ON THE INFLUENCE OF SUBSTRATE STRAIN ON SURFACE ACOUSTIC WAVE SELF-COLLIMATION DEGREE

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1. INTRODUCTION

The dependence of surface acoustic wave (SAW) phase velocity on propagation direction has the large significance for SAW devices. The self-collimation phenomenon existing at some angle dependencies of SAW velocity can be used for decreasing diffraction losses. The directions where the phase and group velocity vectors are collinear are used to prevent the shift of SAW beam Ref. 1. SAW device substrates can have various strains due to external factors. It influences self-collimation degree amongst other parameters.

The changes of SAW phase velocity angle dependencies for Z direction of YZ cut $LiNbO_3$ substrate at various strains are researched in this work. This direction is characterized by the presence of self-collimation that increases Fresnel region for about 10 times.

2. ANALYSIS

The motion equations for prestrained substrate are used for calculating SAW velocities Ref. 2.

$$\frac{\partial}{\partial x_i}(\sigma_{ik} u_{j,k} + T_{ij}) = \rho \ddot{u}_j \qquad (1)$$

where σ_{ik} – is the initial stress, ρ – the mass density, u – the mechanical displacement and T – the stress. Substrate constant tensors are referred to the coordinate system shown in fig.1, where x_1 – is in the direction of SAW propagation, and the subscripts i, j, k, l take on the values 1, 2, 3. The summation convention for repeated indices is employed. Differentiation with respect to time and space are designated by a dot and an index preceded by a comma, respectively.

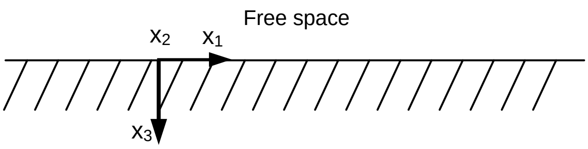

Fig. 1. Coordinate system.

In addition to the equations (1) for $x_3 > 0$ at $-\infty \le x_3 \le 0$ the following equation must be satisfied

$$\nabla^2 \varphi = 0 \,, \qquad (2)$$

together with appropriate boundary conditions at $x_3 = 0$ и $x_3 = -\infty$. Assuming zero traction force at the free crystal surface, the mechanical boundary conditions are Ref. 1

$$(\sigma_{3k} u_{j,k} + T_{3j})\big|_{x_3=0} = 0, \qquad j = 1,2,3. \qquad (3)$$

The boundary conditions on the electric potential are the continuity of φ at $x_3 = 0$, and $\varphi(-\infty) = 0$. Also the normal component of electrical displacement must be continuous across the surface of the crystal.

The transcendental equation obtained by setting the determinant of this system equal to zero determines the allowable surface wave velocities.

The changes of elastic constants caused by substrate strain are taken into account with using the third order elastic constants c_{ijk} (abbreviated matrix notation) Refs 3, 4:

$$c'_{ij} = c_{ij} + c_{ijk}\eta_k, \qquad i, j, k = 1-6, \qquad (4)$$

where η_k is the Lagrangian strain. For small strains, the Lagrangian strains are replaced by Euler strains s_k.

The changing if mass density caused by strain is calculated as following Ref. 5:

$$\rho_1 = -\rho_0(s_1 + s_2 + s_3)\,. \qquad (5)$$

The SAW phase and group velocity vectors angle is defined as Ref.1

$$\varphi = \arctan\left(\frac{1}{v}\frac{dv}{d\theta}\right) \qquad (6)$$

3. COMPUTED RESULTS

The calculation was made for tension strains (s11, s22, s33) and shift strains (s12, s13, s23). The strains are denoted in relative units (microstrain = 10^{-6}). The results are shown in figures 2-7 as SAW velocity differences, and as the differences of angles between phase and group velocity vectors for various directions θ in the range from –10 to +10 degrees in relation to Z direction Y-cut $LiNbO_3$ at prestrained v_s, φ_s and unstrained v_o, φ_o condition $v_d = v_s - v_o$, $\varphi_d = \varphi_s - \varphi_o$.

You can see in the diagrams, the strains s11 (fig. 2), s22 (fig. 3), s33 (fig. 4), and s13 (fig. 5) cause velocity change without shifting the direction of phase and group velocity vectors collinearity. The largest degree and uniformity of changing are caused by s33 in the given angle range. The largest changing of velocity dependence curvature is caused by s11. The last results in changing the angles between energy flow vector and phase velocity vector for different directions, and therefore in changing the self-collimation degree. s12 and s23 strains cause shifting the direction of phase velocity and energy flow vectors collinearity. It causes shifting the direction of excited SAW beam.

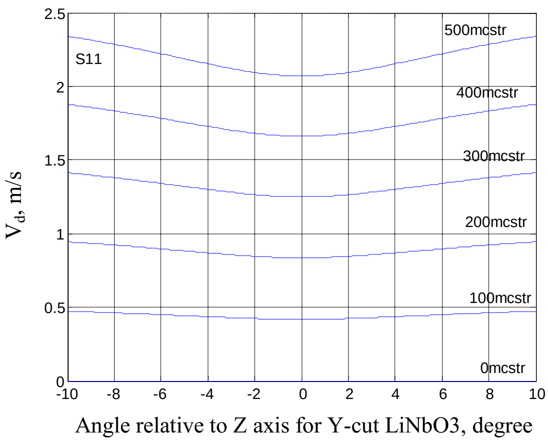

Fig. 2(a) v_d at different s11

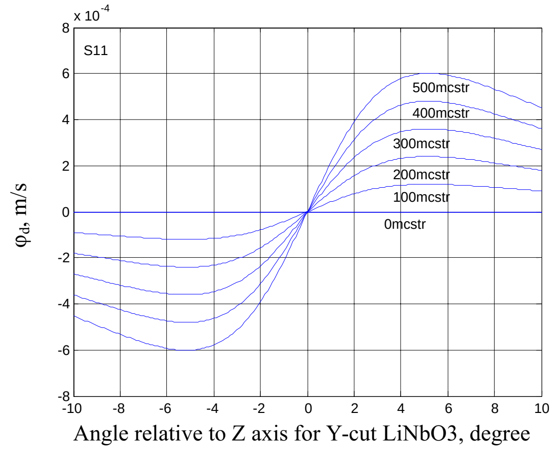

Fig. 2(б) φ_d at different s11

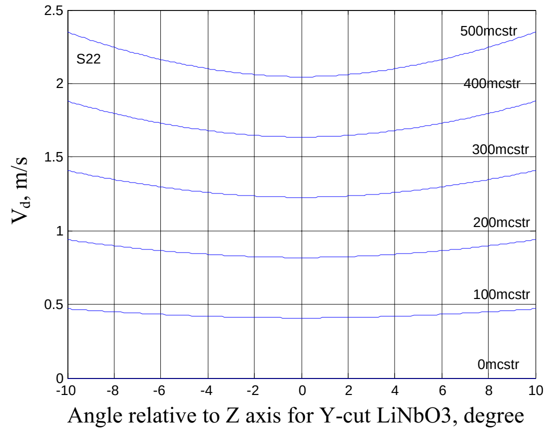

Fig. 3(a) v_d at different s22

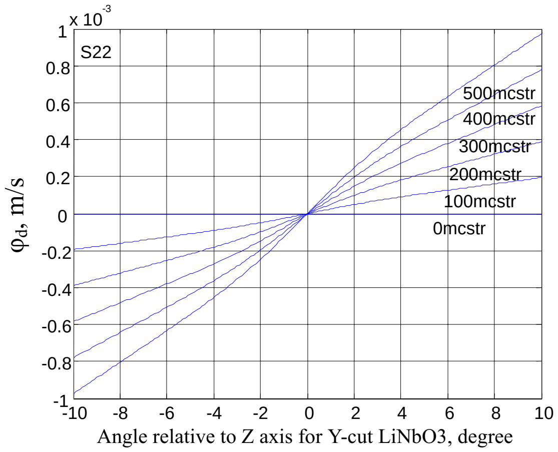

Fig. 3(б) φ_d at different s22

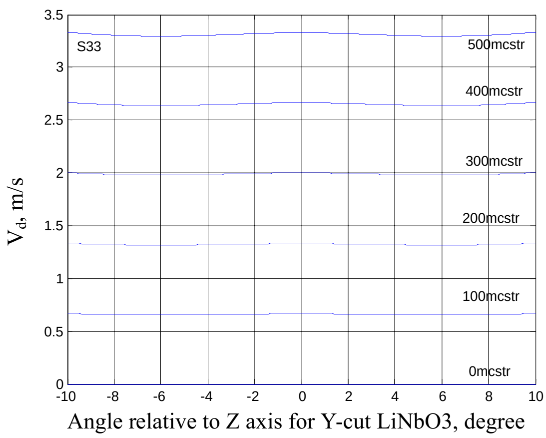

Fig. 4(a) v_d at different s33

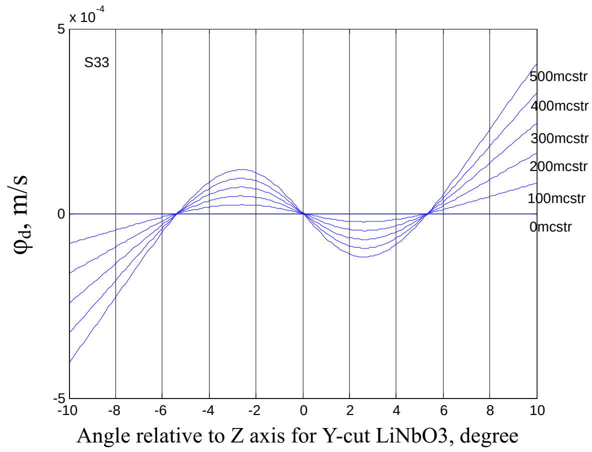

Fig. 4(б) φ_d at different s33

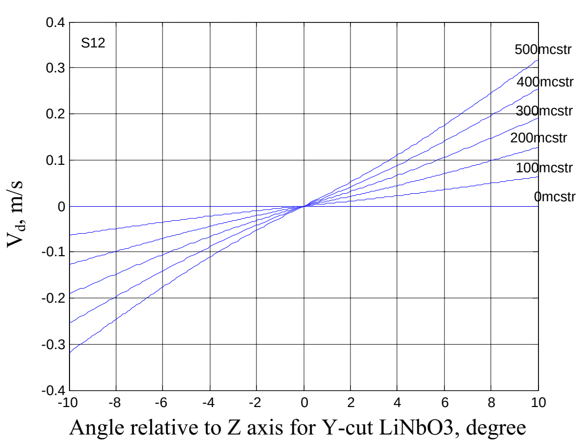

Fig. 5(a) v_d at different s12

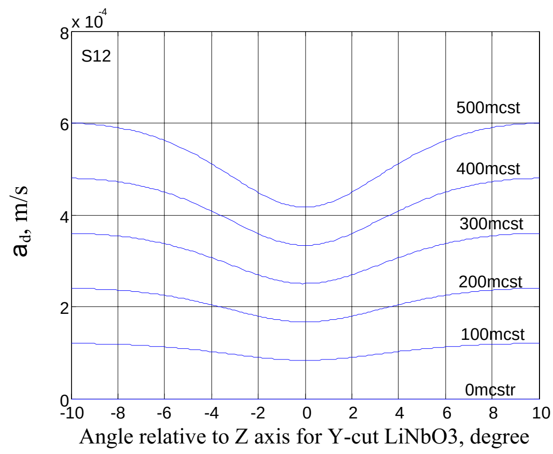

Fig. 5(б) φ_d at different s12

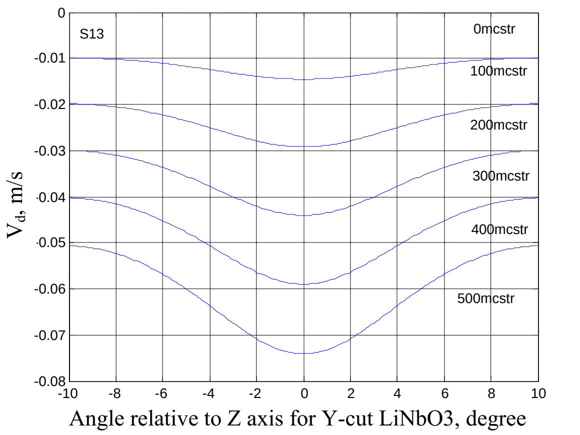

Fig. 6(a) v_d at different s13

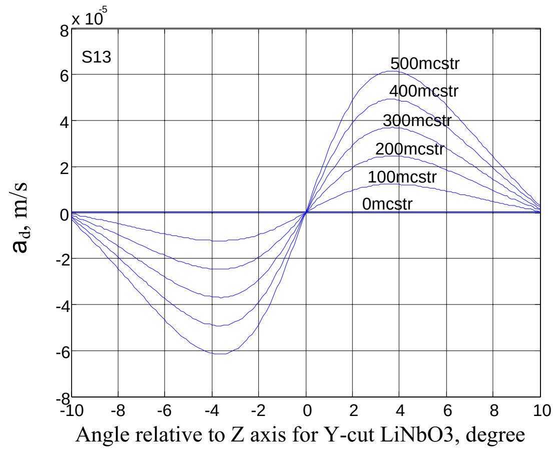

Fig. 6(б) φ_d at different s13

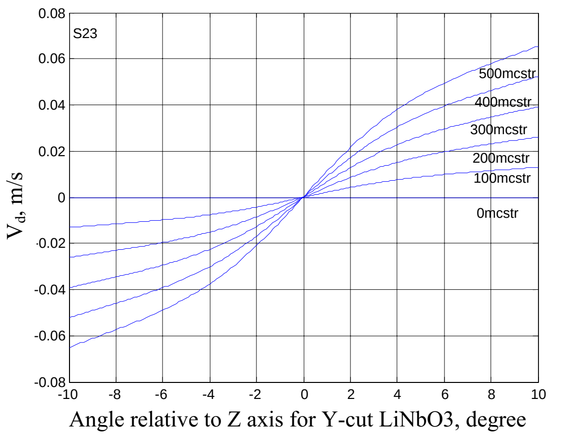

Fig. 7(a) v_d at different s23

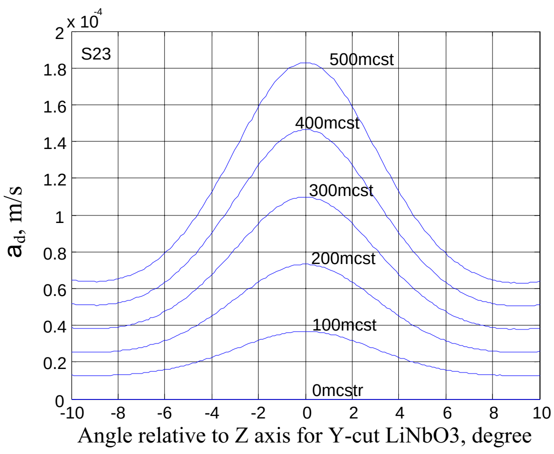

Fig. 7(б) φ_d at different s23

Diagrams in figs. 8 – 10 illustrate the changing of SAW acoustic field of interdigital transducer (IDT) at different distances (100 and 1000 wavelengths from transducer's axis). IDT aperture is 10 wavelengths. SAW field distribution at distance 1000λ and strain of -500 microstrain in compare with SAW field distribution in unstrained substrate is shown in fig.8. As it is seen from compare, SAW beam is less influenced by diffraction in compressed substrate. At hydrostatic pressure it is possible to get a condition at which SAW beam much better keeps the shape of amplitude distribution at long distance. It is illustrated in fig. 10. The expected shift of SAW beam at strain s12 is shown in fig. 9.

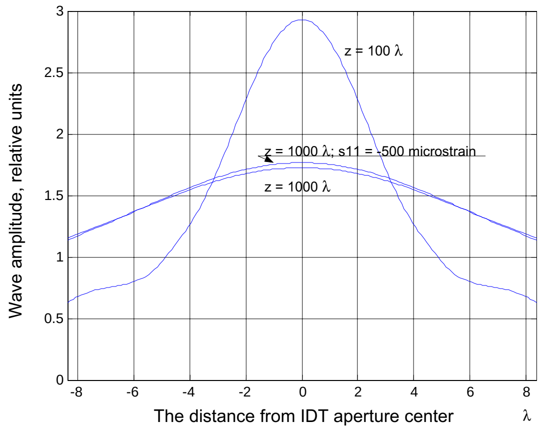

Рис. 8 SAW amplitude distributions at different distances from IDT axis (aperture 10λ).

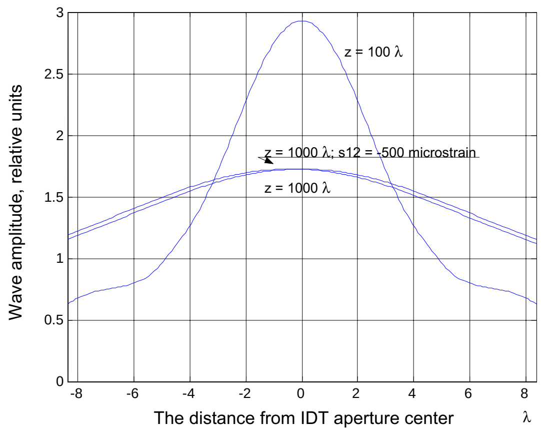

Рис. 9. SAW amplitude distributions at different distances from IDT axis (aperture 10λ) at shift strain s12

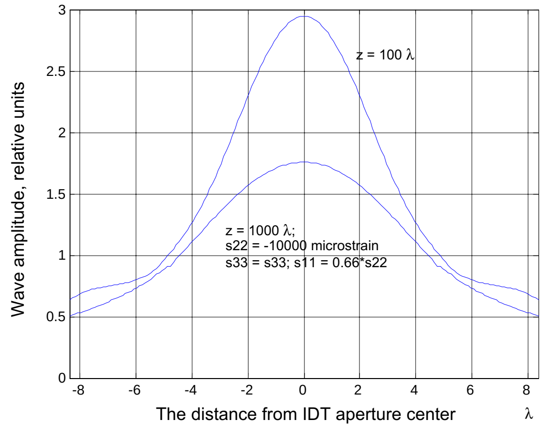

Рис. 10. SAW amplitude distributions at different distances from IDT axis (aperture 10λ) at hydrostatic strain.

4. CONCLUSION

The influence of substrate strain on self-collimation degree is not significant for most applications. But it can be used for increasing the self-collimation degree. It is possible to suppose the existence of substrates where strain has much influence on self-collimation degree.

Literature

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