SLIT WAVES IN PIEZOELECTRIC STRUCTURES

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Abstract - This paper describes the slit electroacoustic waves (SEAW) propagation characteristics for some cuts in some piezoelectric structures. A process of transformation of a slit wave in a common SAW or in Lamb electroacoustic waves at increasing of a slit width H is considered too.

Keywords: surface acoustic waves, slit waves, Lamb waves, piezoelectric crystals

1. INTRODUCTION

As is known (Ref. 1), the slit electroacoustic waves (SEAW) can propagate in a system of two half-spaces, disconnected by vacuum or dielectric slit. The interest to analysis SEAW is called by that circumstance, that the given type of a wave can be used at designing of amplifiers with a low level of a noise – Ref. 2.

2. THEORY

We consider a system of two piezoelectric media between those there is a slit with arbitrary width H (see. Fig.1). A plane $X_3 = 0$ corresponds to a center of a slit. An axis X_1 coincides with a propagation direction of a wave.

The electric potential φ and the amplitudes of a mechanical displacement (u1, u2, u3) of such wave are localized near of the boundaries of two media and considerably decrease on a distance of several wave lengths from boundary in both upper and lower media. For the first time this type of waves was investigated in a work - Ref. 3 experimentally.

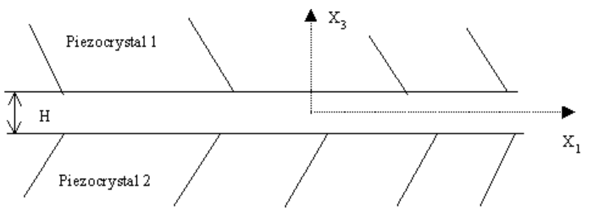

Fig.1. A considered system.

As against of surface acoustic waves (SAW) the velocity of SEAW depends on a wavelength λ. Such dispersion is due to a presence of an element with finite size (a slit with width H) and is similar to a wave dispersion, which takes place in waveguides.

General solution for a slit wave in piezoelectric media includes two four partial SAW solutions for each medium those are coupled each other by electric boundary conditions on each boundary. There is no mechanical couple of two media and of two SAW solutions. Electric potential in a slit is defined by a Laplace equation and contains a combination of two exponential functions.

In general case a solution for SEAW outside the slit can be written as:

$$u^1_i = A_i*C_{im}*\exp(jK*\beta^1_m*X_3)*\exp[jK(X_1-V*t)] \qquad (1)$$

$$u^2_i = B_i*D_{im}*\exp(jK*\beta^2_m*X_3)*\exp[jK(X_1-V*t)]$$

Here i, m = 1 – 4, twice repeating indexes mean summarizing, $u_4 = \varphi$ - electric potential, K – a wave vector, V – a phase velocity, β_m – decay coefficient along X_3 axis, A_i, C_{im}, B_i, D_{im} – amplitudes coefficients.

Substitution of these solutions in wave equations gives Cristoffel's equations system (see Ref. 2), from that one can find values β_m, C_{im}, D_{im} for each piezoelectric medium.

One has to select coefficients β_m, corresponding to decreasing of amplitudes in a depth of each crystal.

Electric potential φ^V inside the slit must satisfy Laplace equation (see Ref. 2) and may be written in follow form:

$$\varphi^V = (\Phi_s*ch(KX_3) + \Phi_a*sh(KX_3))*\exp(jK(X_1-Vt)) \quad (2)$$

The first term describes a symmetric distribution of a potential in a slit, the second term describes antisymmetric one.

Unknown coefficients Φ_s, Φ_a, A_i, B_i can be determined from a system of 10 uniform equations, which correspond to follows boundary conditions on top and bottom boundaries of a slit:

$$\begin{array}{ll} T^1_{3i} = 0,\ \varphi^V = \varphi^1,\ D^1_3 = D^V_3 & \text{for } X_3 = H/2 \\ T^2_{3i} = 0,\ \varphi^V = \varphi^2,\ D^2_3 = D^V_3 & \text{for } X_3 = -H/2 \end{array} \qquad (3)$$

Here T_{3i}, i =1-3 – normal components of mechanical stresses tensor, φ - electric potential, D_3 – normal component of electric displacement.

It is possible to express Φ_s and Φ_a by φ^1 and φ^2 and reduce quantity of equations and an order of corresponding determinant to 8.

According to Farnell - Jones technique (see Ref. 2) one has to find a phase velocity, corresponding to zero value of determinant of a system, mentioned above.

Then can be determined all the other characteristics of a wave (group velocity, power flow angle, temperature coefficient of velocity, temperature coefficient of frequency, diffraction parameter etc.).

3. NUMERICAL EXAMPLES

Fig. 2 shows dependencies of a calculated phase velocity on a normalized slit width H/λ for antisymmetric (curve A) and symmetric (curve S) modes in a system of two identical crystals LGS(0^0,140^0,25^0) with a vacuum slit.

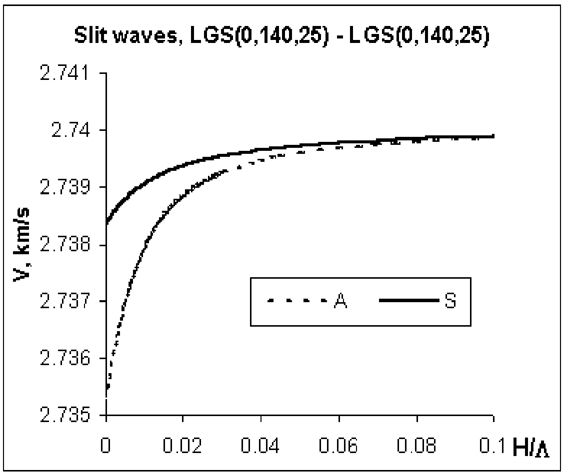

Fig. 2. Dependencies of velocity on slit width H/λ for symmetric (S) and antisymmetric (A) modes in a system LGS(0^0,140^0,25^0)/slit/LGS(0^0,140^0,25^0).

It can be shown, that S-mode corresponds to symmetric distribution of potential inside the slit in the identical media, and A-mode corresponds to antisymmetric one.

Phase velocity of mode A is less, than velocity of mode S as one can see from Fig. 2. For H/λ > 0.1 both modes transform into usual SAW (V_{SAW}=2.7399km/s), corresponding to this direction on crystal LGS(0^0,140^0,25^0).

Fig. 2 shows, that for zero slit width but without acoustic contact between two media two modes of SEAW also exist. This isn't a boundary acoustic wave in this case; boundary wave propagates without dispersion (see Ref. 4).

Calculations show that slit waves in this structure is thermostable, (TCF ≈ 0), because this direction is thermostable for SAW.

Slit waves can propagate also in a system of two different piezoelectric media, disconnected by a slit.

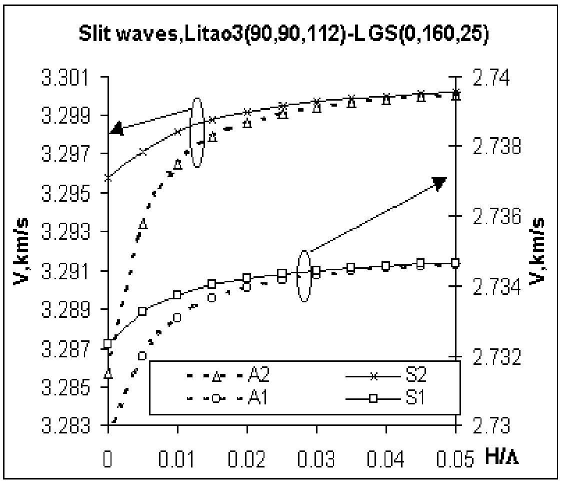

Fig. 3. Dependencies of velocity on H/λ in a system $LiTaO_3$(90^0,90^0,112^0)/slit/LGS(0^0,160^0,25^0).

Fig. 3 shows calculated dependencies of a phase velocity on a normalized slit width for symmetric and antisymmetric modes in a system of two different piezoelectric crystals: $LiTaO_3$(90^0,90^0,112^0), LGS(0^0,160^0,25^0) disconnected by slit.

In such structure symmetric and antisimmetric modes of two types can propagate. One of this type due to one boundary (A1 and S1), another type due to another boundary (A2 and S2). For H/λ > 0.05 A1 and S1 modes transform into SAW, propagating on LGS(0^0,160^0,25^0) (V_{SAW}=2.735km/s) and A2, S2 modes transform into SAW, propagating on $LiTaO_3$(90^0,90^0,112^0) (V_{SAW}=3.301km/s).

Practical interest also presents analysis of SEAW properties in systems: piezoelectric plate – slit – piezoelectric half-infinite medium and piezoelectric plate – slit – piezoelectric plate.

We consider a system, consisting from two piezoelectric plates with slit between these plates (see Fig. 4). Thicknesses of plates H1, H2 and width of a slit H are arbitrary.

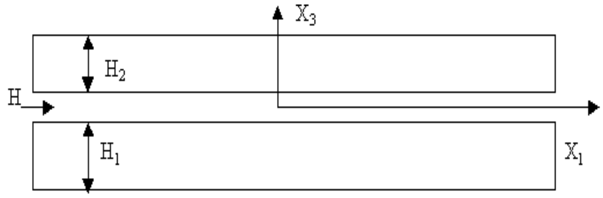

Fig.4. A considered system.

Similar to a single plate in such system can propagate many kinds (modes) of waves. In particular, if thicknesses of plates H1, H2 >> λ (λ is a wavelength) a slit wave between two half-spaces can propagate in this structure .

If thicknesses of both plates H1, H2 ≈ λ it is possible propagation of some modes, which have properties intermediate between Lamb waves and slit waves (see Refs. 2, 3). In a practical sense it is interesting to investigate a case then H2 ≈ λ and H1 >> λ because such construction may be used in many acoustic devices (amplifiers with low level of noise, acoustic sensors etc.).

A general solution for such system can be obtained by known technique of surface acoustic waves (SAW) calculation (see Ref. 2). This solution includes two eight partial SAW solutions for each medium those are coupled each other by electric boundary conditions on each slit boundary.

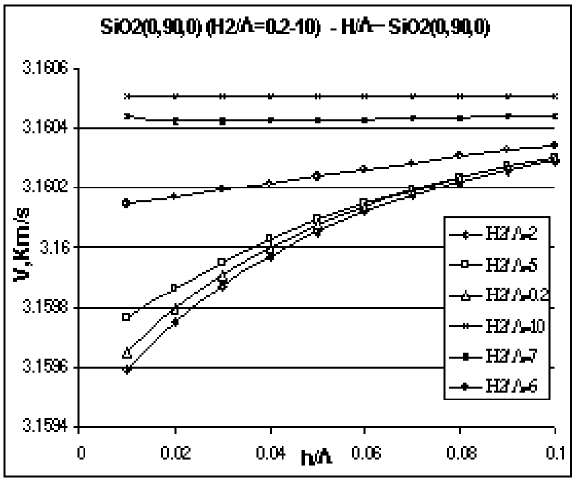

Fig.5. Dependencies of SEAW velocity on a slit width for system: YX-Quartz plate/slit/YX-Quartz half-infinite. Thickness of a plate H2/λ = 0.2, 2, 5, 6 , 7, 10.

There is no mechanical couple of two media and of two SAW solutions. Electric potential in a free space outside plates is defined by a Laplace equation and in a slit contains a combination of two exponential functions. Boundary conditions (zero value of normal components of a mechanical stress and continuity of a normal component of an electric displacement) must be formulated for each of four boundaries (totally 16 boundary condition equations or 12, if one medium is half-infinite).

Fig. 5 shows calculated phase velocities of symmetric SEAW versus slit width H/λ for system: quartz plate (YX cut) – vacuum slit – half-infinite quartz crystal (YX cut) for various thicknesses of a plate H2/λ = 0.2, 2, 5, 6, 7, 10. For H < 0.1λ velocity decreases if slit width H decreases and if thickness of a plate H2 decreases. For H > 0.1λ SEAW transforms into SAW, corresponding to YX cut of quartz.

Fig. 6 shows phase velocities versus slit width for system of two identical thin plates of LGS(0,140,25) (H2 = H1 = λ) with slit between them.

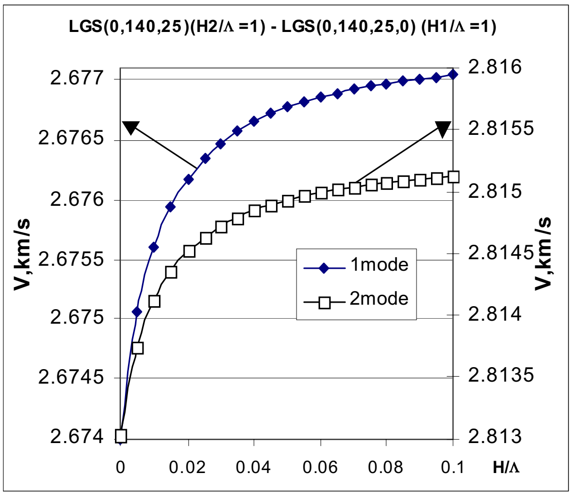

Fig. 6. SEAW modes in system: plate of LGS(0,140,25) /slit/ plate of LGS(0,140,25).

Both modes transform into symmetric and antisymmetric Lamb modes by increasing of a slit width H/λ > 0.1.

Fig 7. shows calculated velocities of basic symmetric (S) and antisymmetric (A) Lamb modes versus plate thickness for single plate of LGS (0^0,140^0,25^0). For H = λ (here H is a thickness of a plate) velocities of corresponding modes are: V_A= 2.6773km/s, V_S = 2.8153km/s.

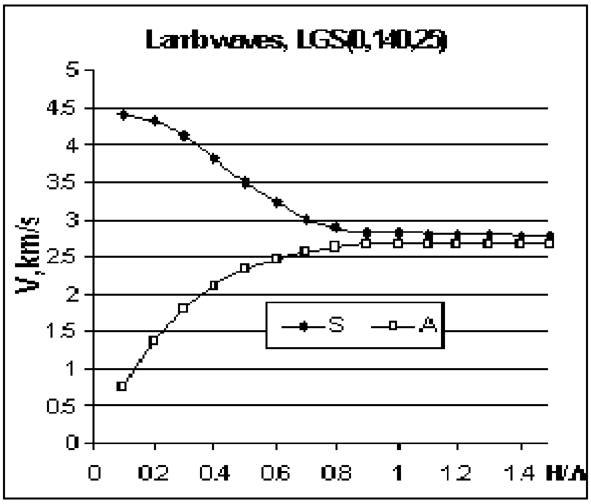

Fig. 7. Symmetric (S) and antisymmetric (A) basic Lamb modes in a single plate of LGS(0,140,25).

When thicknesses of both plates are large (H2, H1 > 5λ) SEAW transforms into SAW for slit width H > 0.1λ (see Fig. 2).

CONCLUSION

Obtained results of calculations show that SEAW modes exist, if slit wave width is not more than about one wavelength. For identical piezoelectric half-infinite crystals, disconnected by a slit, there are symmetric and antisymmetric SEAW modes, those transform into usual SAW by increasing of the slit width. SEAW modes also exist in structures of two different half-infinite piezoelectric crystals disconnected by a slit. Velocity of SEAW depends on properties of both crystals.

SEAW modes also exist in structures of two plates with slit between them and for plate above half-infinite crystal. These modes transform into Lamb modes (for thin plates and wide slit) or into SAW (for thick plates and wide slit).

REFERENCES

1. M.K Balakirev, I.A. Gilinsky, Waves in piezocrystals, M.: Science, 1982.
2. A.Oliner, Surface acoustic waves, M.: Mir, 1981.
3. M.K. Balakirev, S.V. Bogdanov, A.V. Gorchakov, A.E. Chakushin// PhTT, 1979, v. 21, No 8, pp. 2508-2510.
4. K. Yamanouchi, K. Iwahashi, Piezoelectric acoustic boundary waves propagating along the interface between SiO_2 and $LiTaO_3$ // IEEE Trans. on Sonics and Ultrasonics, Vol. SU-25, No.6, 1978, pp. 384-389.