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MINIATURE HIGH-SENSITIVITY SENSORS FOR MEDICAL DEVICES FOR POOR CITIZENS

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Abstract

Multicomponent anisotropic semiconductors I-III-VI2 have ample opportunities for practical application in optoelectronics. The ternary compound CuInSe2 is used as an absorbing layer in high-efficiency solar cells. With a band gap Eg ≈ 1.05 eV, it is characterized by an exceptionally high absorption coefficient (α_L ≥ 105 cm–1). The basis for many photoconverters are heterojunctions created between CdS and CuInSe2, but the metal–CuInSe2 structure can also be a simple and cheap alternative. The study of concentration dependencies of resistivity and strain-sensitivity coefficients of single crystals of TlInSe2-CuInSe2 solutions grown by the Bridgman-Stockbarger method revealed important parameters of semiconductor materials based on theoretical calculations and experimental studies of concentration dependencies of specific conductivity both in the absence and presence of one-sided deformation along the tetragonal axis [001]. The dependence of the sensitivity factor of strain-sensitive elements of Tl1-xCuxInSe2 (0 ≤ X ≤ 0.025) alloys along the axis [001] on the concentration of Cu was determined, and it was found that the tensoresistive properties of these crystals remain stable under repeated exposure to external physical factors.

Keywords: Lattice, mathematics systems, physical model, semiconductors, thermal expansion, vibrational spectrum

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1. Introduction

TlInSe2 crystals are one of the representatives of partial-valency compound semiconductors. The unit cell of these crystals contains two independent structural units that ensure different coordination, valence state and nature of chemical bonds for the components of different cations of the same group. These characteristics, as well as the possibility of introducing aliovalent impurities into the TlInSe2 crystal lattice increased the interest in the studies of the electronic structure and properties of this class of crystals.

2. Problem Statement

The works (Ashurov & Nuritdinov, 2017; Evloev & Borova, 2018) revealed that the introduction of Cu impurity into the structure leads to an increase in electrical conductivity, photosensitivity, increases the sensitivity factor of strain-sensitive elements and decreases the current noise and reduces the dark current of $TlInSe_2$-based photoresistors.

3. Research Questions

The purpose of this work is to study the effect of the change in copper concentration on some electrophysical and tensoresistive properties of $Tl_{(1-x)}Cu_xInSe_2$ crystals at the concentration x = 0–0.1

4. Purpose of the Study

The size of the samples to measure the tensoresistive properties were 10x10x0.25 mm^3. Ohmic contacts were obtained by spot welding of corresponding wires by capacitor discharge on the ends of samples heated in an inert gas stream and on the cleavage, and provided a linear character of voltage-current characteristics up to electric field strengths of E = 100 V/cm. The tensosensitivity of the samples in the direction [001] was measured in a static mode according to the method described in (Umarov & Nuritdinov, 2017) in the temperature range of 300–410 K. The study of the electrical properties of $TlInSe_2$ – $CuInSe_2$ single crystals and the production of these materials, structures and devices cause the need to measure the specific electrical resistance or the specific electrical conductivity of semiconductor materials.

5. Research Methods

$Tl_{(1-x)}Cu_xInSe_2$ in the form of single-crystal ingots, samples of various geometric shapes, plates, diffusion, epitaxial and ion-doped layers, which compose a certain part of semiconductor structures. The method of measurement is chosen taking into account the required information, peculiarities of tested material, possibility of making electrical contacts, geometric shape of samples, metrological characteristics of the measurement method. Ideally, the measurements of the characteristics of $Tl_{(1-x)}Cu_xInSe_2$ solid solution single crystals should not lead to the destruction of the sample and should not require its special treatment.

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6. Findings

Table 01 shows the results of measurements of the electrophysical and photovoltaic properties of $Tl_{(1-x)}Cu_xInSe_2$ alloys in the copper concentration range of x = 0–0.1, which demonstrates that the nominal resistance of alloys R and the specific resistance ρ on copper concentration x in the intervals x = 0–0.025 and 0.025–0.1 decrease linearly forming a characteristic fracture at the concentration of x = 0.025. The copper concentration of x = 0.025 causes a jump in the coefficients of light resistance and light sensitivity of doped samples. Under compression and tension the concentration dependencies of the average value of the sensitivity factor of strain-sensitive elements K also cause a fracture or a jump at the copper concentration of x = 0.025 (Figure 01 and Table 02). Based on differential thermal and X-ray phase analyses, as well as on the measurements of specific electrical conductivity and density of alloys, the authors (Georgobiani et al., 2005; Matiev & Uspazhiev, 2019; Umarov & Hallokov, 2018) found that tetragonal cell parameters are formed within $TlInSe_2$-$CuInSe_2$ system, thus forming a characteristic fracture at the concentration of x = 0.025, which is explained by the phase change in the system at this concentration. It is worth noting that the discovered fractures or jumps in the concentration dependencies of the studied physical properties within $Tl_{(1-x)}Cu_xInSe_2$ system occur precisely at x = 0.025. All this shows that in the field of solid solutions many properties of $Tl_{(1-x)}Cu_xInSe_2$ system, including nominal and specific resistance, light resistance coefficients, light sensitivity and strain sensitivity at fixed temperatures, have linear concentration dependencies that undergo a sharp change during the transition of solid solutions, which is caused by the concentration phase changes in $Tl_{(1-x)}Cu_xInSe_2$ system. The studies of the structure and photovoltaic properties of these crystals (Ismailov et al., 2017; Jabarov et al., 2021; Matiyev, 2021) are well consistent with the presented results.

Table 1. Electrophysical and photovoltaic parameters of $Tl_{(1-x)}Cu_xInSe_2$ crystals

Strain gauge alloy composition	Kav, under compression	Kav, under tension
$TlInSe_2$	464	464
99% $TlInSe_2$-1% $CuInSe_2$	280	862
98% $TlInSe_2$-2% $CuInSe_2$	162	1115
97% $TlInSe_2$-3% $CuInSe_2$	122	341
95% $TlInSe_2$-5% $CuInSe_2$	149	411
90% $TlInSe_2$-10% $CuInSe_2$	300	697

Table 2. Average tensosensitivity factor (Kav) of $Tl_{(1-x)}Cu_xInSe_2$ alloys along axis [001]

Strain gauge crystal compositions	Rated resistances, Ohm	Specific resistance, Om·cm	Light resistance factors, %/lx	Light sensitivity factors, %/lx	Sample sizes, mm^3
$TlInSe_2$	6.87×10^{10}	21.26×10^6	-1.03×10^3	1.76×10^3	0.13×0.25×10.5
99% $TlInSe_2$-1% $CuInSe_2$	4.49×10^{10}	13.7×10^6	-4.01×10^3	4.36×10^3	0.13×0.23×9.8
98% $TlInSe_2$-2% $CuInSe_2$	1.32×10^{10}	6.4×10^6	-7.21×10^3	7.8×10^3	0.16×0.24×7.9
97% $TlInSe_2$-3% $CuInSe_2$	4.3×10^9	2.5×10^6	-3.56×10^3	1.20×10^3	0.19×0.26×8.5
95% $TlInSe_2$-5% $CuInSe_2$	2.86×10^9	1.6×10^6	-4.25×10^3	1.42×10^3	0.14×0.24×6
90% $TlInSe_2$-10% $CuInSe_2$	2.64×10^9	1.31×10^6	-	-	0.14×0.23×6.5

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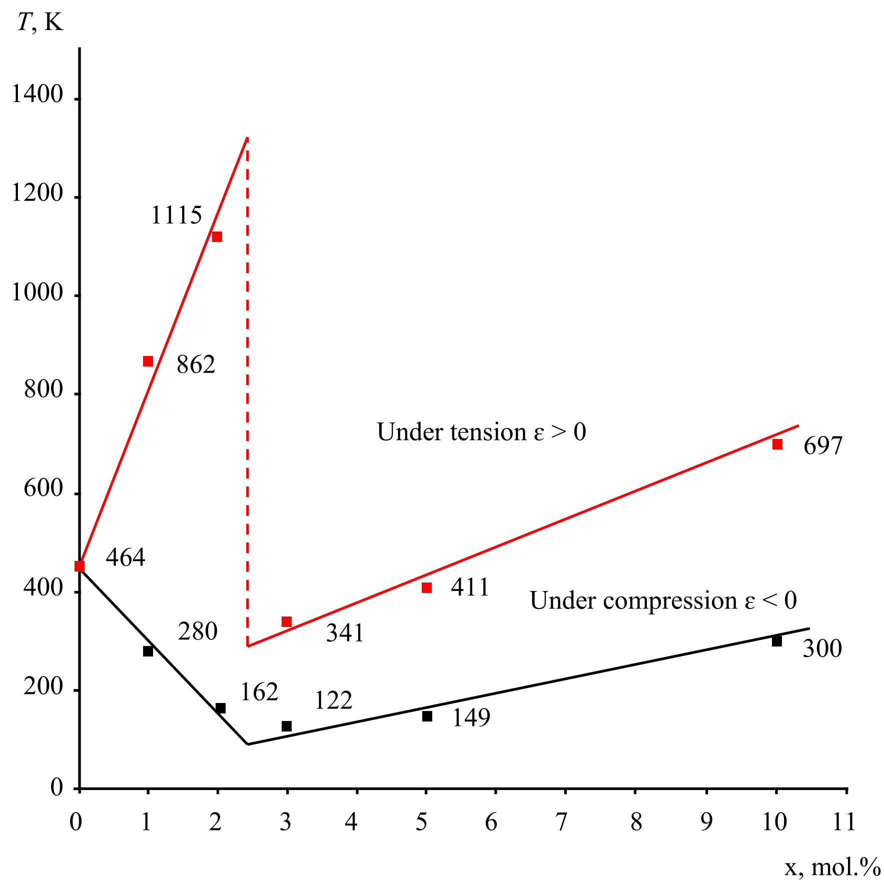

Figure 1. Dependence of the tensosensitivity factor of $Tl_{(1-x)}Cu_xInSe_2$ alloys along the axis [001] on Cu concentration

7. Conclusion

Based on above advantages of $Tl_{(1-x)}Cu_xInSe_2$ single crystals we created strain measuring transducers, which are able to address the following tasks in several fields of their application:

i. to study the physical properties of materials, deformations and stresses in parts and structures;

ii. to use strain gauges to measure mechanical values converted into the deformation of the elastic element;

iii. to use strain gauges in medical practice for simultaneous determination of temperature in different points of the human body by multipoint strain gauging with the accuracy of 0.01 degrees;

iv. to use strain gauges in pulmonological studies to determine the parameters of human lungs during breathing, using the influence of elastic deformation of the chest by the piezoeffect method, which can convert the deformation of TlInSe2 single crystal caused by mechanical stress applied to it into an electrical signal. For example, respiratory capacity, minute inspiratory capacity, inspiratory reserve volume and expiratory reserve volume, vital lung capacity, inspiration and expiration breath hold, etc.

In conclusion it should be emphasized that the presence of a strong piezoresistive effect in $Tl_{(1-x)}Cu_xInSe_2$ crystals holds out the prospect that it is possible to create high-sensitivity sensors of movement, force, pressure, acceleration, and torque on their basis. It should also be noted that it is possible to significantly increase the sensitivity of sensors from $Tl_{(1-x)}Cu_xInSe_2$ single crystals to the measured values using heating and optical lighting.

The thesoresistive properties of these solid solution single crystals remain stable at thousand-fold repetitions of deformation and temperature test cycles at variable deformation ($p = \pm 1.4 \cdot 10^7$ Pa) not exceeding 1–2% and it is more stable at critical temperatures and long-term loads compared to the strain gauges known in the literature, which indicates that $Tl_{(1-x)}Cu_xInSe_2$ single crystals are promising materials for the creation of miniature highly-sensitive medical devices.

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