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New solutions of shear waves in piezoelectric cubic crystals

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Abstract: Acoustic wave propagation in piezoelectric crystals of classes $\bar{4}3m$ and 23 is studied. The crystals Tl_3VS_4 and Tl_3TaSe_4 ($\bar{4}3m$) of the Chalcogenide family and the crystal $Bi_{12}TiO_{20}$ (23) possess strong piezoelectric effect. Because the surface Bleustein-Gulyaev waves cannot exist in piezoelectric cubic crystals, it was concluded that new solutions for shear-horizontal surface acoustic waves (SH-SAWs) are found in the monocrystals using different electrical boundary conditions such as electrically "short" and "open" free-surfaces for the unique [101] direction of wave propagation. For the crystal Tl_3TaSe_4 with coefficient of electromechanical coupling (CEMC) $K_e^2=e^2/(C\times g)$~1/3, the phase velocity V_{ph} for the new SH-SAWs can be calculated with the following formula: $V_{ph}=(V_a+V_t)/2$, where V_t is the speed of bulk SH-wave, $V_t=V_{t4}(1+K_e^2)^{1/2}$, $V_a=a_KV_{t4}$, $a_K=2[K_e(1+K_e^2)^{1/2}-K_e^2]^{1/2}$, and $V_{t4}=(C_{44}/\rho)^{1/2}$. It was found that the CEMC K^2 evaluation for Tl_3TaSe_4 gave the value of $K^2=2(V_f-V_m)/V_f$~0.047 (~4.7%), where V_f~848 m/s and V_m~828 m/s are the new-SAW velocities for the free and metallized surfaces, respectively. This high value of $K^2(Tl_3TaSe_4)$ is significantly greater than $K^2(Tl_3VS_4)$~3% and about five times that of $K^2(Bi_{12}TiO_{20})$.

Key words: New shear-horizontal surface acoustic waves (SH-SAWs), Strong piezoelectric effect, Piezoelectric cubic crystals, Solutions for latent waves
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INTRODUCTION

The shear-horizontal surface acoustic waves (SH-SAWs) were theoretically distinguished from the bulk SH-waves by Bleustein (1968) and Gulyaev (1969) simultaneously at the end of the 1960s. The surface Bleustein-Gulyaev (BG) waves (Bleustein 1968; Gulyaev, 1969), possessing a hybridization between the mechanical displacement U_2 and the electric potential $\varphi=U_4$, can propagate on some surface cuts of the transversely-isotropic crystals of the hexagonal and tetragonal classes when propagation directions are perpendicular to an odd-order symmetry axis. It was recently noted by Gulyaev and Hickernell (2005) that SH-SAWs cannot exist in piezoelectric cubic crystals. Kessenikh and Shuvalov (1982) also discusses that SH-SAWs on electrically open or shorted surfaces of piezoelectric crystals of symmetry classes 622 and 422 cannot exist if the propagation direction is perpendicular to six- or four-fold axis. However, when the transversely-isotropic symmetry decreases from 622 to 6 or from 422 to 4 classes, the surface BG-waves can be found. In addition, Maerfeld and Tournois (1971) discovered new possibilities for shear-horizontal waves propagating along the interface between two opposite-polarized similar piezoelectric materials as well as between two dissimilar ones. It is noted that both the surface BG-wave and interfacial electroacoustic Maerfeld-Tournois (MT) wave may be caused by interfacial crack propagation between two dissimilar piezoelectric crystals. Note that the interfacial MT-waves, like the surface BG-waves, can exist in transversely-isotropic piezoelectrics.

This paper is aimed to report theoretical study of surface SH-waves in piezoelectric cubic crystals with the strong piezoelectric effect. The Chalcogenide family (Tl_3VS_4 and Tl_3TaSe_4) (Henaff *et al.*, 1982) are soft crystals belonging to the cubic class $\bar{4}3m$ and possessing both zero temperature coefficients and strong piezoelectric coupling. In spite of their very large potential interest, especially for moderate frequency and large bandwidth, such ternary thallium Chalcogenides are not commercially available—probably due to their mechanical softness and fabrication difficulties. In contrast to the Chalcogenides, the piezoelectric ceramics of the point group symmetry 23 [$Bi_{12}SiO_{20}$ and $Bi_{12}GeO_{20}$ (Kamenov *et al.*, 2000; Zakharenko, 2005), and $Bi_{12}TiO_{20}$ (Kamenov *et al.*, 2000)] can be used in piezoelectronics.

THEORY

Fig.1 introduces a rectangular coordinate system (x_1, x_2, x_3), with the x_1Ox_3 sagittal plane being perpendicular to the lowest odd-order symmetry axis of a piezoelectric cubic crystal with the x_1-axis showing wave propagation in [101] direction. It is necessary to write governing equations of linear piezoelasticity. Constitutive relations are as follows:

$$\sigma_{ij} = C^E_{ijkl}\varepsilon_{kl} - e_{ijm}E_m, \tag{1}$$

$$D_m = e_{mij}\varepsilon_{ij} + g_{mn}E_n, \tag{2}$$

in which σ_{ij} and ε_{ij} (or ε_{kl}) are the stress and strain tensors, respectively; D_m and E_m (or E_n) are components of the electric displacement and electric field (E_m=$-\partial\varphi/\partial x_m$, where φ is the electric potential); the indices i, j, k, l, m and n run from 1 to 3. According to the usual Voigt's notation, C_{ijkl}, e_{ijm} and g_{mn} can be written as 6×6, 3×6 and 3×3 matrices standing for the elasticity, piezoelectricity, and dielectricity tensors, respectively. Equilibrium equations are $\sigma_{ij,j}$=0 and $D_{i,i}$=0. It is assumed that the material is free of body forces and inertial effects as well as body electric charge.

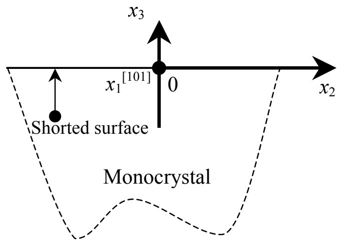

Fig.1 The coordinate system for monocrystal with the open surface or surface metallization, where the x_1-axis is directed perpendicular to the figure plane

The motion equation of an elastic medium is written as follows:

$$\rho\frac{\partial^2 U_i}{\partial t^2} = \frac{\partial\sigma_{ik}}{\partial x_k}, \tag{3}$$

where ρ and U_i denote the material density and displacement components; t is time. Using Eqs.(1)~(3) and φ=U_4, one can write the coupled equations of motion for a piezoelectric medium as follows:

$$\left.\begin{aligned}&\rho\frac{\partial^2 U_i}{\partial t^2} = C_{ijkl}\frac{\partial^2 U_l}{\partial x_j\partial x_k} + e_{kij}\frac{\partial^2 U_4}{\partial x_j\partial x_k},\\ &e_{ijk}\frac{\partial^2 U_k}{\partial x_i\partial x_j} - g_{ij}\frac{\partial^2 U_4}{\partial x_i\partial x_j} = 0.\end{aligned}\right\} \tag{4}$$

Solutions of the homogeneous partial differential Eq.(4) of the second order are found in the following plane wave view: $U_i = U_i^0\exp[\mathrm{j}(\boldsymbol{kr} - \omega t)]$, where the index i runs from 1 to 4; U_i^0 is an initial amplitude; $\boldsymbol{kr}$ denotes the scalar multiplication of two vectors; ω is the angular frequency. {k_1, k_2, k_3}=k{n_1, n_2, n_3} are the components of the wavevector $\boldsymbol{k}$ and {x_1, x_2, x_3} are the components of the real space vector $\boldsymbol{r}$, and {n_1, n_2, n_3} are the so-called directional cosines.

The coupled equations of motion can be readily written in the following simplified form, leaving only equations for waves with polarization perpendicular to the sagittal plane as well as non-zero components of the material tensors:

$$\left.\begin{aligned}&\rho\frac{\partial^2 U_2}{\partial t^2} = C_{44}\left(\frac{\partial^2 U_2}{\partial x_1^2} + \frac{\partial^2 U_2}{\partial x_3^2}\right) + e_{16}\frac{\partial^2\varphi}{\partial x_1^2} + e_{34}\frac{\partial^2\varphi}{\partial x_3^2},\\ &e_{16}\frac{\partial^2 U_2}{\partial x_1^2} + e_{34}\frac{\partial^2 U_2}{\partial x_3^2} - g_{11}\left(\frac{\partial^2\varphi}{\partial x_1^2} + \frac{\partial^2\varphi}{\partial x_3^2}\right) = 0.\end{aligned}\right\} \tag{5}$$

In Eq.(5), the mechanical displacement component U_2 is directed along the x_2-axis (Fig.1):

$$U_{2,4} = U_{2,4}^0\exp[\mathrm{j}k(n_1x_1 + n_3x_3 - V_{\mathrm{ph}}t)], \tag{6}$$

using the phase velocity definition such as V_{ph}=ω/k. For piezoelectric cubic crystals, many propagation directions being perpendicular to [010] direction can exist giving C_{44}=C_{66} and g_{11}=g_{33}. It is also possible to cut a cubic crystal in order to study wave propagation in [101] direction with e_{14}=e_{36}=0 and the non-zero piezoelectric constants {e_{16}, e_{34}} that is shown in Eq.(5).

Substituting the mechanical displacement U_2 and electrical potential φ=U_4 of Eq.(6) into Eq.(5), the equations of motion can be readily written in the well-known tensor form, using corresponding components of the modified Green-Christoffel tensor: $GL_{22}=C_{44}(1+n_3^2)$, $GL_{24}=GL_{42}=e_{16}+e_{34}n_3^2$, and $GL_{44}=-g_{11}(1+n_3^2)$ with n_3=k_3/k. That gives the following system of two homogeneous equations:

$$\begin{pmatrix} GL_{22}-C_{44}(V_{\text{ph}}/V_{\text{t4}})^2 & GL_{24} \\ GL_{42} & GL_{44} \end{pmatrix}\begin{pmatrix} U_2^0 \\ \varphi^0 \end{pmatrix}=0. \quad (7)$$

In Eq.(7), the directional cosines are defined as follows: n_1≡1, n_2≡0 and n_3=n_3. Equaling to zero the matrix determinant in Eq.(7), the suitable phase velocity V_{ph} satisfying boundary conditions discussed in the next section and four polynomial roots $n_3^{(p)}(V_{\text{ph}})$, as well as the functions $U_2^0(V_{\text{ph}})$ and $\varphi^0(V_{\text{ph}})$ can be found. For example, the functions can be taken in the following form: φ^0=GL_{42} and $U_2^0=-GL_{44}$.

Substituting $m_3=(1+n_3^2)$ in Eq.(7) and using the piezoelectric constants e_{16}=−e_{34} for [101] direction, the following polynomial can be introduced from Eq.(7):

$$(1+K_{\text{e}}^2)m_3^2-Bm_3+4K_{\text{e}}^2=0, \quad (8)$$
$$\text{with} \quad B=(V_{\text{ph}}/V_{\text{t4}})^2+4K_{\text{e}}^2,$$

where K_{e}^2 is the so-called static coefficient of the electromechanical coupling (CEMC), $K_{\text{e}}^2=e_{16}^2/(C_{44}g_{11})$. Note that the speed V_{t} of the bulk SH-wave is:

$$V_{\text{t}}=V_{\text{t4}}(1+K_{\text{e}}^2)^{1/2}. \quad (9)$$

Two roots of Eq.(8) are as follows:

$$m_3^{(1,2)}=\frac{-B\pm\sqrt{B^2-16K_{\text{e}}^2(1+K_{\text{e}}^2)}}{2(1+K_{\text{e}}^2)}, \quad (10)$$

giving four polynomial roots of Eq.(7) representing eigenvalues:

$$n_3^{(1,2,3,4)}=\pm\sqrt{-1+m_3^{(1,2)}}. \quad (11)$$

Note that for each eigenvalue n_3 there is the so-called eigenvector {U_2^0, φ^0}.

Further analyzing the roots for [101] propagation direction in Eqs.(10) and (11), it can be found that all complex roots will be calculated when the expression under square root sign in Eq.(10) is negative. That fulfills for velocities V_{ph} being less than some velocity V_a obtained solving the following equation B^2−$16K_{\text{e}}^2(1+K_{\text{e}}^2)$=0 and defined by the following formula:

$$V_a=a_KV_{\text{t4}} \text{ with } a_K=2\sqrt{K_{\text{e}}\sqrt{1+K_{\text{e}}^2}-K_{\text{e}}^2}. \quad (12)$$

It is clearly seen in Eq.(12) that the factor a_K is a function of the CEMC K_{e}^2 together with the other function $f(K_{\text{e}}^2)$=$(1+K_{\text{e}}^2)^{1/2}$ from Eq.(9). The function $a_K(K_{\text{e}}^2$=K_0^2=1/3) approaches the function $f(K_{\text{e}}^2)$= $(1+K_{\text{e}}^2)^{1/2}$ giving the following equality V_a=V_{t}, and only complex polynomial roots can exist for V_{ph}<V_a. The CEMC K_0^2=1/3 is readily found by substituting the velocity V_{t} from Eq.(9) to replace the phase velocity V_{ph} in equation B^2−$16K_{\text{e}}^2(1+K_{\text{e}}^2)$=0. Note that for K_{e}^2<K_0^2 there are all imaginary roots for V_{ph}>V_a, but a giant K_{e}^2>K_0^2 gives real roots for V_{ph}>V_a. It is also noted that only complex/imaginary roots with negative imaginary parts are chosen in order to have wave damping towards depth of a crystal corresponding to negative values of the x_3-axis shown in Fig.1. Probably, surface waves cannot be found in the cubic crystals with a giant K_{e}^2>1/3 in the V_{ph}-range: V_a<V_{ph}<V_{t}. Here there are two real roots for V_{ph}>V_{t}. It is thought that a great K_{e}^2 can be observed in complex compounds, as well as in simple materials including piezoelectric cubic crystals. For instance, the classic ferroelectric $PbTiO_3$ has been known to have a single ferroelectric tetragonal (T) to paraelectric cubic phase transition with increased temperature or pressure. Wu and Cohen (2005) studying $PbTiO_3$ discussed an unexpected tetragonal-to-monoclinic-to-rhombohedral-to-cubic phase transition sequence induced by hydrostatic pressure and a morphotropic phase boundary in a pure compound.

BOUNDARY CONDITIONS FOR SH-WAVES

Boundary conditions for studying SH-waves in monocrystals are based on several requirements which must be satisfied. There is the single mechanical boundary condition for the normal component of the stress tensor σ_{32} such as σ_{32}=0 at x_3=0, where

$$\sigma_{32}=\sum_{p=1,2}F^{(p)}[C_{44}k_3^{(p)}U_2^{(p)}+e_{34}k_3^{(p)}U_4^{(p)}]. \quad (13)$$

Also, there are two electrical boundary conditions: continuity of the normal component D_3 of the electrical displacements at x_3=0 being the interface between vacuum (D_3^{f}) and the crystal surface, where

$$\left.\begin{aligned} D_3&=\sum_{p=1,2}F^{(p)}[e_{34}k_3^{(p)}U_2^{(p)}-g_{33}k_3^{(p)}U_4^{(p)}],\\ D_3^{\mathrm{f}}&=-F^{(0)}\phi_0^{\mathrm{f}}\mathrm{j}k_1g_0,\end{aligned}\right\} \quad (14)$$

and continuity of the electrical potential $U_4=\phi$ at x_3=0 ($\phi=\phi^{\mathrm{f}}$), where

$$\phi=\sum_{p=1,2}F^{(p)}\phi^{(p)} \text{ and } \phi^{\mathrm{f}}=F^{(0)}\phi_0^{\mathrm{f}}. \quad (15)$$

Therefore, the boundary conditions determinant (BCD) for the case of free surface can be readily written from matrix view as shown in Eq.(16).

The BCD for the metallized surface can be also written from matrix view as shown in Eq.(17).

The complete mechanical displacement U_2^{Σ} and electrical potential $\varphi^{\Sigma}=U_4^{\Sigma}$ are written in the plane wave view as follows:

$$U_{2,4}^{\Sigma}=\sum_{p=1,2}F^{(p)}U_{2,4}^{0(p)}\exp[\mathrm{j}k(n_1x_1+n_3^{(p)}x_3-V_{\mathrm{ph}}t)]. \quad (18)$$

The weight functions $F^{(1)}$ and $F^{(2)}$ are readily found from Eq.(16), which can give the same eigenvectors $\{U_2^{0(1)}, \varphi^{0(1)}\}$ and $\{U_2^{0(2)}, \varphi^{0(2)}\}$ for two equal eigenvalues $n_3^{(1)}=n_3^{(2)}$ and hence, $F^{(1)}=-F^{(2)}$. It is obvious that for this case the weight factors $F^{(1)}=-F^{(2)}$ will zero the complete mechanical displacement U_2^{Σ} and electrical potential φ^{Σ} in Eqs.(16) and (17) giving "latent" characteristics in Eq.(18). On the other hand, unequal eigenvalues $n_3^{(1)}$ and $n_3^{(2)}$ give different eigenvectors $\{U_2^{0(1)}, \varphi^{0(1)}\}$ and $\{U_2^{0(2)}, \varphi^{0(2)}\}$. Concerning experimental measurements of surface acoustic waves, it is also thought that some elements of crystals symmetry (screw axis or glide reflection) must be broken near the surface. The same relates to simple reflections and axis if the surface restricts the crystal in such a way that it breaks some simple elements of the crystals class group. Thus, to experimentally distinguish different types of surface waves is difficult and not unequivocal.

RESULTS AND DISCUSSIONS

Calculations of the phase velocity V_{ph}, the velocities V_a, V_{t4} and V_{t}, as well as the CEMC K_{e}^2 were carried out for different piezoelectric cubic crystals: Chalcogenides Tl_3VS_4 and Tl_3TaSe_4 (cubic, class $\bar{4}3$m), and Bismuth Titanate $Bi_{12}TiO_{20}$ (cubic, class 23). For the ternary thallium Chalcogenide Tl_3TaSe_4, material constants for [100] direction are as follows: ρ=7280 [kg/m^3], C_{44}=0.41×10^{10} [N/m^2], e_{14}=0.32 [C/m^2], and g_{11}/g_0=10.1. g_0 is the dielectric constant of vacuum, g_0=0.08854×10^{-10} [F/m]. Note that difference between [101] and [100] directions are confined in the piezoelectric constants: $|e_{16}|^{[101]}=|e_{14}|^{[100]}$. The same material constants for Tl_3VS_4 are: ρ=6140 [kg/m^3], C_{44}=0.47×10^{10} [N/m^2], e_{14}=0.55 [C/m^2], and g_{11}/g_0=34.8. These material constants give great CEMCs $K_{\mathrm{e}}^2(Tl_3TaSe_4)=(e_{16})^2/(C_{44}g_{11})$ ~0.2793 and $K_{\mathrm{e}}^2(Tl_3VS_4)$~0.2089. All the wave characteristics were calculated with an accuracy of about 1 μm/s that is useful and allows distinguishing V_{ph}-solutions when they are close to each other. The

$$\begin{pmatrix} C_{44}k_3^{(1)}U_2^{(1)}+e_{34}k_3^{(1)}U_4^{(1)} & C_{44}k_3^{(2)}U_2^{(2)}+e_{34}k_3^{(2)}U_4^{(2)} \\ e_{34}k_3^{(1)}U_2^{(1)}-(g_{33}k_3^{(1)}-\mathrm{j}g_0k_1)U_4^{(1)} & e_{34}k_3^{(2)}U_2^{(2)}-(g_{33}k_3^{(2)}-\mathrm{j}g_0k_1)U_4^{(2)} \end{pmatrix}\begin{pmatrix} F^{(1)} \\ F^{(2)} \end{pmatrix}=0. \quad (16)$$

$$\mathrm{j}g_0k_1\begin{pmatrix} C_{44}k_3^{(1)}U_2^{(1)}+e_{34}k_3^{(1)}U_4^{(1)} & C_{44}k_3^{(2)}U_2^{(2)}+e_{34}k_3^{(2)}U_4^{(2)} \\ U_4^{(1)} & U_4^{(2)} \end{pmatrix}\begin{pmatrix} F^{(1)} \\ F^{(2)} \end{pmatrix}=0. \quad (17)$$

wave characteristics for Tl_3TaSe_4 are as follows: V_{t4}~750.4577358 m/s, V_t~848.8104580 m/s, and V_a~846.9869546 m/s. The speed V_t of the bulk SH-wave is slower than 1000 m/s and the value of V_a is close to V_t because K_e^2 is close to K_0^2=1/3. According to the recent publication (Gulyaev and Hickernell, 2005), SH-SAWs (for instance, the surface BG-waves) cannot exist in piezoelectric cubic crystals. Hence, any found V_{ph}-solutions below the speed V_t for the boundary conditions' determinants (BCDs) in Eqs.(16) and (17), except in the case of V_a with two equal roots, will represent new-wave solutions of SAWs. The V_{ph}-solutions are found when values of the BCDs fall to zero. Indeed, new SAWs can be found in cubic crystals with strong piezoelectric effect for electrical boundary conditions of both free and metallized surfaces. For the strongest piezoelectrics Tl_3TaSe_4 of the treated cubic crystals, the existence possibility of new SAWs for both electrical boundary conditions is obvious that allows evaluation of the coefficient of electromechanical coupling:

$$K^2 = 2(V_{\text{new}} - V_{\text{new},m}) / V_{\text{new}}, \tag{19}$$

where V_{new} and $V_{new,m}$ are the velocities of new SAWs for the free and metallized surfaces, respectively. The velocities V_{new}~848.125556 m/s and $V_{new,m}$~828.335498 m/s for the crystal Tl_3TaSe_4 give K^2~0.04667, and the behavior of corresponding BCDs is shown in Fig.2. Note that here the new-SAW velocity V_{new} can be approximated with $V_{new}=(V_t+V_a)/2$, because the value of V_{new} is situated between the values of V_t and V_a.

The V_{ph}-solutions for both the BCDs are shown in Fig.3 for the other strong piezoelectrics Tl_3VS_4 with the value of K_e^2 being significantly less than the one for Tl_3TaSe_4. The characteristics of Tl_3VS_4 are: V_{t4}~874.9127458 m/s, V_t~961.9607843 m/s, and V_a~948.1841318 m/s. The calculated velocities of the new SAWs are V_{new}~961.927246 m/s and $V_{new,m}$~947.491302 m/s giving about 1.5 times decrease in the CEMC, $K^2(Tl_3VS_4)$~0.030, calculated with Eq.(19). Here the velocity $V_{new,m}$ is still significantly less than V_t and is about V_a. On the other hand, it is clearly seen from the above written values of V_{new} and V_t that they are close to each other for the large value of $K_e^2(Tl_3VS_4)$~0.2089, which is about two times greater than that for the cubic crystal $Bi_{12}TiO_{20}$: $K_e^2(Bi_{12}TiO_{20})$~0.1118. That is true for the other crystals of class 23, $Bi_{12}SiO_{20}$ and $Bi_{12}GeO_{20}$, which possess smaller values of K_e^2(class 23)~0.10 to 0.15 (Zakharenko, 2005). Fig.4 shows the BCD behavior for the cubic crystal $Bi_{12}TiO_{20}$, using the following material constants taken from (Kamenov *et al.*, 2000): ρ=11200 [kg/m^3], $C_{44}=2.60\times10^{10}$ [N/m^2], e_{14}=1.10 [C/m^2], and $g_{11}=4.16138\times10^{-10}$ [F/m]. The $Bi_{12}TiO_{20}$ material constants result in relatively high velocities V_{t4}~1523.62350 m/s, V_t~1606.562692 m/s, and V_a~1495.282953 m/s being about two times greater than those for the Chalcogenides. The velocity V_{new}~1606.556882 m/s here is very close to the speed V_t, but can still be distinguished in the calculations using the set accuracy of about 1 μm/s. The velocity $V_{new,m}$~1598.414906 m/s is significantly less than V_t, but greater than V_a, which means that $V_{new,m}$ can also reach V_t. Using the calculated velocities V_{new} and

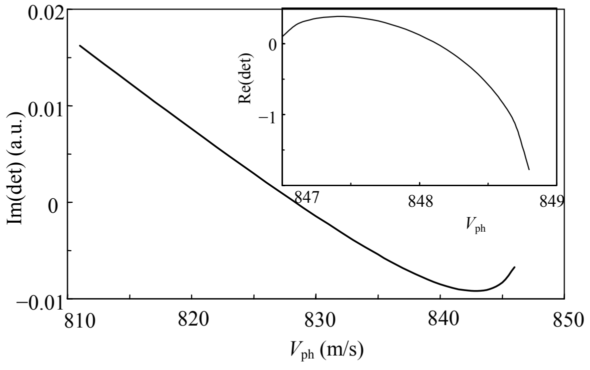

Fig.2 The dependence of the boundary conditions determinants (BCD) on the phase velocity V_{ph} for [101]-direction of wave propagation in the cubic crystal Tl_3TaSe_4 with the metallized surface. The insertion shows the solution of Re(det)×10^{-3} for the open surface

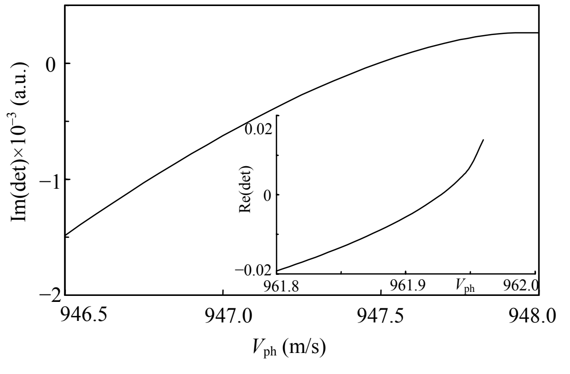

Fig.3 The dependence of the boundary conditions determinants (BCD) on the phase velocity V_{ph} for [101]-direction of wave propagation in the cubic crystal Tl_3VS_4 with the metallized surface. The insertion shows the solution of Re(det) for the open surface

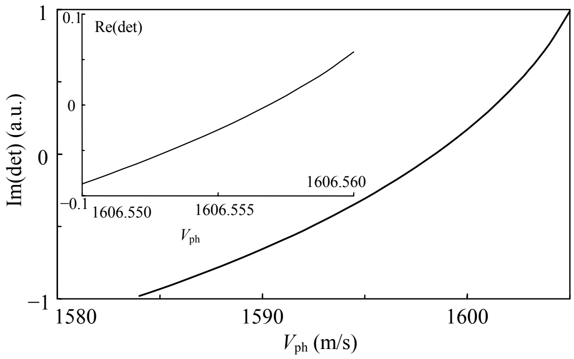

Fig.4 The dependence of the boundary conditions determinants (BCD) on the phase velocity V_{ph} for [101]-direction of wave propagation in $Bi_{12}TiO_{20}$ with the metallized surface. The insertion shows the Re(det) solution for the open surface

$V_{new,m}$, the evaluated value of the K^2 from Eq.(19) is as high as $K^2(Bi_{12}TiO_{20})$~0.010 that is only 1%. It is thought that the bulk SH-wave with the speed V_t is unstable and can be readily treated as the SH-SAWs for the weaker piezoelectrics such as the crystals of class 23. Indeed, the penetration depth here can reach macroscopic distances towards the crystal depth.

CONCLUSION

In this report of theoretical work, the phase velocity V_{ph} and coefficient of electromechanical coupling K^2 were calculated for new SH-SAWs propagating in [101] direction on the surface of piezoelectric cubic crystals, in which the surface Bleustein-Gulyaev waves cannot propagate. For the Chalcogenide Tl_3TaSe_4 with the greatest CEMC K_e^2~1/3, the velocity V_{new} for the new SH-SAWs is significantly less than the speed V_t of the bulk SH-waves, $V_D=V_{new}-V_t$~0.7 m/s for the free surface, while the difference V_D for the crystal Tl_3VS_4 with the CEMC K_e^2~1/5 is V_D~0.03 m/s. For the Bismuth Titanate possessing the smallest value of the CEMC $K_e^2(Bi_{12}TiO_{20})$~1/10 concerning the studied crystals, the difference V_D is very small and equals to ~0.007 m/s which already makes difficulties for numerically finding the phase velocity V_{new} of new SH-SAWs, as well as for distinguishing it from the bulk SH-wave propagating with the speed V_t. Using the surface metallization, the corresponding differences V_D for the studied crystals are as follows: $V_D(Tl_3TaSe_4)$~20.5 m/s ($V_{new,m} << V_a$), $V_D(Tl_3VS_4)$~14.5 m/s with $V_{new,m}$~V_a and $V_D(Bi_{12}TiO_{20})$~8 m/s ($V_{new,m} >> V_a$). Also, the additional solutions for the V_a, which is significantly less than the speed V_t for weakly-piezoelectric cubic crystals, give latent displacements or zero ones. However, it is thought that different surface perturbations can result in visualization of the displacements that must be experimentally verified for sensor application.

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