay (TCD)

$$TCD_i = \alpha_{11} - \frac{1}{40}\frac{v_i(40°) - v_i(0°)}{v_i(20°)} \qquad (3)$$

for a lot of crystal directions has been carried out by our software. Quantity α_{11} in the equation (2) represents an efficient coefficient of linear thermal expansion along the wave's propagation direction. Only zero-order modes were taken into account that corresponds to the thin plate condition. Data on material linear and nonlinear electromechanical properties and its temperature coefficients of LGS crystals were taken from [23, 24].

Wave parameters were calculated for the (001), (100), (010) crystal cuts and for a more complicated cuts such as rotated Y- and Z-cuts which are of great practical importance. It was important to take into account the dispersive dependences all of the Lamb and SH wave's parameters on the h×f product where h is the plate thickness and f is the frequency. It was supposed that dc electric field was applied along X_1, X_2 and X_3 axes of special Cartesian coordinate system in which the X_1 axis coincides with wave's propagation direction $\vec{N}$ and the X_3 axis is parallel to the unit vector $\vec{n}$ normal to free plate surface.

TABLE I. LAMB AND SH MODES PARAMETERS OF LANGASITE INCLUDING DC ELECTRIC FIELD INFLUENCE

Cut	Angle φ, deg.	Mode	Phase velocity, m/s	h×f, m/s	K^2, 10^{-3}	TCD, 10^{-6} K^{-1}	$\alpha_v, 10^{-12}$ m/V		
							E‖X_1	E‖X_2	E‖X_3
Z-cut	15; 165	A_0	2190.2	1000	1.22	-0.97	28.2 -31.2	-1.4	12.6 -13.0
	15; 165	SH_0	2744.5	1500	4.73	-0.76	6.0 -4.8	42.5	-19.8 19.4
	63; 117	S_0	4871.1	1500	6.45	8.70	16.6 -17.1	2.6	2.2 -2..4
Y-cut	48; 132	A_0	1791.6	500	1.13	0.72	3.2 -4.0	0.8	26.7 -27.9
	90	SH_0	2920,8	500	1.61	1.51	-0.1	-30.8	
	39; 141	S_0	4759.1	1500	2.28	0.00	-25.8 24.4	-20.0	35.8 39.2
X-cut	60	A_0	2198.5	1000	3.48	0.57	-0.6	-0.2	-22.8
	51	SH_0	3235.1	500	3.19	0.87	-0.5	-0.5	-30.2
	90	S_0	4605.7	1500	6.05	0.46	-0.1	-0.6	-39.6
55° Y-cut	66	SH_0	2968.4	500	1.71	0.00	22.8	7.8	66.4
15° Y-cut	171	S_0	4928.6	500	9.32	-0.10	43.6	-15.6	1.1

Fig. 1 represents the angle dependence of parameters for the waves propagating in the Y-cut, and there are taken into account the dispersive dependences for three h×f product values. As an example on Fig. 1b it can see α_v coefficients anisotropy when dc electric field coincides with X_3 axis. Comparison of the results on Fig. 1c and Fig. 1d gives us a possibility to choice the cut's orientation combining thermostability and efficient electromechanical coupling for some modes. Wave's propagation parameters for one of rotated cuts are presented on Fig. 2. A thermostable directions exist for all the modes, in particular for 35° Z-cut and $\psi = 63°$ there is $TCD = 5.8 \cdot 10^{-08}$ K^{-1} and $K^2 = 0.67\%$ for SH_0 mode if h×f = 1000 m/s; for 35° Z-cut and $\psi = 15°$ there is $TCD = 1.5 \cdot 10^{-07}$ K^{-1} and $K^2 = 0.24\%$ for A_0 mode. Note that there exists a strong dependence of parameters on the plate thickness for such modes as A_0 and S_0 in comparison with SH_0 mode. Summary of the most interesting cuts has resulted in the Table I.

CONCLUSION

Using the data Table 1 and Fig. 1 and 2 it can conclude that in langasite there are some Lamb and SH modes possessing the thermostability and sufficient electromechanical coupling. Estimation of dc electric field influence indicates that E variation may cause a delay's change which can compensate the temperature fluctuations of these modes' velocities. It should be noted that thermostability of Lamb and SH modes has a strong dependence on h×f product.

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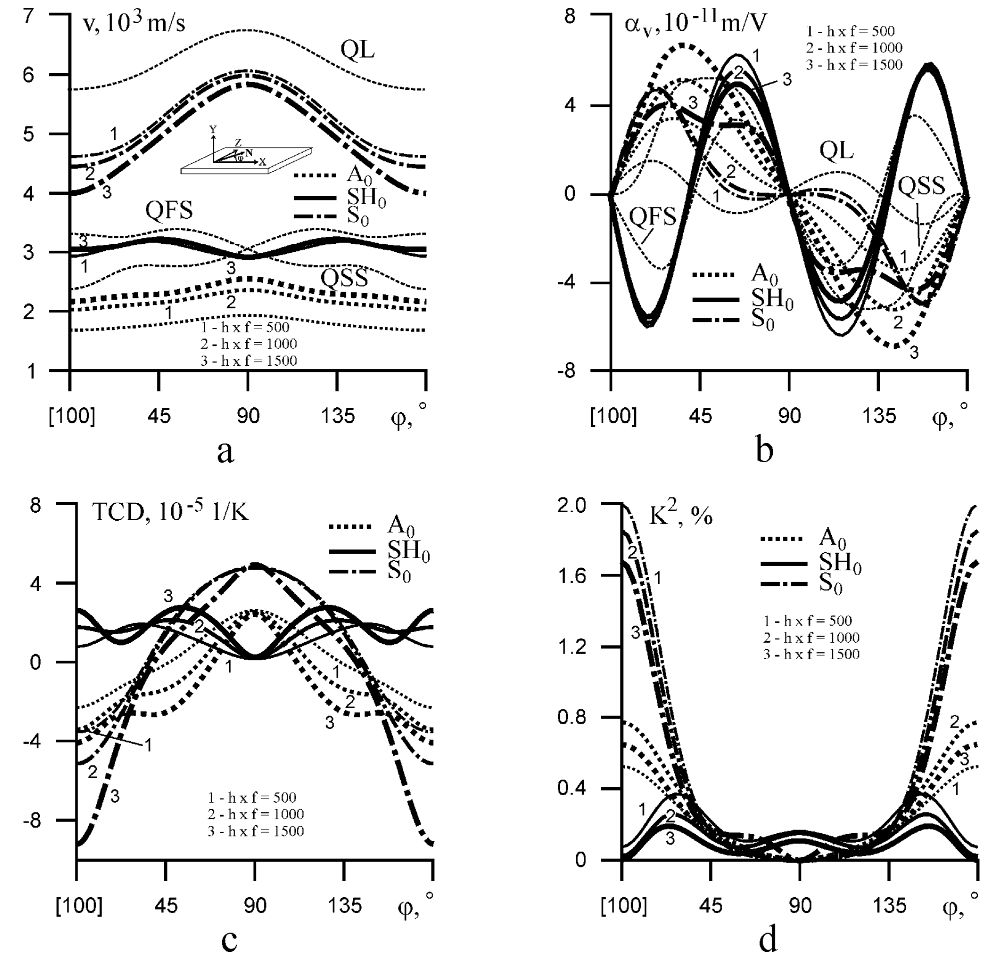

Figure 1. BAW, Lamb and SH wave's parameters for Y-cut of langasite crystal plate: a) phase velocities; b) α_v coefficients when $E||X_3$; c) temperature coefficients of delay; d) electromechanical coupling coefficients.

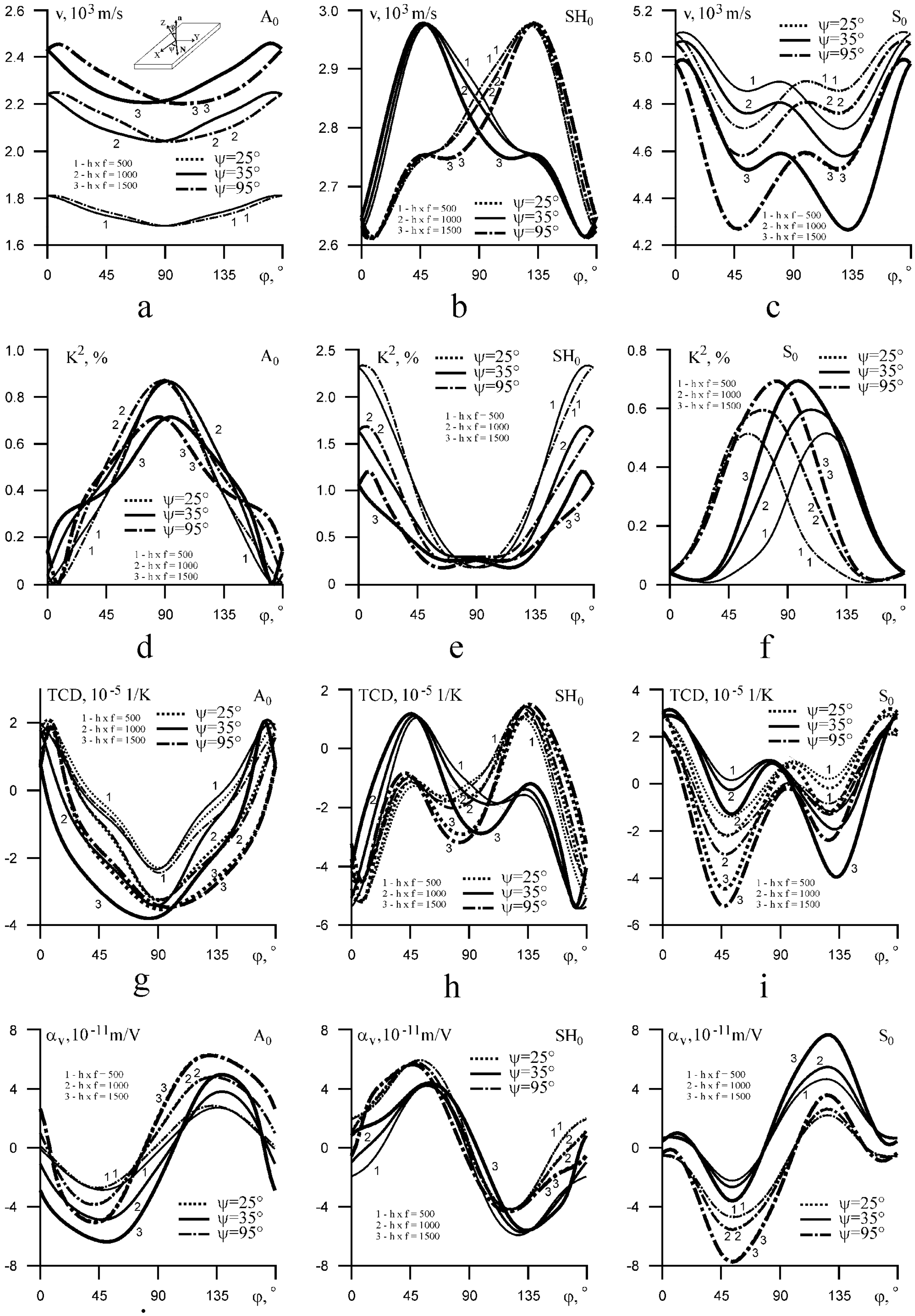

Figure 2. Zero order Lamb and SH wave's parameters for rotated Z-cuts of langasite crystal plate: a-c) phase velocities; d-f) electromechanical coupling coefficients; g-i) temperature coefficients of delay; j-l) α_v coefficients when $E||X_1$