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# STUDY OF ELECTRIC AND SOME STRAIN-RESISTIVE PROPERTIES OF FILM SENSITIVE ELEMENTS BASED ON BISMUTH-ANTIMONY TELLURIDES

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**Abstract**

The work is devoted to the study of electrophysical and tensometric properties of polycrystalline film sensitive elements based on bismuth-antimony tellurides. The paper considers the influence of the deposition rate on the resistivity and strain-sensitivity coefficient of bismuth-antimony telluride films grown on a polyimide substrate. These dependences show that with an increase in the deposition rate from 10 nm/s to 40 nm/s, the resistivity of the films decreases, and the value of the strain sensitivity coefficient passes through a maximum at 20 nm/s, the amplitude of which is determined by the evaporation temperature.

**Keywords.** film sensing elements, bismuth and antimony tellurides, strain gauges, strain gauge, thermal deposition, electrical conductivity, resistivity, gauge factor, substrate temperature, evaporation temperature, deposition rate

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## INTRODUCTION

As is known, the Bi-Sb-Te ternary compound of variable composition is one of the most promising materials used as semiconductor film strain gauges, which are the most effective tool for studying the stress state of machine-building structures. The main advantage of film strain gauges is rather small size, high strain sensitivity, the possibility of changing their mechanical and electrical properties of elements over a wide range, which is not feasible in metal resistors.

To date, the electrical and some tensoresistive properties of film sensitive elements based on the Bi-Sb-Te system of variable composition have been studied sufficiently.

However, the results obtained are rather contradictory and do not allow us to understand the mechanism of such a high strain sensitivity ($\sim 10^4$ and more) in these films. The conditions of condensation and the associated mechanism of growth of the sensitive layer on various substrates determine its phase and chemical composition, as well as the structure and, accordingly, structurally sensitive, electrophysical and tensometric parameters.

## MATERIALS AND METHODS

The study of the electrical properties of semiconductor films of antimony bismuth tellurides is a task related to the study of the electronic and tensometric properties of semiconductor materials based on antimony bismuth tellurides. Various methods can be used to conduct the study, such as measuring the electrical conductivity and thermopower, determining the optical properties (transparency, absorption, refraction) of antimony bismuth telluride films using spectroscopy in the IR, visible, and UV regions. It is also possible to carry out measurements of thermally stimulated conductivity, which allows you to determine the concentration of defects in the material and their effect on electrical conductivity.

The study of the electrophysical properties of antimony bismuth telluride semiconductor films can be important for various fields of science and technology, such as electronics, optoelectronics, photovoltaics, and many others. The results of the study can be used to develop new materials and devices, as well as to improve existing ones.

The main method for producing film strain gauges is thermal deposition of a semiconductor material in vacuum through a mask of a certain size onto a neutral dielectric substrate. Thus, film strain-sensing elements made of Bi, Te, Bi2Te3, Sb2Te3 and other materials were obtained.

At present, the study of the electrical and some tensoresistive properties of film elements obtained as a result of thermal evaporation of solid solutions based on Bi-Sb-Te in vacuum makes it possible to find out the greatest information about the mechanism of high tensoresistance and other electronic processes occurring in thin layers.

When a polycrystalline film of antimony bismuth telluride is subjected to mechanical stress, its crystal structure begins to deform. This leads to a change in the distance between atoms in the material, which in turn leads to a change in the electrical and tensoresistive properties of the films.

These properties depend on the compositions of the evaporated and condensed molecular beams, the type of evaporation and temperature $T_s$ of the substrates, the evaporation temperature $T_e$ and the deposition (growth) rate v, thickness h, heat treatment, and other microscopic technological parameters. The $T_s$ of the substrate was measured with a chromel-alumel thermocouple, and the evaporation process was monitored visually.

The thickness of the Bi-Sb-Te film was set by the evaporation time of the substance and was 50-150 nm, and the evaporation rate was set by the evaporator temperature. Since the average atomic number of the substance under study is much higher than that of carbon, the scattering of electrons from the substrate is negligible compared to the scattering from the object under study.

The electrical conductivity and strain sensitivity of the films are estimated by the value of the specific resistance ρ and the value of the strain gauge coefficient K, which mainly change with the number of deformation cycles, then studies were carried out to determine the value of the technological parameters v, $T_s$ on the values of ρ and K of films of bismuth and antimony tellurides.

To study the effect of deformation on the properties of films, it is favorable to transfer the deformation to the sample from an elastic element - a beam of equal resistance. An axle with a double-row self-aligning ball bearing was fixed at the moving end. In this case, the object under test must be rigidly connected to the elastic element using glue. The film was deformed by bending the plate. Beam bending is carried out with the help of an adjustable eccentric mounted on the motor shaft.

The studied samples were deformed up to $\varepsilon=10^{-3}$ relative units, which repeatedly deform the same sample. Measurements were made at direct current. The film strain sensitivity coefficient K was calculated from the expression

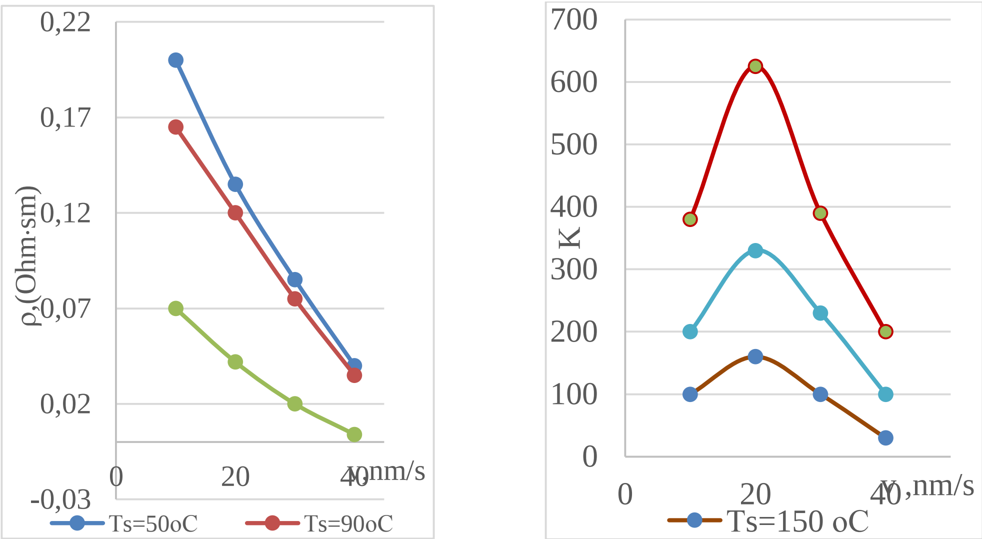
$$K = \frac{\Delta R}{R \cdot \varepsilon}$$

The error in determining the coefficient of strain sensitivity of the films K consisted mainly of the error in determining the relative deformations and the relative change in resistance ΔR/R. The maximum measurement error did not exceed 3%.

## RESULT AND DISCUSSION

Figure 1 shows the results of studies on the effect of deposition rate v on the value of ρ and K of films grown on a polyimide substrate. These dependences show that with an increase in the deposition rate from 10 nm/s to 40 nm/s, the resistivity of the films decreases, and the value of the strain sensitivity coefficient passes through a maximum at 20 nm/s, the amplitude of which is determined by the evaporation temperature (in this case, the deposition rate was changed by changing the evaporation temperature).

Note that a change in the mass of the initial sample, the temperature of the substrate, and the distance between the evaporator and the substrate at the same evaporation temperature led to a change in v, which affected the values of ρ and K.




a) b)

Fig.1. a) the dependence of resistivity and b) the strain gauge coefficient on the rate of deposition of the Bi-Sb-Te solid solution onto the polyimide substrate.

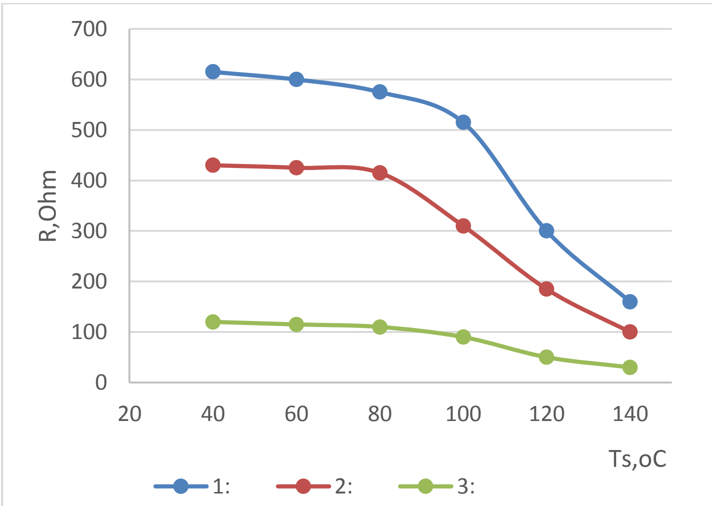



Fig. 2. Dependence of the resistance (curves 1-3) of the films on the substrate temperature Ts during deposition. Film sizes 8mm*1mm*6 microns. v: 10 nm/s (curve 1), 20 nm/s (curve 2) and 40 nm/s (curve 3).

Figure 2 shows the dependence of R for films 6 μm thick on $T_s$. It can be seen that at the same film thickness, its resistance sharply decreases at $T_s$>90°C. This decrease is accompanied by the appearance of a maximum at $T_s$=90…100 °C of independence K($T_s$).

## CONCLUSION

The presented results show that the resistivity and strain sensitivity coefficient of the films obtained by evaporation of the Bi-Sb-Te solid solution depend on the film thickness, the substrate temperature during deposition, and the layer growth rate. By annealing the films after growth, their tensometric properties and parameter stability can be significantly improved. The optimal technological parameters for obtaining layers with high values of strain-electric properties have been found, which are as follows:

1. Deposition of a layer with a thickness of 5-6 μm at a deposition rate of 20 nm/s at a substrate temperature of Ts=90.
2. Film annealing at 125 oC in air or in vacuum in tellurium vapor for 4-8 hours.

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