AMERICAN JOURNAL OF SOCIAL AND HUMANITARIAN RESEARCH

ISSN: 2690-9626
Vol.3, No 6, 2022

Influence of the Ratio of the Components of Indium with Cobalt on the Electro Physical and Tensoresistive Properties of $Tlin_{1-X}Co_xSe_2$ ($0 \leq X \leq 0.5$)

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ANNOTATION: The paper presents the results of a study of the effect of the ratio of cobalt components on the electro physical and strain-resistive characteristics of TlIn1-xCoxSe2 alloys in the concentration range of cobalt x = 0-0.5. it is established that in the range of x = 0 - 0.02 these properties have linear concentration dependencies, which undergo sharp changes in the range of 0.02 - 0.5.

KEYWORD: ratios of cobalt components, electro physical, strain-resistive characteristics, concentration range.

Introduction: In the study of various properties of solid materials, an important place is occupied by the study of their tensometric properties. The study of the tensoresistive properties of semiconductors and dielectric compounds makes it possible to obtain information about their band structure, about local color centers, trapping, recombination, etc. According to the study of the tensometric properties of complex semiconductor materials, including $A^{III}B^{III}C_2^{VI}$ and solid solutions based on them $TlIn_{1-x}Co_xSe_2$, makes it possible to create highly sensitive miniature strain gauges.

The use of strain gauges in various fields of science and technology brings significant benefits to the national economy. With the help of a flexible measuring instrument which is characterized by simplicity, reliability, speed, stability, economy, small overall dimensions and weight, low cost, various problems are successfully solved, such as studying constant and variable elastic and plastic deformations, measuring mechanical stresses in various crystallographic axes, forces, pressures, moments and other physical parameters. Currently, more than 80% of mechanical transducers use strain gauges.

The successes of modern electronics, in particular integrated microelectronics, which provide the possibility of creating inexpensive compact and highly sensitive reliable amplifiers and converters for matching the low-power output of strain gauges with the actuators of electronic automation devices, have contributed to the increasing use of strain gauge devices and systems for automatic control,

ISSN 2690-9626 (online), Published by "Global Research Network LLC"
under Volume: 3 Issue: 6 in Jun-2022 https://grnjournals.us/index.php/AJSHR

signalling and regulation of various technological and test processes, equipment diagnostics, including human organs.

However, the existing information in the literature on strain gauge does not sufficiently reflect the issues of practical application of strain gauges in specific systems of industrial automation, astronautics, modern medicine, etc. cannot answer with the necessary completeness the questions that arise when designing the use of strain gauge devices.

There is almost no systematized information in the literature. Therefore, the growing needs of modern micro- and optoelectronics stimulate the development of scientific research in the direction of the search for new semiconductor materials, which, in particular, have a specific structure of the crystal lattice. Such materials also include low-dimensional chalcogenides having layered and chain structures. Recently, many interesting features of their electrical, photoelectric, optical and tensoresistive properties have been revealed, as well as the prospects for their practical use. However, to date, their potential is far from being fully disclosed.

In this regard, the purpose of this work, the influence of the ratio of the components of indium with cobalt on the electrical and tensoresistive characteristics of single crystals of solid solutions $TlIn_{1-x}Co_xSe_2$ ($0 \leq x \leq 0.5$) is relevant.

Samples for research and experimental technique: Large homogeneous pure and doped $TlInSe_2$ single crystals and solid solutions based on them $TlIn_{1-x}Co_xSe_2$ ($0 \leq x \leq 0.5$) necessary for physical research were grown by Professor S. Kh. Umarov at the Institute of Physics of the National Academy of Sciences of Azerbaijan , improved by the Bridgman - Stockbarger method [1 - 3]. The starting materials for the synthesis were elements of high purity: thallium Tl - 000; cobalt Co - 000, indium In - 000, selenium OSCh 17 - 4. Crystals grew in evacuated (up to 10^{-4} mm. rt. st.) and sealed quartz ampoules. The temperature of the melting zone during the growth of single crystals was T_1 = 1060 K, the annealing temperature was T_2 = 960 K, and a temperature gradient of 25 deg /cm was created in the crystallization zone.

The authors of [2] succeeded in growing single crystals with the desired geometric configurations of various sizes, and the perfect thin plates of the grown single crystals turned out to be quite flexible and withstood bending with a radius of curvature of about 3 mm. Table 1 shows the growth modes and some characteristics of the obtained single crystals of $TlInSe_2$ and $TlIn_{1-x}Co_xSe_2$ ($0 \leq x \leq 0.5$). The crystals obtained in this way were easily chipped along the basal plane and had a mirror-smooth surface.

Table 1. Growing regime and some characteristics single crystals of $TlIn_{1-x}Co_xSe_2$ solid solutions.

Co concentration, x	Temperature zone, T, K		Speed crystallization, mm / hour	Dimensions single crystals mm^3	Conductivity type	ρ,at 300K, Om·cm	ρ,at 77K, Om·sm
	I zone	II zone					
0	1110-1020	1015-910	0,9-1,0	60x15x8	p	$6{,}4\cdot10^6$	$1{,}9\cdot10^9$
0,1	1090-1020	1010-890	- " - " -	60x15x8	p	$4{,}0\cdot10^6$	$2{,}0\cdot10^9$
0,2	1070-1015	1000-850	- " - " -	60x15x6	p	$2{,}5\cdot10^4$	$3{,}3\cdot10^6$
0,3	1070-1010	990-860	- " - " -	60x12x8	p	$4{,}4\cdot10^4$	$3{,}5\cdot10^7$
0,4	1060-1010	980-860	- " - " -	60x15x6	p	$2{,}3\cdot10^4$	$3{,}6\cdot10^6$
0,5	1050-1010	970-850	- " - " -	60x12x8	p	$2{,}8\cdot10^3$	$3{,}1\cdot10^5$

ISSN 2690-9626 (online), Published by "Global Research Network LLC"
under Volume: 3 Issue: 6 in Jun-2022 https://grnjournals.us/index.php/AJSHR

The manufacturing technology of semiconductor strain gauges is very complex, time - consuming and costly. Difficulties are mainly caused by cutting and processing the necessary whiskers, which are inevitably accompanied by such labor-intensive operations as mechanical cutting of materials, grinding of workpieces, special chemical processing (chemical - dynamic etching is usually used to remove a mechanically disturbed surface layer after grinding) and, finally, finishing workpieces for strain gauges. The specificity of the crystal structure features of the layered $TlInSe_2$ crystals studied by us and solid solutions based on them, i.e. folded semiconductors, systems allows manufacture strain gauges using a very simple technology that does not require the painstaking operations listed above.

The task is simplified by the use of "fresh" chips, chipped off without much difficulty from a massive ingot of standard thin strain-sensitive plates with opposite vertical mirror faces of a natural chip (section 0.01 - 0.2 mm^2, length 1 - 40 mm).

We obtained the identical crystals necessary for the study by simply pressing a sharp knife with a blade thickness of ≤ 0.01 mm onto the loose end of a thin, but wide and long single crystal plate at an angle of 45°.

After setting the selected step, which determines the width of the blanks along the sight lines, the semiconductor plate, together with the micromanipulator table, moves under the microscope across the cleavage line. The "needle" crystals obtained by this method are obtained with mirror faces without any additional processing and are ready for welding the leads and placing them on the base of the substrate.

When soldering "antennae", i.e. when creating mechanically reliable ohmic contacts on the above workpieces, two methods were used:

1) the direct spot welding of the corresponding wires by a capacitor discharge to the ends of a billet heated in an inert gas flow;

2) fusion of indium onto a workpiece in an inert gas flow, followed by soldering of nickel or copper wires with a diameter of Ø = 0.01mm.

The first method turned out to be more reliable and efficient (especially for moderate temperatures).

Steel plates 45 with a length of 20 mm to 80 mm and a thickness of 0.5 - 1mm served as calibration beams for gluing the sensors. According to the processing class, the surface of the substrate corresponded to class 7. Medium-carbon steel grade 45 contains 0.45% carbon, and the remaining impurities are extremely small, and therefore steel of this grade has increased strength and belongs to structural and high - quality materials.

Research results and discussion: We have studied the influence of the Co impurity concentration on some electrical and tensoresistive characteristics of crystals of the $TlIn_{1-x}Co_xSe_2$ system at concentration values x = 0 - 0.5 [4 - 6].

Table 2 shows the results of measurements of the electrical properties of alloys of the $TlIn_{1-x}Co_xSe_2$ system in the range of cobalt concentration x = 0 - 0.5. The data obtained show that the resistivity ρ decreases linearly with the concentration x of cobalt in the ranges x = 0 - 0.02 and 0.02 - 0.5, forming a characteristic break at the concentration x = 0.02 (see Fig. 1).

ISSN 2690-9626 (online), Published by "Global Research Network LLC"
under Volume: 3 Issue: 6 in Jun-2022 https://grnjournals.us/index.php/AJSHR

Table 2. Electrophysical parameters of $TlIn_{1-x}Co_xSe_2$ crystals.

Strain Gage Crystal Compositions	$TlInSe_2$	$TlIn_{0,99}Co_{0,01}Se_2$	$TlIn_{0,98}Co_{0,02}Se_2$	$TlIn_{0,97}Co_{0,03}Se_2$	$TlIn_{0,95}Co_{0,05}Se_2$	$TlIn_{0,9}Co_{0,1}Se_2$	$TlIn_{0,7}Co_{0,3}Se_2$	$TlIn_{0,5}Co_{0,5}Se_2$
Resistivity, Om.cm	$6400 \cdot 10^4$	$3300 \cdot 10^4$	$510 \cdot 10^4$	$480 \cdot 10^4$	$460 \cdot 10^4$	$400 \cdot 10^4$	$194 \cdot 10^4$	$0,28 \cdot 10^4$
Sample sizes, mm^3	60x15x8	60x15x8	60x15x6	60x12x8	60x15x6	60x15x8	60x15x6	60x12x8

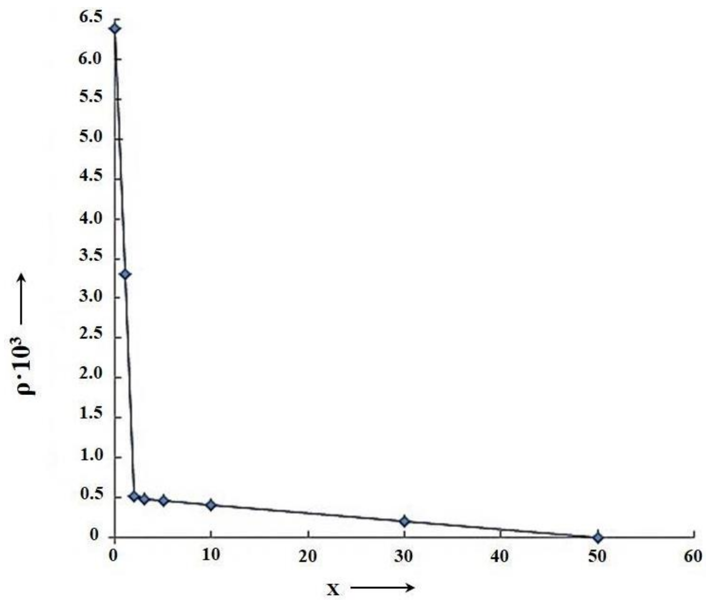

Fig.1. Dependence of the resistivity *ρ* of $TlIn_{1-x}Co_xSe_2$ alloys on the concentration of Co.

In the concentration dependences of the strain sensitivity factor $\mathbf{K}_\varepsilon$, a break also occurs precisely at the cobalt concentration $x = 0.02$ (see Table 3 and Fig. 2).

Table 3. Strain sensitivity coefficients K_ε of solid solutions $TlIn_{1-x}Co_xSe_2$

($0 \le x \le 0.5$) compared with $TlInSe_2$ crystals along the [001] axis.

№	Load cell crystal composition	K_ε, under compression	K_ε, under tension	Note
1.	$TlInSe_2$	577	406	With relative deformation $\varepsilon = 0,57 \cdot 10^{-3}$ T = 300K
2.	$TlIn_{0,99}Co_{0,01}Se_2$	1741	4041	
3.	$TlIn_{0,98}Co_{0,02}Se_2$	2730	6800	
4.	$TlIn_{0,97}Co_{0,03}Se_2$	2760	6830	
5.	$TlIn_{0,95}Co_{0,05}Se_2$	2800	6849	
6.	$TlIn_{0,9}Co_{0,1}Se_2$	2839	6881	
7.	$TlIn_{0,7}Co_{0,3}Se_2$	2903	6993	
8.	$TlIn_{0,5}Co_{0,5}Se_2$	2951	7143	

ISSN 2690-9626 (online), Published by "Global Research Network LLC"
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When studying the nominal, specific resistances and strain sensitivity coefficients of $TlIn_{1-x}Co_xSe_2$ alloys in the concentration range x = 0 - 0.5, it was found that these properties undergo sharp changes at a cobalt concentration x = 0.02. On the one hand, $TlInSe_2$ compounds crystallize according to the

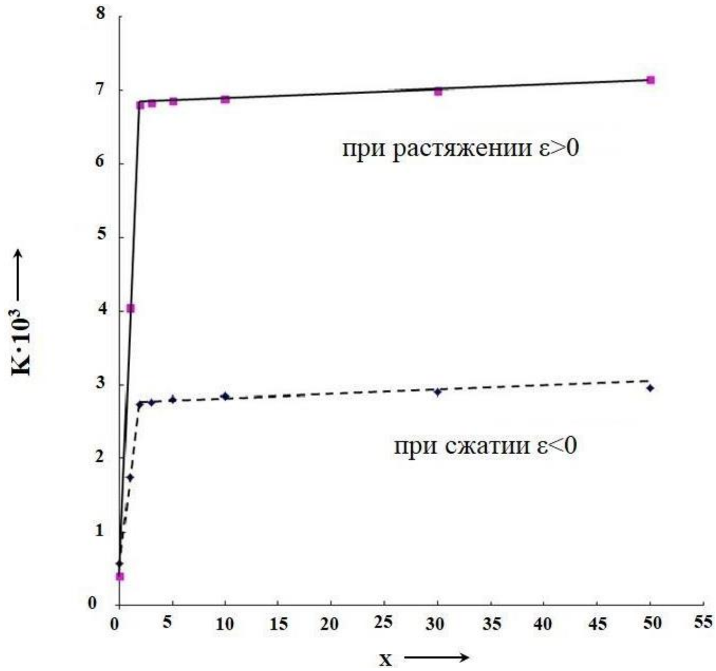

Fig.2. Dependences of the strain-sensitivity coefficient of $TlIn_{1-x}Co_xSe_2$ alloys along the [001] axis on the concentration of Co.

tetragonal system with lattice parameters a = 8.075 Å, c = 6.847 Å [7], and $TlCoSe_2$ compounds crystallize according to the hexagonal system with parameters a = 3.747 Å, c = 22.772 Å [8], on the other hand on the other hand, due to the large difference in the sizes of the covalent ionic radii of indium (1.497 Å) and cobalt (1.09 Å); these two compounds cannot form an unlimited solid solution, but can only form a limited solid solution over a narrow concentration range. Therefore, it is assumed that, by analogy with the $Tl_{1-x}Cu_xInSe_2$ system, limited solid solutions are formed in the $TlIn_{1-x}Co_xSe_2$ system at the concentration range x = 0 - 0.02, and in the range x = 0.02 - 0.5 alloys are multiphase. Therefore, when this boundary is crossed, a sharp change in the physical properties of the alloys occurs which is reflected in the form of a break in the figures, and which indicates a sharp difference in the mechanisms of the above phenomena, the establishment of which requires special studies.

As can be seen from Table 3, a strong tensoresistive effect is manifested in all the studied samples at room temperature both under compression and under tension of the crystals in the [001] direction. The strain sensitivity coefficient both for positive and negative strains increases with increasing Co concentration in $TlIn_{1-x}Co_xSe_2$ solid solutions.

The temperature dependence of the resistance of samples and the change in the strain gauge coefficient with temperature are among the important indicators of semiconductor strain gauge materials [9]. Therefore, the influence of the temperature of solid solutions on the strain gauge coefficient in the temperature range 300 K ≤ T ≤ 410 K was studied. Experiments show that with an increase in the temperature of the samples, their sensitivity to deformation significantly increases in all the compositions of $TlIn_{1-x}Co_xSe_2$ solid solutions studied by us (see Table 4).

ISSN 2690-9626 (online), Published by "Global Research Network LLC"
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Temperature coefficients of strain sensitivity per degree G_T in percent are given in Table 5. G_T of the studied crystals varied markedly from sample to sample depending on the concentration of Co in the compounds.

The value of the temperature coefficient of strain sensitivity significantly depends on the considered areas of the temperature interval. These results show that, unlike most semiconductor strain gauge materials, in crystals of solid solutions $TlIn_{1-x}Co_xSe_2$, with increasing temperature, it is possible to increase the sensitivity of strain gauges. Thus, strain gauges based on $TlIn_{1-x}Co_xSe_2$ make it possible to provide high registration accuracy under temperature-controlled operating conditions.

Table 4. Strain sensitivity coefficients during compression of $TlIn_{1-x}Co_xSe_2$ crystals depending on the composition and temperature [5].

№	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 $\varepsilon = 0{,}57\cdot 10^{-3}$
2	320	586	2442	2930	3715	
3	350	592	3170	4691	5011	
4	375	610	3930	5184	5928	
5	410	655	4242	6088	7466	

Table 5. Temperature coefficient of strain sensitivity (G_T) of $TlIn_{1-x}Co_xSe_2$ crystals depending on the composition.

№	T_{cp}, 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.	310	0,078	2,01	1,43	0,86	$G_T = \frac{\Delta K / K_0}{\Delta T}\cdot 100\%$, $T_{cp} = 300 + \frac{1}{2}\Delta T$
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	

As already noted, the temperature dependence of the resistance and the change in the strain gauge coefficient with temperature are the most important indicators of semiconductor strain gauge materials. In the case of applying semiconductor strain gauges to parts with variable temperature, it becomes necessary to take into account and change the resistance and thermal change in the strain gauge coefficient of the sensors. Changes in the resistance of the sensor with temperature are taken into account by applying appropriate compensation methods, and changes in strain gauge - by introducing a correction.

The conducted studies have shown that crystals of solid solutions of the $TlIn_{1-x}Co_xSe_2$ system, due to the relatively high strain sensitivity, significant flexibility and the ability to chip off onto the desired filamentous plates with mirror faces in the direction of the maximum strain-resistive effect [001], and also due to the linear temperature dependence of the strain - sensitivity in the range of $300 \leq T \leq 410$ K are efficient materials for semiconductor strain gauge.

The above experimental results show that in the single-phase region of the studied solid solutions, an increase in the concentration of copper or cobalt leads to a significant linear change in the resistivity, light resistance coefficient, and strain sensitivity coefficient of strain gauges made on the basis of $TlInSe_2$ crystals. Upon transition to the two - phase region, the properties of solid solutions change abruptly, which indicates a sharp difference between the mechanisms of the above phenomena in different concentration ranges of substitution atoms.

Conclusion: When studying the influence of the ratio of components on the electrical and tensoresistive characteristics of $TlIn_{1-x}Co_xSe_2$ alloys in the concentration range of cobalt x = 0 - 0.5, it

ISSN 2690-9626 (online), Published by "Global Research Network LLC"
under Volume: 3 Issue: 6 in Jun-2022 https://grnjournals.us/index.php/AJSHR

was found that in the range x = 0 - 0.02 these properties have linear concentration dependences that undergo sharp changes in the range 0.02 - 0.5. It is assumed that in the $TlIn_{1-x}Co_xSe_2$ system at the concentration range x = 0 - 0.02 limited solid solutions are formed, and in the range x = 0.02 - 0.5 the alloys are multiphase.

At room temperature, the strain-sensitivity coefficient both for positive and negative deformations along the [001] direction increases with increasing Co concentration in $TlIn_{1-x}Co_xSe_2$ solid solutions

It has been established that with an increase in temperature in the region of $300 \leq T \leq 410$ K, in all the studied compositions of the $TlIn_{1-x}Co_xSe_2$ solid solution, the sensitivity to deformation increases significantly.

Studies of the tensoresistive properties of crystals of solid solutions $TlIn_{1-x}Co_xSe_2$ in the cobalt concentration range $0 \leq x \leq 0.5$, as well as the temperature dependence of the strain sensitivity of these crystals in the range $300 \leq T \leq 410$ K, showed their promise as effective materials for electronic technology.

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