SEMICONDUCTOR SENSOR FOR DETECTING VOLUME CHANGES AT LOW TEMPERATURES.

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Abstract: The article discusses the technological aspects of the production of stoichiometric alloys with the addition of Pb with high thermoelectric properties and their use in the film version as sensors for volume changes at low temperatures.

Keyword: adhesion, deformation, defect, alloy, thermoelectricity, strain sensitivity.

Introduction. To study the strength of structures, it is necessary to measure local deformations, forces, pressure, temperatures, displacement, control the moments of occurrence of defects and the speed of their development. At the same time, special requirements are imposed on measuring devices: ensuring high metrological characteristics of each individual measurement, provided that the measurements are massive. Mass measurements are understood to mean measurements during which a correspondence is established between the measured value and the reference value for a plurality of homogeneous sensors of primary transducers.

Material and Methods: Upon receipt of semiconductor materials, the thermoelectric properties of alloys depend not only on the composition, but also on the purity of the starting components. Therefore, materials obtained from various batches of raw materials often differ in their thermoelectric properties. In practice, it is convenient to determine the characteristics of the feedstock by the thermoelectric properties of the base (undoped material) fused from this feedstock [1].

As is known, when Bi_2Te_3 and Bi_2Se_3 are alloyed the thermoelectric properties of the alloy change with a change in the batches of the feedstock, since while the properties of the base itself also change. Naturally, when the thermoelectric properties of the base change, the optimal concentration of the dopant, should also be changed. Usually, the optimum concentration of a dopant for a substrate with certain properties is found empirically by conducting a gray melt with a different concentration of dopant. For alloying Bi_2Te_3 and Bi_2Se_3, bases with the following thermoelectric properties are selected: electrical conductivity σ =200÷600 $\Omega^{-1}\cdot sm^{-1}$, thermoelectric coefficient α =240÷200 μV/deg.

Discussion: The initial components chosen by us for the preparation of the alloy of the required composition were of the following purity: bismuth GOST 10928-64 brands B4-00, tellurium ГОСТ9514-60 brands TA-1, antimony ГОСТ 1069-62 brands C-0 и lead C-00. Based on the works [2], the composition of the solid solution corresponding to 74 mol % was chosen as the basis for the study. Sb_2Te_3 and 26 mol % Bi_2Te_3.

To obtain a doped hole conductivity material in a quartz crucible with a gate, the following charge composition was taken: Bi- 16,179 % the weight, Te- 56,993 % the weight, Sb- 25,828 % the weight, corresponding to the following thermoelectric properties of the base: σ=1000 $\Omega^{-1}\cdot sm^{-1}$, α= 200 μV/deg. Lead was used as an alloying additive.

The dopant - lead, was located in the crucible between equal layers of tellurium.

To clarify the effect of additives on the main characteristics of the alloys, the following studies were carried out.

Effect of dopant concentration on thermoelectric and electro physical properties.

To determine the optimal concentration of the dopant, lead was introduced into the charge in an amount of from 0.05% weight to 0.25% weight.

Figure 1 shows the change in electrical conductivity (σ), thermoelectric coefficient (α), thermoelectric power (α2σ) and loss (M).

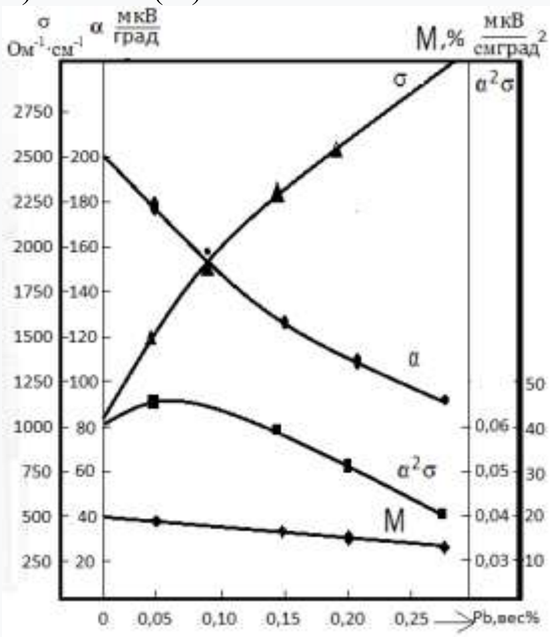

Fig. 1. Investigation of the influence of the concentration of the *Pb* dopant on the properties of Bi_2Te_3- Sb_2Te_3 material and the amount of losses.

With increasing concentration of the dopant, the electrical conductivity and thermoelectric coefficient change almost linearly.

Optimum thermoelectric properties of the alloy are obtained with the introduction of 0.05% weight, dopant. In this case, specific conductivity σ=1500 $Om^{-1}\cdot cm^{-1}$, thermoelectric coefficient α=175 μV / deg.

The percentage loss M decreases with increasing concentration of the dopant, which is associated with the formation on the melt surface of the thinnest layer of lead telluride, the vapor elasticity, which is much less than the vapor elasticity of antimony and bismuth telluride.

Temperature dependences of thermoelectric properties of Bi_2Te_3- Sb_2Te_3 doped with lead.

To study the temperature dependence of the thermoelectric properties of the alloyed material, 0.05% lead weight was introduced into the base (σ=1000 $Om^{-1}\cdot sm^{-1}$, α=200 μV/deg.). Semi-elements were made from the ingot obtained, in which the changes in electrical conductivity (σ), thermoelectric coefficient (α), dielectric constant (χ) and thermoelectric power (z=α2σ) were studied in the temperature range from 200°C to 3000°C (Fig. 2).

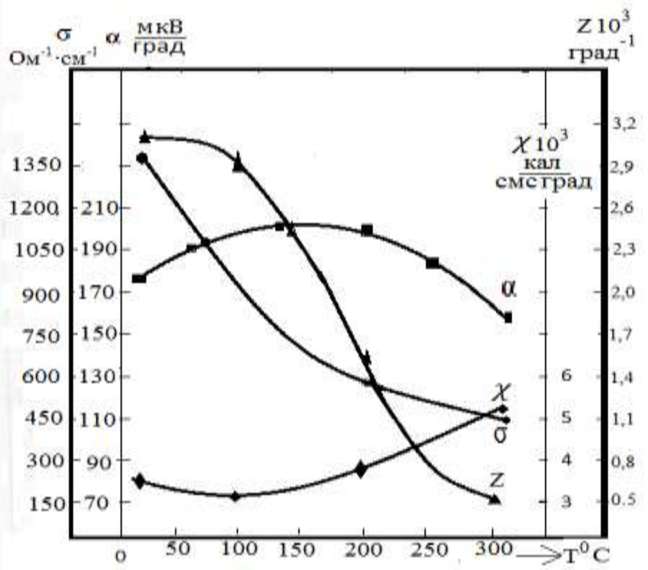

Fig. 2. Change in the thermoelectric properties of Bi_2Te_3- Sb_2Te_3 doped with lead as a function of temperature.

b) Investigation of the uniform distribution of thermoelectric properties along the length of the ingot.

When Bi_2Te_3- Sb_2Te_3 was doped with lead, stirring was not performed. Therefore, the change in thermoelectric properties along the length of the ingot was studied. To determine the uniformity of distribution, 500 g of Bi_2Te_3– 26 mol % and Sb_2Te_3– 74 mol% alloys were fused, which corresponds to the following mixture composition: bismuth - 80.8940 g, tellurium - 284.9660 g, antimony - 134.1400 g and lead - 0.2500 g. A lead alloy was placed between two layers of tellurium. The mixture was melted at a temperature of 7500C for 30 minutes.

The obtained ingot was a cylindrical rod 9 cm long and 3.2 cm in diameter. The loss of material during smelting due to evaporation was 0.04% by weight. The ingot was cut into 10 equal parts, and semi-elements were made from each such part. The results of measurements of thermoelectric properties along the length of the ingot show good uniformity, which shows that alloy mixing during melting is not required (Fig. 3).

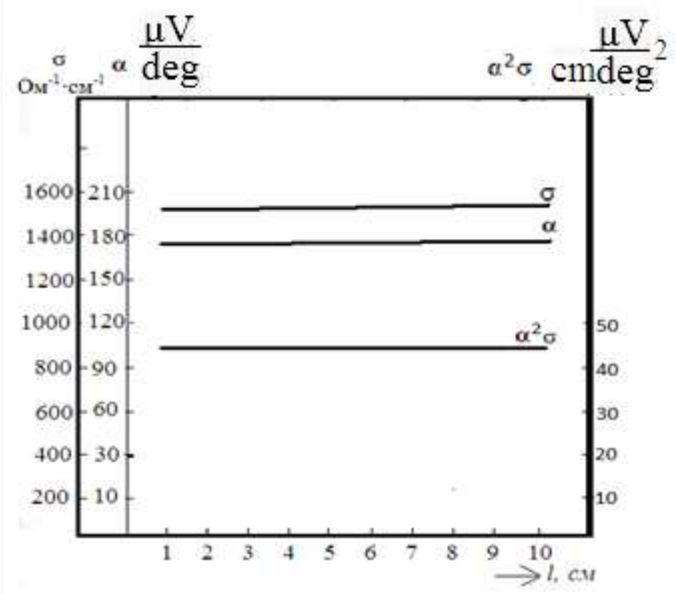

Fig. 3. Investigation of the homogeneity of thermoelectric properties of a Bi_2Te_3-Sb_2Te_3, *Pb* ingot along its length.

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In order to study the tens metric properties of semiconductor film structures based on Bi_2Te_3- Sb_2Te_3, a mechanical powder was made from the material of the alloy, we introduce 0.05% weight, and the dopant is lead. To obtain strain gauges operating in a wide temperature range, strain-sensitive sensors were obtained by thermal vacuum spraying under vacuum in the order of ~ 10-4 ÷ 10-6 torr, which has the properties of a dry vacuum. Strain-sensitive semiconductor films were obtained from $(BiSb)_2Te_3$: Pb on a polyamide film [2].

The substrate was heated to Tn=90°C. Spraying was performed at a temperature of ~700°C from tantalum boats. The film thickness was d=4–5.2 μm. The resulting films have good adhesion to the substrate and possess the necessary electromechanical properties for strain elements. The resistance of the samples was measured by a two-probe electric circuit with a B7-23 instrument, ohmic contacts made of silver were applied in vacuum using special stencils.

Table 1 shows the values of the Hall coefficient Rx, mobility μr, and the Hall concentration px measured at room temperature for films obtained at T_n= 90°C.

Table 1

N	Thickness, μm	Rx · 10^{-2} $\frac{sm^2}{C}$	μp , $10^{-2} \frac{sm^2}{B \cdot C}$	Px , $10^{20} sm^{-3}$
16	4.9	1.2	49	5.2
38	4.4	0.9	37	7.3
76	5.2	1	42	6.25
109	5.1	0.95	40	6.4

The relative change in resistance under the influence of uniaxial deformation was measured at temperatures of 300.77, 4.2 ° K (Fig. 4).

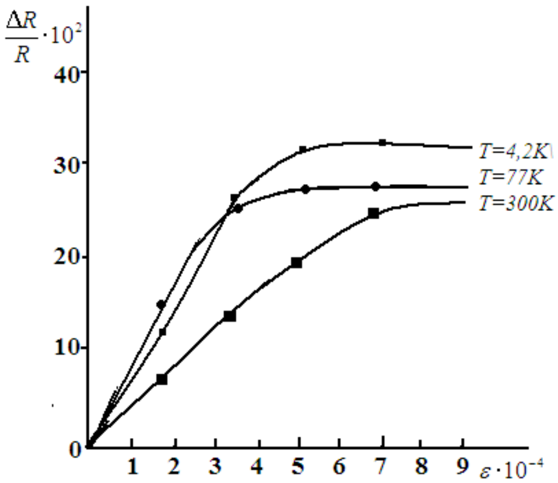

Fig. 4. Relative change in resistance from elongation of the film.

The results of the studies showed that $(BiSb)_2Te_3$ films with an admixture of 0.05 atomic percent of *Pb* thermally sprayed on a polyamide substrate at room temperature have a high strain sensitivity of K=100÷1000, where K is the coefficient of strain sensitivity equal to the ratio of the relative change in resistance when films are deformed to elongation

$$\hat{E} = \frac{\Delta R}{R} / \frac{\Delta L}{L}$$

We studied the temperature coefficient of film resistance in the temperature range 300–0.5 K. The films were cooled in a refrigerator with He3 vapor evacuation to obtain a temperature of up to 0.5 K [3]. A change in the resistance of undeformed films during cooling was not detected (film dimensions 4·6 mm², resistance 50 0 m).

The strain sensitivity of the films was measured at low temperatures up to 4.20 K using a cryogenic insert. The temperature of the strain film was changed by raising the cryogenic insert above the level of liquid He_4 in the STG-25 transport vessel. Films (4·10 mm² in size) were glued onto a bronze plate, which was bent using a special installation [4].

Elongation was determined by the formula

$$\frac{\Delta l}{l} = \frac{6d\Delta y}{L^2}$$

where d is the film thickness, L is the distance between the stops, Δ is the mixing of the plate.

The results showed that the strain sensitivity of the films at helium and nitrogen temperatures is greater than the values at room temperature (Table 2).

Table 2

T,K	300	77	4,2
K	444	944	777

The saturation of strain sensitivity at helium and nitrogen temperatures occurs faster, $\left(\frac{\Delta l}{l} 4\cdot 10^{-4}\right)$ than at room temperature $\left(\frac{\Delta l}{l} 7\cdot 10^{-4}\right)$.

To find out the cause of the spread of strain resistance, the noise voltage spectrum was measured at given currents flowing in the film. Experimental results showed that the source of voltage fluctuations is the noise resistance of the sample. To clarify the contribution of current contacts to the sample noise, we compared the noise voltage of the initial film with the contacts and the corresponding value of the noise signal obtained from the sample with a partially removed film and the same contacts. With partial removal of the film, an increase in noise was observed approximately in proportion to the increase in film resistance. Therefore, the film is responsible for the appearance of the noise signal, not the contacts.

At a temperature of 4.2 K, the character of the noise signal (dependence on frequency, current, and film resistance) did not change compared to values at room temperature.

In order to compare the relative value of the mean square fluctuation of the film resistance during tens metric measurements and noise measurements, an estimate was made

$$\frac{SR_{sh}}{R_k} = \frac{1}{IR_{sh}}\sqrt{\int_{f_1}^{f_2} p(f)df} = \frac{1}{IR_{\kappa}}\sqrt{C\ln\frac{f_2}{f_1}} = 1{,}5\cdot 10^{-5},$$

where R_{sh}, R_k is the average resistance of the sample, respectively, for noise and strain measurements, I is the current through the sample, p(f) is the spectral density of voltage fluctuations taken from the experiment, $1/f_1$ is the maximum characteristic time of the device B7-23, $1/f_2$ - the minimum characteristic time of the device B7 -23.

Result: The fluctuations in the resistance of the sample during tens metric measurements are greater, $\frac{SR_{sh}}{R_k} \sim 0{,}1$ than received during noise measurements $\frac{SR_{sh}}{R_k} \sim 10^{-5}$ and this is due to the mechanical backlash of the screw. By eliminating the contribution of mechanical fluctuations in strain gauge films, $\frac{\Delta l}{l} = \frac{SR_{sh}}{R_k} \sim 10^{-8}$ one can achieve a resolution of elongation at room and helium temperatures.

Conclusion: This value can be compared, for example, with the relative elongation of metals during the superconducting transition, which indicates the possibility of recording volume changes during the normal metal – superconductor transition using the studied tens metric films $\frac{\Delta l}{l} \sim 10^{-7}$ [5].

References

[1] Ioffe A.F. Semiconductor thermocouples. ML 1957, 60 s
[2] B.A. Atakulov, E.A. Abdullaev, A.Ya. Afuzov, E.I. Bilyalov, A.U. Rakhimov. Deformation effects in inhomogeneous semiconductors. T. Fan. 1978.
[3] Onarkulov K.E., Ubaidullaev M.I. Electrophysical properties of polycrystalline films $(Bi_{2x}Sb_x)_2Te_3$ at temperatures of 0.5-300 K. Abstracts of the report of the regional scientific and practical conference. Fergana. 1990.
[4] B.A. Atakulov, B.G. Zhurkin, M.I. Ubaidullaev, A.M. Tskhovrebov. Investigation of the strain sensitivity of $(BiSb)_2Te_3$: *Pb* films at temperatures of 0.5–300K. Preprint No. 89 FIAN.M.1984.
[5] Olsen J.L., Rohrer H. Helv.Phuzs.Akta.1960. 33.p.872.