# Acoustic and piezoelectric properties of new polar semiconductor compounds of $Sn_2P_2S_6$ family

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## Introduction

The crystals of uniaxial ferroelectric $Sn_2P_2S_6$ family are very interesting for several reasons in the context of applications and basic research [1,2]. One reason is that these crystals exhibit strong piezoelectric effect and are photosensitive semiconductors. This offers a possibility for applications in acoustoelectronic and electroacoustic devices; consequently, investigations of acoustoelectric interaction are necessary. Another reason is that the sulphur substitution by selenium in a material leads to appearance of the incommensurate phase and the Lifshitz point providing unique possibility to investigate the critical behaviour of the phase diagram near such point [3,4]. Recently it was shown, that the mobile charge carriers also play essential role in the critical behaviour of crystals [5,6]. The variation of the electron density in energy levels can change the Lifshitz point position in the phase diagram and strongly modifies thermodynamic characteristics, such as optic and dielectric properties. Investigations of elastic and piezoelectric properties near Lifshitz point are also interesting. Recently the new layered crystals of this family were obtained: i.e. $CuInP_2S_6$ and $CuCrP_2S_6$ , which also are promising materials for microelectronics. In $CuInP_2S_6$ crystals the first order order-disorder phase transition occurs at $T_c$ = 312 K, which is related to the hopping motions of Cu ions [7]. In the paraelectric phase crystal belongs to C2/c symmetry group. Below $T_c$, in the ferrielectric phase with symmetry Cc spontaneous polarization appears and the polarizaton vector is oriented normally to the structure layers along c-axis. The spontaneous polarization is determined by two anticollinear contributions – ordering of $Cu^+$ ions and shifting of $In^{3+}$ ions [8]. At $T<T_c$ the piezoeffect was found [9]. In layered $CuCrP_2S_6$ crystals, three consecutive phases were identified by means of differential scanning calorimetry and neutron powder diffraction: normal-nonpolar (T>190 K), antipolar (T<150 K) and intermediate phase (150<T<190 K) [8]. Diffraction investigations confirmed the following structures of room temperature and low temperature phases (monoclinic space groups C2/c and Pc respectably). In the intermediate phase incomplete antipolar ordering of the copper was observed. This quasi-antipolar phase can be interpreted in terms of occasionally flipping dipoles in an otherwise antipolar phase, or static clusters of up and down dipoles that form "glassy" precursor to long range order. The nonpolar phase also was shown to be not of the usual paraelectric type, but, because of relatively strong dipole-dipole interactions, has polar clusters even at temperatures far above the transition. Here we present the investigation of phase transitions and ultrasonic, piezoelectric and acoustoelectric properties of these $Sn_2P_2S_6$ family crystals. The ultrasonic and piezoelectric measurements were carried out by pulse-echo and resonance methods.

## Results and discussion

The phase diagram of $Sn_2P_2(Se_xS_{1-x})_6$ crystals is complicated. Pure $Sn_2P_2S_6$ exhibits the second order ferroelectric phase transition (PT) near 337 K. At this PT the large critical slowing down in ultrasonic velocity is observed for all longitudinal ultrasonic modes. With substitution S by Se the PT temperature decreases and velocity anomalies increases (Fig. 1). In this figure the temperature dependencies of ultrasonic velocity measured at 10 MHz are shown for compounds with Se content x=0 (1), x=0.15 (2) and x=0.28 (3). The velocity anomalies at PT are accompanied by large and narrow ultrasonic attenuation peaks.

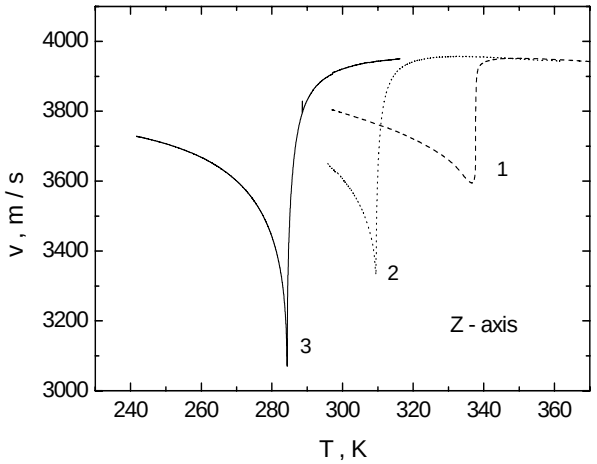


Fig.1. **The temperature dependencies of longitudinal ultrasonic velocity in $Sn_2P_2(Se_xS_{1-x})_6$ single crystals for different Se content x=0 (1), x=0.15 (2) and x=0.28 (3)**

It is interesting to note, that the critical exponent for anomalous part of ultrasonic velocity in paraelectric phase $\alpha$ = 0.5 (Fig. 2), what is in good agreement with calculations according renormalization group theory [3]. For more detail discussion of anomalous ultrasonic attenuation, we refer to original papers [4,10].

With increase Se content above x=0.28 the PT splits to two and intermediate incommensurate (IC) phase appears. Therefore at $x_L$=0.28 and $T_L$=283 K the Lifshitz point exists in $Sn_2P_2(S,Se)_6$ system [2]. With further increase of x the temperature interval of existence of IC phase increases and for pure $Sn_2P_2Se_6$ it reaches $\Delta T_{IC}$=30 K

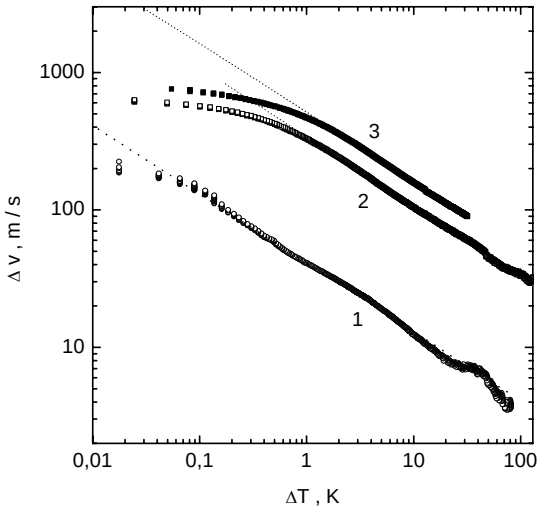


Fig.2. **The temprature dependence of critical part of velocity in double logarithmic scale. in Sn $_2$P$_2$ (Se$_x$S$_{1-x}$)$_6$ single crystals for different Se content x=0 (1), x=0.15 (2) and x=0.28 (3)**

(Fig. 3). The low temperature transition from IC phase to commensurate ferroelectric phase is the first order PT and the thermal hysteresis of about 1.5 K appears in heating and cooling measurement cycles.

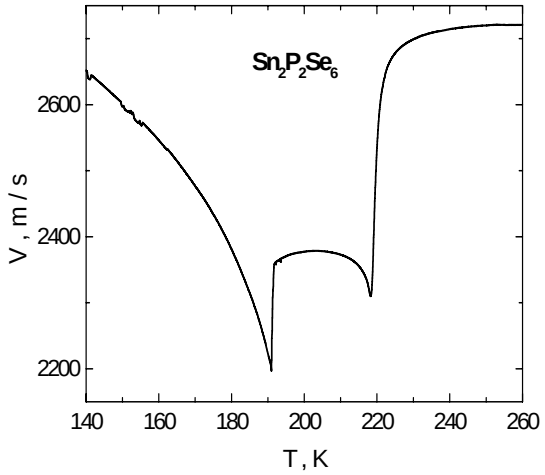


Fig.3. **The temperature dependence of longitudinal ultrasonic velocity in Sn $_2$P$_2$Se$_6$ crystal along Y-axis**

In the ferroelectric phase of $Sn_2P_2(Se_xS_{1-x})_6$ crystals the photosensitive ultrasonic attenuation caused by acoustoelectric interaction with free charge carriers was found for piezoactive modes. The dependencies of electronic attenuation coefficient $\alpha_{el}$ on electro-conductivity $\sigma$ of polarised crystals are presented in Fig. 4. Conductivity σ was changed by illumination of a sample. The photosensitivity of crystals is not very high and, at comparatively small $\sigma$, condition $\omega\tau >> 1$ is fulfilled ($\omega$-angular frequency of ultrasonic wave, $\tau$- Maxwel relaxation time of electronic subsystem). In this case, $\alpha_{el}$ is independent on frequency and depends linearly on $\sigma$, what we observe in experiment. From this linear dependence, it

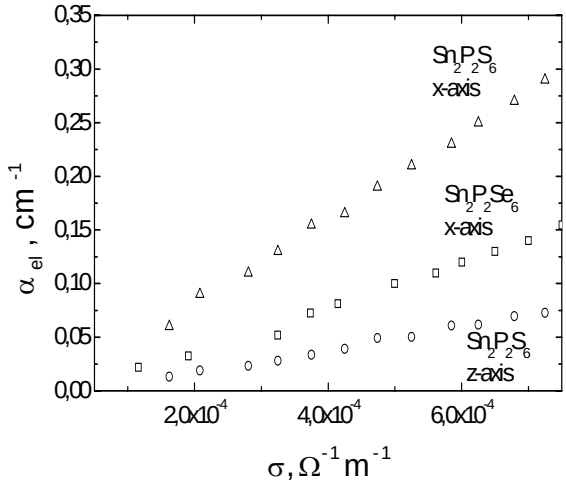


Fig.4. **The dependence of $\alpha_{el}$ on conductivity σ of Sn $_2$P$_2$S$_6$ and Sn $_2$P$_2$Se$_6$ crystals in ferroelectric phase**

was possible to calculate the values of electromechanical coupling parameters $K$ (see [6] for details). The largest $K$ values have been obtained for pure $Sn_2P_2S_6$ crystals: $K_{11}$=0.7, $K_{33}$=0.17. With increase of Se amount in the compound electro-mechanical coupling decreases and in pure $Sn_2P_2Se_6$ sample: $K_{11}$=0.4.

In $CuInP_2S_6$ single crystals the acoustoelectric interaction was weak, therefore we performed piezoelectric measurements using resonance method. We measured the

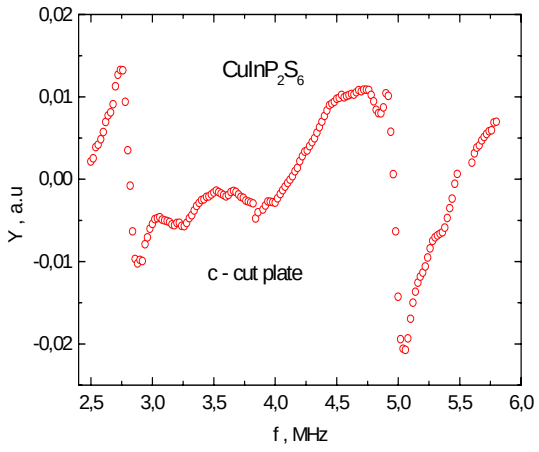


Fig.5. **The frequency dependence of electric admittance of the $CuInP_2S_6$ crystal. The linear background is subtracted**

frequency dependence of the modulus of electric admittance Y of a thin crystalline plate (thickness d = 0.42 mm). The orientation of the sample was such, that a.c electric field was directed along c - axis. The results are shown in Fig. 5. We attributed the antiresonance frequencies $f_a$ to the thickness and shear vibrations of the $CuInP_2S_6$ plate. The antiresonance frequencies are observed when the thickness of sample matches the halfwavelength of shear or longitudinal elastic wave: $f_a = V/2d$. From this equation the values of ultrasonic velocities along c - direction were calculated at room temperature: $V_{SH}$ = 3320 ± 50 m/s; $V_L$ = 4460 ± 50 m/s. The square of the

electromechanical coupling coefficient was calculated for corresponding vibration modes from the equation:

$$K^2 = \frac{\pi f_r}{2 f_a} tg\left(\frac{\pi}{2}\frac{f_a - f_r}{f_a}\right). \qquad (1)$$

At room temperature for longitudinal vibrations along ferroelectric *c*-axis the value $K_{33}^2$ = 0.08 for coefficient of electromechanical coupling was obtained. The $K_{35}^2$ value for shear mode is of the order of 0.05. These values are comparable to the electromechanical coupling coefficients of well known materials such as quartz or bismuth germanate.

The ultrasonic velocity and attenuation anomalies were recorded in layered $CuInP_2S_6$ samples at $T_c$=310 K (Fig. 6). Due to the small thickness of sample the data of ultrasonic attenuation are not very accurate. Dependence of ultrasonic velocity on temperature shows that there is a little softening at the phase transition temperature $T_c$ = 312.8 K. In the

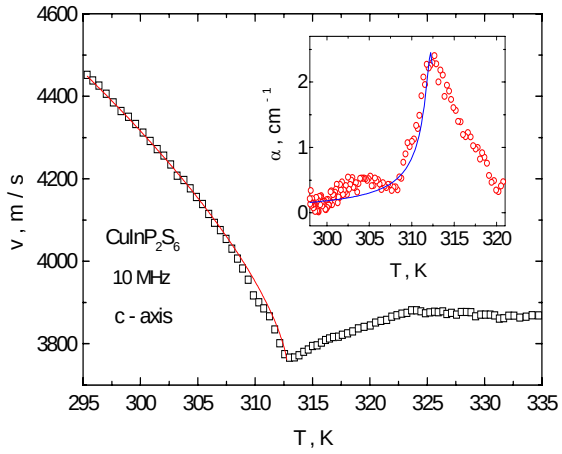


Fig.6. **Dependence of ultrasonic velocity along the c - axis of the $CuInP_2S_6$ crystal on temperature. The solid line shows the least squares fit using Eq. (2). In the inset: ultrasonic attenuation vs. temperature (solid line - the approximation to Eq. 3**

ferroelectric phase additional contribution in ultrasonic velocity exists. Such behaviour is similar to that observed in DDSP and DMAAS ferroelectric crystals [10], where relaxation time of the order parameter (spontaneous polarisation) was comparatively long. In this case, the additional part of ultrasonic velocity in the ferroelectric phase was proportional to polarisation square (see [10] for details). Therefore it is possible to obtain critical parameter from this contribution. In order to obtain the critical exponent for temperature dependence of order parameter, bearing in mind that contribution of the quadratic term is prevailing in the low temperature phase, we approximated the ultrasonic velocity by equation:

$$v = v_0 + A(T - T_c)^{2\beta}, \qquad (2)$$

where $\beta$ is the critical exponent of the order parameter. The comparatively good least square fits (solid line in Figure 6) have been obtained using parameters; $T_c$ = 312.8±0.1 K, $v_0$ = 3755±5 m/s, $A$ = 100±5 and $\beta$ = 0.335±0.015. The ultrasonic attenuation in low temperature phase arises from the elastic strain - polarisation interaction and can be described by the Landau Chalatnikov theory [11]:

$$\alpha = 2\alpha_{\max}\frac{\omega\tau}{1+\omega^2\tau^2}, \qquad 3)$$

here $\alpha_{max}$ - the attenuation coefficient at maximum, $\omega$ - the angular frequency of elastic wave and $\tau = \tau_0/(T_c - T)$ - the polarisation relaxation time, which increases critically approaching $T_c$. The solid line is drawn in the inset of Fig. 6 by approximation according to Eq. 3 ($\tau_0 = 7.2\times10^{-9}$ s×K). The long polarisation relaxation time was also obtained from dielectric experiments, where the low frequency dielectric dispersion was observed [12]. Above $T_c$ the pretransitional effects in ultrasonic and piezoelectric properties are clearly seen. Such effects can be determined by polar clusters existing in paraelectric phase.

Further, in this contribution, we present similar as in $CuInP_2S_6$ measurements of layered $CuCrP_2S_6$. As it was described in introduction, two successive phase transitions are expected to occur in these crystals. It was confirmed by our ultrasonic velocity and attenuation measurements. The temperature dependencies of longitudinal ultrasonic velocity and attenuation have been measured along *c*-axis at 10 MHz frequencies in $CuCrP_2S_6$ crystals and anomalies at the phase transition have been observed (Fig.7 and 8). Due to the small thickness of sample ($d$ =0.14 mm) the data of ultrasonic attenuation and velocity are not very perfect. The temperature dependence of ultrasonic velocity shows that there are two minima near temperatures $T_1$=180 K and $T_2$=145 K (Fig.7). Velocity minima correspond to the attenuation peaks (Fig.8). Such ultrasonic behaviour is in very good agreement with colorimetric data [13]. The attenuation has additional contribution, which increases with temperature increasing. It can be determined by the influence of high ionic conductivity of $CuCrP_2S_6$ crystals as in other fast ionic conductors [14]. Indeed, the ionic conductivity, according to [15], is comparatively high for $CuCrP_2S_6$ and $CuInP_2S_6$ crystals. The long tail in ultrasonic velocity in the high temperature phase ($T$>180 K) of $CuCrP_2S_6$ as in case of $CuInP_2S_6$ may be caused by polar clusters, which were mentioned in introduction. The critical

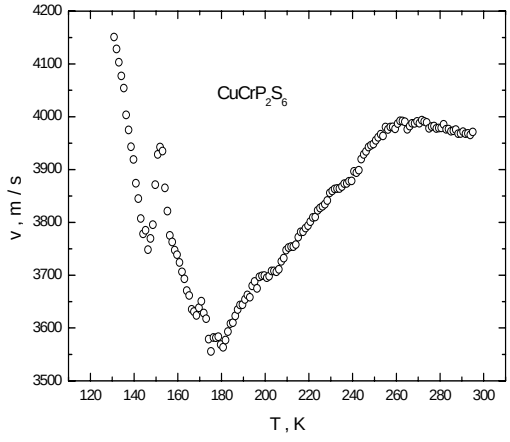


Fig. 7. **The temperature dependence of longitudinal ultrasonic velocity measured along c-axis of the $CuCrP_2S_6$ crystal**

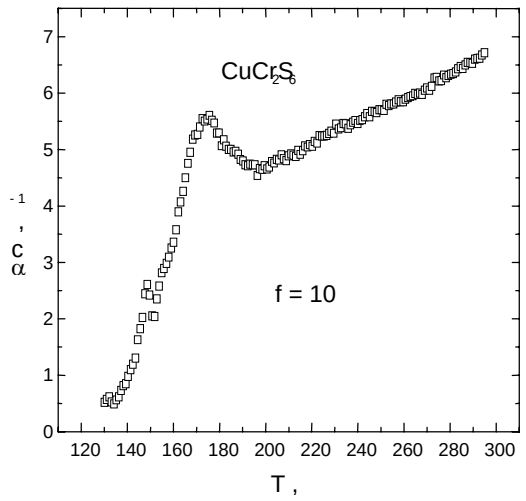


Fig.8. **The temperature dependence of ultrasonic attenuation measured along c-axis of $CuCrP_2S_6$ sample**

contribution of defects is also possible in high temperature phase. The steep increase of velocity in antipolar phase (below 145 K) is similar to that which was observed in DDSP, DMAAS and $CuInP_2S_6$ single crystals [9,10,16], where the relaxation time of the order parameter was comparatively long. In this case the temperature dependence of ultrasonic velocity in the low temperature phase was proportional to square of order parameter. In order to confirm the existence of piezoeffect we measured the frequency dependence of modulus of electric admitance Y for thin crystalline plate (thickness $d$ = 0.14 mm). The orientation of the sample was such, that a.c electric field was directed along $c$ - axis of the $CuCrP_2S_6$ crystal. The results are shown in Fig. 9. The resonance and antiresonance character in admittance Y frequency dependence is clearly seen near 15 MHz frequency. We attributed the resonance frequencies $f_a$ to the thickness vibrations of the $CuCrP_2S_6$ plate. The antiresonance frequency is observed when the thickness of sample

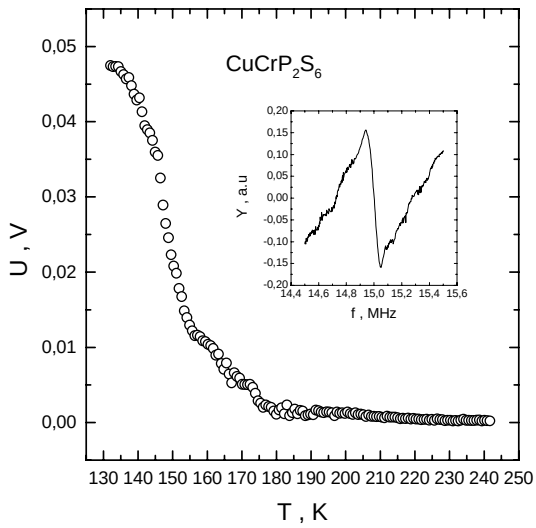


Fig.9. **The temperature dependence of electric signal detected by $CuCrP_2S_6$ plate. In the inset: the frequency dependence of electric admittance of the $CuCrP_2S_6$ plate at 130 K temperature. The linear background is subtracted**

matches the half wavelength of longitudinal elastic wave: $f_a = V/2d$. From the equation the values of ultrasonic velocity along c - direction have been calculated at temperature $T$=130 K: $V_L$ = 4160 ± 50 m/s. This value we used for calibration of ultrasonic velocity measured by pulse echo method (Fig.7). The square of the electromechanical coupling coefficient was calculated for this vibration mode from the equation (1). The $K_{33}^2$ value of 2 % has been obtained for the longitudinal mode of $CuCrP_2S_6$ crystal. This value is less than corresponding value for $CuInP_2S_6$ crystals. In order to confirm the existence of the piezoeffect in $CuCrP_2S_6$ we made direct experiment on the same thin 0.14 mm plate working as a piezoelectric transducer. The longitudinal ultrasonic wave was excited by $LiNbO_3$ transducer on 10 MHz frequency and was detected by $CuCrP_2S_6$ plate at $T$=130 K temperature. The efficiency of such transducer was quite good. The temperature dependence of detected by $CuCrP_2S_6$ transducer signal was measured (Fig.9) and it was shown, that this signal drops down at $T$=145 K and completely disappears in the paraelectric phase (above $T$ = 190 K). If we assume that the amplitude of detected by ultrasonic transducer signal is roughly proportional to the square of electromechanical coupling coefficient, which somewhat shows the polarisation of material, we can conclude that, below $T$=145 K the antipolar phase exists and in intermediate phase (145<$T$<180 K) the quasiantipolar phase is present in $CuCrP_2S_6$ crystal.

The other photosensitive ultrasonic phenomena such as acoustoelectric voltage, temperature oscillations, relaxing intermediate-incommensurate phase and photostimulated shift of PT temperature were observed and investigated in all these polar crystals of $Sn_2P_2S_6$ family. Illumination induces the intermediate-IC phase not only in the compound $Sn_2P_2(Se_{0.28}S_{0.72})_6$ where the Lifshitz point exists, but also in pure $Sn_2P_2S_6$ crystal [6]. For investigation of photo stimulation phenomena in $Sn_2P_2Se_6$ crystals at first the sample was annealed in dark at 320 K temperature and we took measurements of ultrasonic velocity $v = f(T)$ and attenuation $\alpha = f(T)$ in cooling run. The results for longitudinal wave along Y - axis are shown in Fig. 10 (lines 1). The temperature dependencies of $v = f(T)$ and $\alpha = f(T)$ are completely the same as we observed previously [17]. After that, the sample was heated up to 320 K and measurements of velocity and attenuation were resumed in illuminated sample. In later case the shift of $v = f(T)$ and $\alpha = f(T)$ anomalies to lower temperature was observed (Fig.7 , lines 2). The shift of incommensurate PT: $\Delta T_I \approx 1.6$ K, and that of the ferroelectric PT: $\Delta T_C \approx 2.1$ K. It is interesting to note that the dependence of velocity is modified in all ferroelectric phase. Such behaviour we attribute to the photodomain effect: i.e. free charge carriers are screening the polarisation and internal electric field changes under illumination. Also the influence of acoustoelectric field can not be ruled out. The phenomenological theory of photostimulated shift of the ferroelectric PT is developed in [18]. There it was shown that: $\Delta T_C = -(C/2\pi)aN$, where $C$-Curie constant, $a$ - coefficient of electron phonon interaction, $N$ - the total density of charge carriers. Our experiment does not contradict this theory. The relaxation time of

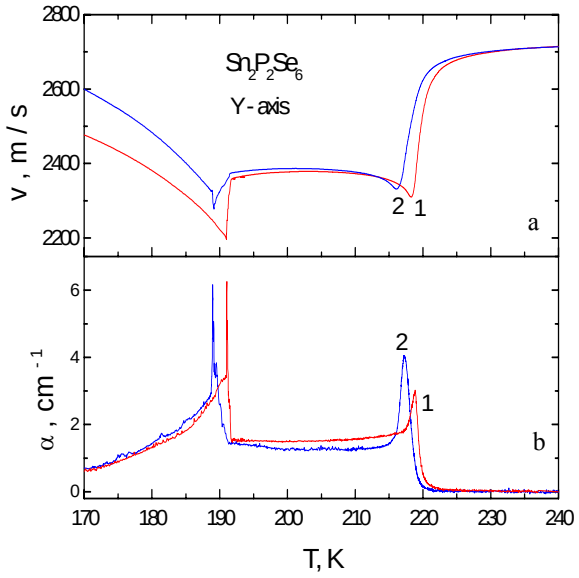


Fig.10. **The temperature dependencies of ultrasonic velocity (a) and attenuation coefficient measured along Y- axis in $Sn_2P_2Se_6$ crystal. Sample in dark (1), illuminated sample (2)**

photostimulated effect we measured using chopped light beam and it was longer than 30 s for $Sn_2P_2Se_6$ samples. It shows that the main reason of observed photostimulated phenomena is the redistribution of charge carriers in deep energy levels.

Another interesting phenomenon was the ultrasonic velocity and attenuation oscillations, which were observed in incommensurate phase of $Sn_2P_2Se_6$ sample in conditions of very slow heating. The temperature dependencies of these oscillations are shown in Fig.11. The correspondence between velocity and attenuation behaviour is clearly seen. Similar oscillations were observed before in optical

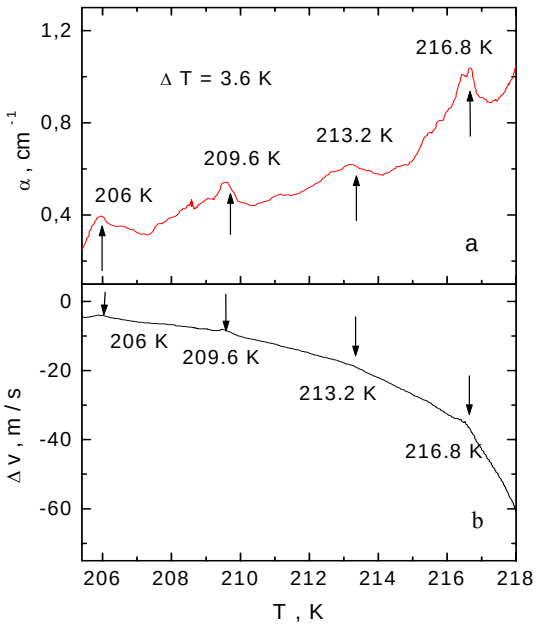


Fig.11. **The ultrasonic attenuation (a) and velocity (b) oscillations in the incommensurate phase of $Sn_2P_2Se_6$ crystal**

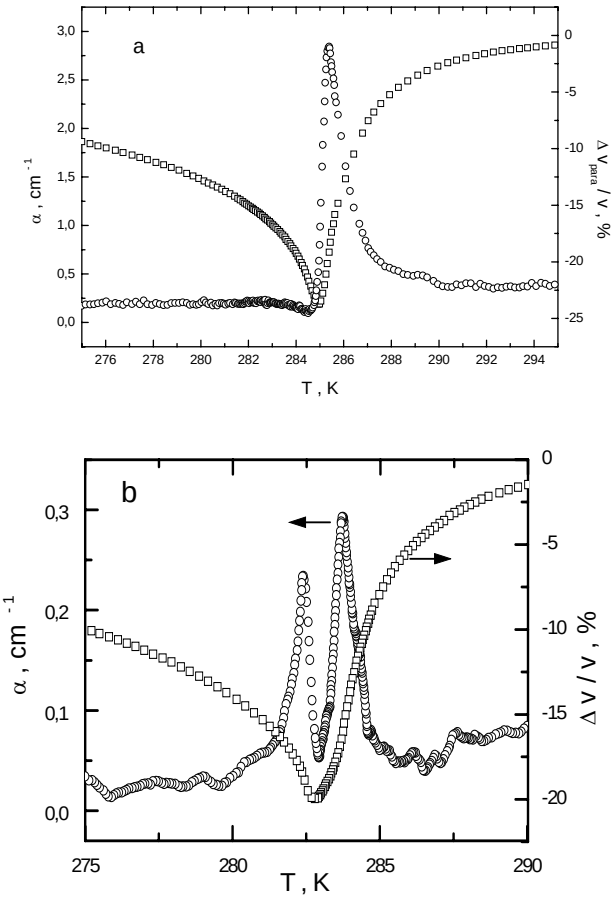


Fig.12. **The dependence of ultrasonic velocity and attenuation on temperature measured along Z - axis of $Sn_2P_2S_{0.28}Se_{0.72}$ crystal. Sample in dark (a), illuminated sample (b)**

experiments in $Sn_2P_2Se_6$ crystal and in dielectric measurements of the IC phase of urea doped thiourea [19,20]. To our mind this phenomenon is closely related to the nature of IC phase.

Special attention was paid to the $Sn_2P_2S_{0.28}Se_{0.72}$ compound where the Lifshitz point exists. Original ultrasonic studies of this material revealed ultrasonic anomalies as large as to make us to choose the Z-axis along which elastic anomalies were the smallest. The $\Delta v/v = f(T)$ and $\alpha = f(T)$ curves are shown in Figure 12a. The attenuation anomaly is wider in the paraelectric phase showing a strong influence of fluctuations which increase at the Lifshitz point. The most interesting result was obtained when measurement was performed on illuminated sample: apart from the shift of phase transition to lower temperature splitting of the transition was observed ( Figure 12b). Two sharp attenuation peaks are clearly seen indicating that illumination at the Lifshitz point leads to appearance of the incommensurate phase. The width of attenuation peaks shows that the order parameter relaxation time decreases when the charge carrier density is increased by illumination. The photosensitive ultrasonic phenomena in $Sn_2P_2S_{0.28}Se_{0.72}$ caused by the shift of the transition exist far in the paraelectric phase >50 K above

$T_C$. where we were able to detect small ultrasonic velocity variations.

## Conclusions

To summarise: all investigated materials have strong piezoelectric effect, nevertheless they are wide band gap semiconductors and charge carriers in deep energy levels create space charge, which modifies the elastic, dielectric and, as a result, electroacoustic parameters. This manifests itself in long time relaxation of these properties, especially near PT and in IC phase. So, for applications it is important to verify the conditions for the optimisation of electroacoustic parameters.

## Acknowledgement

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**References**

1. **Samulionis V., Valevichius V., Grigas J. and Vysochanskii Yu. M.** Investigation of the second ultrasonic harmonic generation in $Sn_2P_2S_6$ and $Sn_2P_2Se_6$ crystals. Ferroelectrics. 1990. Vol.105**.** P.397.
2. **Vysochanskii Yu. and Molnar A.** The relaxation phenomenon in proper uniaxial ferroelectric-semiconductor crystals $Sn_2P_2S(Se)_6$ with incommensurate phase. Journal of Physical Studies. 1997. Vol.1. P.535-543.
3. **Folk R.** Multicritical Behavior in Ferroelectrics. Phase Transitions. 1999. Vol. 67. P. 645.
4. **Samulionis V., Banys J., Vysochanskii Yu. and Grabar A. A.** The critical behaviour of ultrasonic velocity at a second order phase transition in $Sn_2P_2S_6$ single crystals. Phys. stat. sol. (b). 1999. Vol.215. P.1151.
5. **Vysochanskii Yu. M., Molnar A. A., Horvat A. A. and Nakonechnii Yu. S.** Critical phenomena in ferroelectric-semiconductor crystals $Sn_2P_2S_6$: Dielectric investigation Ferroelectrics. 1995. Vol.169. P.141.
6. **Samulionis V., Banys J. and Vysochanskii Yu.** Investigation of acoustoelectric phenomena in $Sn_2P_2S_6$ single crystals. Ferroelectrics. 1999. Vol.224**.** P.89.
7. **Simon A., Ravez J., Maisonnneuve V., Pyen C. and Cajipe V.B.** Paraelectric-ferroelectric transition in the lamellar tiophosphate $CuInP_2S_6$. Chem. Mater. 1994. Vol.6. P.1575.
8. **Maisonneuve V., Cajipe V.B., Simon A., Von der Muhll R. and Ravez J.** Ferrielectric ordering in lamellar $CuInP_2S_6$. Phys. Rev. B56. 1997. P.10860.
9. **Samulionis V., Banys J. and Vysochanskii Yu.** Elastic and electromechanical properties of new ferroelectric-semiconductor materials of $Sn_2P_2S_6$ family. Ferroelectrics. 2001. Vol. 257. P.135.
10. **Valevichius V., Samulionis V. and Banys J.** Ultrasonic dispersion in the phase transition region of ferroelectric materials. Journal of Alloys and Compounds. 1994. Vol.211/212. P.369.
11. **Landau L. D. and Khalatnikov I. M.** About anomalies of ultrasonic attenuation in the vicinity of the second order phase transition. Doklady AN SSSR. 1954. Vol. 96. P.469 (in Russian).
12. **Banys J., Samulionis V., Cajipe V. B. and Vysochanskii Yu.** Dielectric properties of ferroelectrics $CuInP_2S_6$ and $CuCrP_2S_6$. Ferroelectrics. 2001. Vol. 257. P.163.
13. **Cajipe V. B., Ravez J., Maisonnneuve V., Simon A., Pyen C., Von Der Muhl R. and Fisher J. E.** Copper ordering in lamellar $CuMP_2S_6$ (M=Cr, In); transition to an antiferroelectric or ferroelectric state. Ferroelectrics. 1996. Vol. 185. P.135.
14. **Vaitkus R., Kezionis A., Samulionis V., Orliukas A. and Skritskij V.** Electrical and acoustical relaxation in fast ionic conductors. Solid State Ionics. 1990. Vol. 40/41. P.922.
15. **Maisonnneuve V., Reau J. M., Dong M., Cajipe V. B., Payen C. and Ravez J.** Ionic conductivity in ferroic $CuInP_2S_6$ and $CuCrP_2S_6$ Ferroelectrics. 1997. Vol. 196**.** 257.
16. **Sobestijanskas R., Grigas J., Samulionis V. and Andreyev E. F.** Dielectric relaxation jn ferroelectric $(CH_3)_2NH_2Al(SO_4)_2*6H_2O$ crystal. Phase transitions. 1991. Vol. 29. P.167.
17. **Valevichius V., Samulionis V., Vysochanskii Yu., Major M. and Gurzan M.** Elastic anomalies in the vicinity of the phase transitions in ferroelectric with incommensurate phase $Sn_2P_2Se_6$. Fyz.tv.tela. 1989. Vol.31. No.7. P.144.
18. **Fridkin V. M.** Ferroelectric semiconductors. Moscow: Nauka,. 1979. P. 19 (in Russian).
19. **Vysochanskii Yu. M. and Slivka V. Yu.** Ferroelectrics of $Sn_2P_2S_6$ family. Properties in the vicinity of the Lifshitz point. Lviv. 1994. P.76 (in Russian).
20. **Onodera A., Denoye F., Godard R. J and Lambert M.** Dielectric anomalies in the incommensurate phase of urea-doped thiourea. J. Phys. France. 1988. Vol.49**.** P.2065.

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**Naujų polinių puslaidininkinių $Sn_2P_2S_6$ šeimos junginių ultragarsinės ir pjezoelektrinės savybės**

Reziumė

Straipsnyje pateikiama $Sn_2P_2S_6$ šeimos junginių ultragarsinių ir pjezoelektrinių savybių tyrimo apžvalga. Šios medžiagos yra feroelektrikai - puslaidininkiai, kuriuose žemos temperatūros fazėje susidaro gana stiprus pjezoefektas. Fazinių virsmų aplinkoje šiuose kristaluose atsiranda anomalusis ultragarso slopinimas ir greičio dispersija. Pastebėta nemaža fotojautrio reiškinių: akustoelektrinė sąveika, ultragarso greičio ir slopinimo osciliacijos nebendramatėje fazėje, fotostimuliuotas fazinio virsmo poslinkis žemų temperatūrų link ir fazinio virsmo skilimas į du Lifšico taško aplinkoje. Manoma, kad visi šie reiškiniai atsiranda dėl krūvininkų persiskirstymo ir relaksacijos giliuose energijos lygmenyse.

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