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SINGLE CRYSTALS OF SOLID SOLUTIONS $TlIn_{1-x}Co_xSe_2$ ($0 \leq x \leq 0.5$) - EFFECTIVE MATERIAL FOR CREATION OF MINIATURE HIGHLY SENSITIVE MEDICAL DEVICES

Abstract.Results of tenzoresistive mechanisms of solid solutions of $lIn_{1-x}Co_xSe_2$ monocrystals. It is defined that temperature influence on tenzosensitivity of $TlIn_{1-x}Co_xSe_2$ monocrystals in the interval of $0 \leq x \leq 0,5$ cobalt concentration. It is stressed that on $TlIn_{1-x}Co_xSe_2$ crystals strong pezoresistive effect is shown in the direction [001] which makes them as perspective materials for creation of new miniature highly sensitive and trustworthy electromechanical transformers.

Key words:monocrystals, tenzoresistive characteristics, solid solutions, tenzosensitivity of crystals, electromechanical transformers.

Introduction. The paper reports the results of our study of the influence of directional deformation on the tensoresistive properties of $TlIn_{1-x}Co_xSe_2$ solid solutions, on the basis of which an assumption was made about the most probable locations of extrema in the Brillouin zone. It is shown that $TlIn_{1-x}Co_xSe_2$ single crystals, due to their high strain sensitivity, significant flexibility and the ability to chip onto the desired filamentous plates with mirror faces in the direction of the maximum piezoresistive effect, are extremely effective materials for semiconductor strain gauges. The strain sensitivity of the samples was measured in the temperature range of 300 - 410 K in the static mode specified by the technique in [1 - 3].

The obtained new single crystals $TlIn_{1-x}Co_xSe_2$ satisfies the main general requirements of semiconductor strain gauges: - if possible, a high strain sensitivity coefficient; linear dependence of resistance change with deformation; no hysteresis characteristics; minimal sensitivity to the influence of side external physical factors.

The parameters listed above are determined mainly by the properties of the semiconductor material itself, although they can also be significantly influenced by the technology of manufacturing strain gauges.

To emphasize the uniqueness of the proposed new material $TlIn_{1-x}Co_xSe_2$, first of all, we note that their characteristics should be compared with the parameters of the known and most widely used materials in semiconductor strain gauges.

Experimental technique: Alloys of a given composition were synthesized by fusing components in accordance with stoichiometry in evacuated to a pressure of 1.2×10^{-4} mm. rt. Art. quartz ampoules with a diameter of 12 - 15 mm, a melt height of 50 - 60 mm, especially pure elements were used as initial components: thallium 000, indium 000, cobalt 000, sulfur of high purity - 16 - 5 and selenium of high purity - 17 - 4.

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Single crystals were grown by the improved Bridgman-Stockbarger method using electronic temperature controllers to maintain the optimal thermal regime during crystallization. The directional crystallization rate was about 0.9 mm/h. $TlIn_{1-x}Co_xSe_2$ single crystals had p-type conductivity. Samples for research were made by cleaving single crystals in two mutually perpendicular planes of natural cleavage and had the shape of a rectangular parallelepiped. The dimensions of the studied samples were 10x10x0.25 mm^3. Ohmic contacts are obtained by spot welding of the corresponding wires (ø = 0.01 mm) by a capacitor discharge on the ends of samples heated in an inert gas flow [1-3].

The strain sensitivity of the samples was measured in the temperature range of 300–410 K in the static mode specified by the method in [4]. In this case, the permanent deformation was transferred to the measured crystal using a special device designed for this purpose (Fig. 1).

static mode. Permanent deformation was transferred to the measured crystal using a special device designed for this purpose (Fig. 1). The measured crystal 1, in the form of the thinnest (1 - 10 µm thick) rectangular "hairs" with the mirror faces of a natural cleavage, was glued onto a flat steel plate 2, with a thickness t, bent by moving its middle part (by Δh) relative to the plane of the sharp ends of the two side supports 3, spaced ℓ. The value of relative deformation and was calculated by the formula:

$$\varepsilon = \frac{4t}{\ell^2}\,\Delta h \qquad (1).$$

And in the case when the static deformation of the crystal 1 was carried out by bending the free end of the calibration cantilever beam 2, thickness t and length ℓ from the fixed reference point 3, the relative deformation at a given distance of the crystal "a" from the free end was calculated by the formula:

$$\varepsilon = \frac{3at}{\ell^3}\,\Delta h \qquad (2).$$

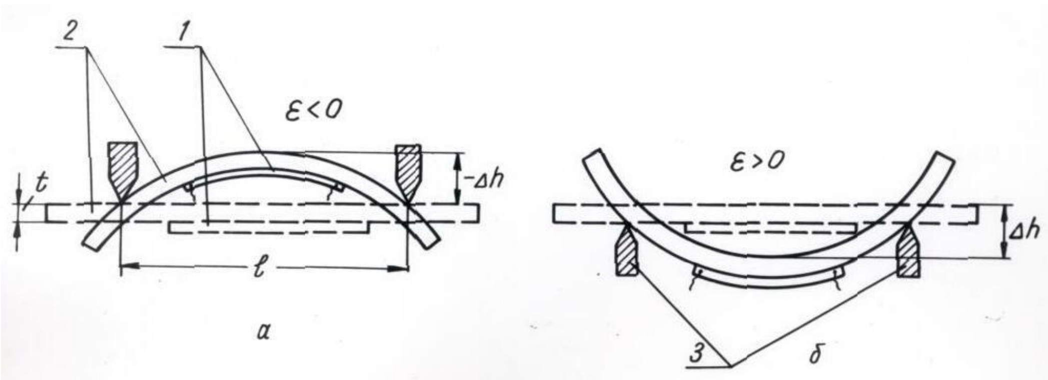

Fig.1. Schematic view of a device for measuring relative deformations in static mode: 1 - crystal, 2 – steel beam, 3 - side supports [4]

Research results and discussion. The study of $TlIn_{1-x}Co_xSe_2$ crystals in this regard led to very interesting results. First of all, it should be emphasized that crystals of solid solutions $TlIn_{1-x}Co_xSe_2$ show a strong piezoresistive effect in the [001] direction, which, in combination with their mechanical, elastic, crystallographic and a number of other features, makes them promising for creating new miniature highly sensitive and reliable electromechanical converters. as sensors of displacement, force, pressure, etc.

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The efficiency of new $TlIn_{1-x}Co_xSe_2$ crystals in comparison with known crystals in semiconductor strain gauges is mainly provided by the following three features, namely: - high (record) strain sensitivity (see table 1); high elasticity and tensile strength; the ability to easily cleave onto the desired identical filiform rectangular plates with mirror edges in the direction of maximum piezoresistive effect [4,5]. $TlIn_{1-x}Co_xSe_2$ crystals in their sensitivity to deformation significantly exceed all materials known to date in semiconductor strain gauges (Table 1).

Table 1. The average value of the strain sensitivity coefficient ($K_{Aver.}$) of solid solutions $TlIn_{1-x}Co_xSe_2$ ($0 \le x \le 0.5$) compared to the initial $TlInSe_2$ crystals along the [001] axis

№	Load cell crystal composition	$K_{Aver.}$, When compressed	$K_{Aver.}$, Tensile	Note
1.	$TlInSe_2$	577	406	With relative deformation $\varepsilon = 0{,}57 \cdot 10^{-3}$ T = 300 K
2.	$TlIn_{0,99}Co_{0,01}Se_2$	2752	6641	
3.	$TlIn_{0,9}Co_{0,1}Se_2$	2839	6881	
4.	$TlIn_{0,5}Co_{0,5}Se_2$	2941	7143	

The effect of temperature on the tensoresistive properties of $TlIn_{1-x}Co_xSe_2$ single crystals has been studied. The temperature dependence of the initial resistance and the change in the piezosensitivity coefficient with temperature are the most important indicators of semiconductor strain gauge materials. In the case of applying semiconductor strain gauges to a part with a variable temperature, it becomes necessary to take into account both changes. The change in the initial resistance of the sensor with temperature is taken into account by applying appropriate compensation methods, and the change in strain sensitivity is taken into account by introducing a correction. Nevertheless, the loss in sensitivity at elevated temperatures turned out to be inevitable: for the strain sensitivity of all materials known in semiconductor strain gauges decreases significantly with increasing temperature. In this regard, the following valuable specificity of $TlIn_{1-x}Co_xSe_2$ crystals deserves special attention, with an increase in temperature, the sensitivity to deformation increases significantly (Table 2). In this case, the strain gauge coefficient increases linearly with temperature. The strain-sensitivity coefficient of $TlIn_{1-x}Co_xSe_2$ crystals of various compositions depending on temperature and relative deformation is given in table 2.

The temperature coefficient of strain sensitivity per unit degree in percent is given in Table 3. The temperature coefficient of strain sensitivity of these crystals varied markedly from sample to sample, depending on its resistance - the concentration of impurities. The samples with the highest concentration of impurities were characterized by the lowest value of the above temperature coefficients. The value of the latter significantly depended on the considered regions of the temperature interval.

Table 2. Dependence of the strain-sensitivity coefficient of solid solutions $TlIn_{1-x}Co_xSe_2$ on the composition and temperature

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№	T, K	$TlInSe_2$	$TlIn_{0,99}Co_{0,01}Se_2$	$TlIn_{0,9}Co_{0,1}Se_2$	$TlIn_{0,5}Co_{0,5}Se_2$	Note
1.	300	577	1741	2839	2951	With relative deformation $\varepsilon = 0,57\cdot10^{-3}$
2.	320	586	2442	3652	3460	
3.	350	592	3170	4841	5011	
4.	375	610	3930	5184	5928	
5.	410	655	4242	6088	7466	

Table 3. Temperature coefficient of strain sensitivity (G_T) of single crystals of solid solutions $TlIn_{1-x}Co_xSe_2$ on the composition

№	$T_{Aver.}$, K	$TlInSe_2$	$TlIn_{0,99}Co_{0,01}Se_2$	$TlIn_{0,9}Co_{0,1}Se_2$	$TlIn_{0,5}Co_{0,5}Se_2$	Примечание
1.	310	0,078	2,01	1,43	0,86	$T_{cp} = 20 + \frac{1}{2}\Delta T$
2.	325	0,052	1,64	1,41	1,39	
3.	337,5	0,034	1,67	1,10	1,34	
4.	355	0,052	1,31	1,04	1,39	

Thus, strain gauges made of $TlIn_{1-x}Co_xSe_2$ crystals make it possible to provide high registration accuracy under temperature-controlled operating conditions.

On the basis of the indicated advantages of $TlIn_{1-x}Co_xSe_2$ single crystals, we created strain gauge measuring transducers, with which you can solve the following diverse tasks in several areas of their application:

•research of physical properties of materials, strains and stresses in parts and structures;

• the use of strain gauges to measure mechanical quantities that are converted into deformation of the elastic element;

• the use of strain gauges in medical practice, for the simultaneous determination of temperature at various points of the human body, by the method of multipoint strain gauge with an accuracy of 0.01 degrees;

• in pulmonological studies can be used to determine the parameters of human lungs during breathing, using the effect of elastic deformation of the chest by the piezoelectric method, which can convert the deformation of a TlInSe2 single crystal caused by mechanical stress applied to it into an electrical signal. Например, respiratory rate (HR), tidal volume (TV), inspiratory minute volume (IMV), inspiratory reserve volume (IRV), expiratory reserve volume (ERV), and vital capacity (VC), breath holding on inhalation and exhalation, etc.

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Conclusion. In conclusion, it should be emphasized that the presence of a strong piezoresistive effect in $TlIn_{1-x}Co_xSe_2$ crystals allows us to hope that they can be used to create highly sensitive sensors for displacement, force, pressure, acceleration, and torque sensors. It should also be noted that it is possible to significantly increase the sensitivity of sensors made of $TlIn_{1-x}Co_xSe_2$ single crystals to measured values using heating and optical illumination..

The theoresist properties of these single crystals of solid solutions remain stable with thousands of repetitions of the deformation and temperature test cycles at variable deformation ($p = \pm 1.4 \cdot 10^7$ Pa) does not exceed 1 - 2% and it is more stable at critical temperatures and long-term loads compared to those known in literature of strain gauges, which indicates that $TlIn_{1-x}Co_xSe_2$ single crystals are promising materials for the creation of miniature - highly sensitive medical devices

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