International Journal of Advance Scientific Research
(ISSN – 2750-1396)
VOLUME 02 ISSUE 12 Pages: 149-155
SJIF IMPACT FACTOR (2021: 5.478) (2022: 5.636)
METADATA IF – 7.356

Journal Website: http://sciencebring.com/index.php/ijasr

Research Article

INVESTIGATION OF THE FREQUENCY DEPENDENCE OF THE RESISTANCE OF PbTe FILMS

Submission Date: December 11, 2022, **Accepted Date:** December 16, 2022,
Published Date: December 21, 2022
Crossref doi: https://doi.org/10.37547/ijasr-02-12-22

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ABSTRACT

In this paper, we consider the frequency dependence of the resistance of PbTe films. Establishing that the resistance of films containing an excess of lead up to 0.2 wt% decreases with increasing frequency of the supply voltage, and for samples containing more than 0.2 wt%, an increase in resistance is observed. At $\omega=3\ 10^5$, the difference in the resistance of the films decreases significantly and the resistance weakly depends on the frequency of the alternating signal

KEYWORDS

Polycrystalline film, semiconductor, strain sensitivity, strain, resistivity.

INTRODUCTION

On the basis of narrow-gap and wide-gap semiconductors, photoreceivers [1], high-temperature diodes [2], and the electrical conductivities and diffusions of minority carriers in thermally oxidized thin PbTe films [3], the effect of oxygen on the transport properties in polycrystalline PbTe films [4], and structural and optical properties of undoped and antimony doped lead telluride thin films [5] and the effect of nonstoichiometry on the oxidation processes in n-type PbTe thin films [6]. In the study by the authors of [7], an infrared photoelectric property was found on columnar films of PbTe doped with tellurium. Despite the large number of works [8, 9, 10], along with the advantages, film elements of PbTe semiconductor compounds also have a number of disadvantages. The latter include - insufficient stability, poor reproducibility of structurally sensitive properties. The elimination of these shortcomings requires an in-depth study of the physics of the processes occurring in inhomogeneous semiconductor films. In this regard, we studied the effective permittivity and electrical conductivity of polycrystalline PbTe films with disturbed stoichiometry.

Experimental technique and discussed experimental results

One of the most effective methods for studying the mechanisms of electrical conductivity of inhomogeneous structures is to study the dependence of resistance on an alternating signal. If the film structure under study contains electrically active inhomogeneities surrounded by space charge regions, then on the signal variable, the contribution to the electrical conductivity will be made by capacitances associated with inhomogeneities. Moreover, with an increase in the frequency of the alternating signal, the contribution to the total electrical conductivity of the regions containing electrical inhomogeneities will change.

The measurement of the frequency dependences of the resistance of the PbTe films was carried out according to the scheme of a DC generator in the frequency range ω=(0÷106)Hz. Figure 1 shows the dependences of the resistances of samples of stoichiometric composition and with an excess of tellurium of 0.8 and 3.8 wt.% on the frequency of the supply sinusoidal voltage. Similar dependences were obtained for samples with a different Te excess content. As can be seen from the figure, a sharp decrease in the resistance of the films begins at frequencies of ~105 Hz. The difference in film resistances for samples with different contents of excess components is the greater, the lower the frequency of the supply signal. At ω>3*105 Hz, the difference in the resistance of the films decreases significantly and the resistance weakly depends on the frequency of the alternating signal. Films containing superstoichiometric lead behave differently. The resistance of films containing an excess of lead up to 0.2 wt.% decreases with increasing frequency of the supply voltage, and for samples containing more than 0.2 wt.%, an increase in resistance is observed. This is clearly seen from the I–V characteristics of specimens with excess lead (see Fig. 2) at ΔPb≤0.2 wt%, with an increase in the frequency of the alternating signal, the slope of the I–V characteristic increases, which indicates a decrease in the resistance of the films (see curves 1, 2), and for ΔPb>0.2 wt.% the slope of the CVC decreases (curves 3.4). After heat treatment in air, the dependences R(ω) for all samples are similar to the data in Figs. 1 and 2.

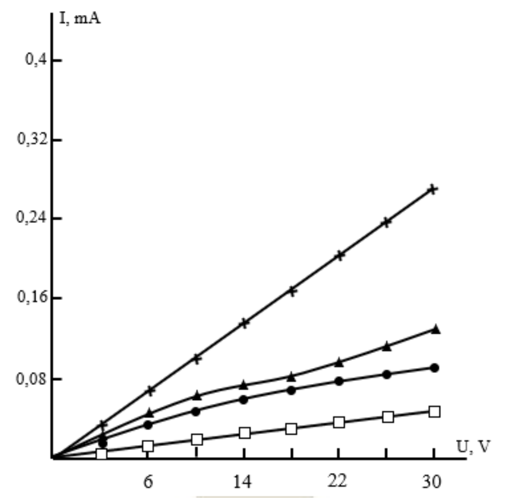

Fig.1. Frequency dependence of the resistance of PbTe films with an excess of Te. ΔTe, weight%: 1-0; 2-0.8; 3-3.8.

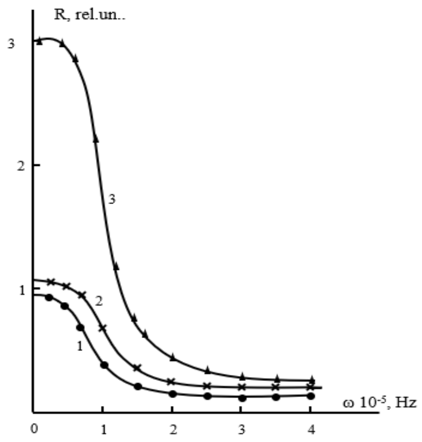

Fig.2. I–V characteristics of PbTe-Pb (1.2) and Pb-Te (3.4) films with an excess of lead at different frequencies of the supply signal. ω, Hz: 1.3-0; 2.4-4*10^5.

The decrease in the electrical conductivity of PbTe films upon thermal treatment in air is explained by the increase in barriers in the interaction of the films with oxygen. PuTe with an excess of lead of 2.2 wt.%, the activation energy of electrical conductivity is 1.5 10-2 eV (without heat treatment) [11]. After heat treatment, ΔEa increases to -0.1 eV while maintaining the type of conductivity, which undoubtedly indicates an increase in the height of intercrystalline barriers due to the influence of adsorbed diffused oxygen. In favor of the fact that the decisive factor in the formation of potential barriers is the interaction with oxygen is also evidenced by the fact that the films obtained at low Tn in a short time of heat treatment become more high-resistance. And it is known that the smaller Tn, the more dispersed the film, therefore, the more channels in the tanks through which the films interact with oxygen. In the case of p-type films (with an excess Te) of conductivity, the formation of barriers can occur due to the existence of localized states for holes at the crystallite boundaries, as well as the existence of a Te phase with a different carrier concentration (the formation of nonideal heterojunctions at the PbTe-Te interface). It should be noted that the ratio of the electrical conductivity of films to the electrical conductivity of single crystals (σM) at the same carrier concentration $^{\sigma}/_{\sigma_M}$, observed experimentally is much less than exp((-ΔE_a)/kT), i.e.

$$\frac{\sigma_M}{\sigma} > \exp\left(\frac{\Delta E_a}{kT}\right)$$

Where ΔEa is the value of the activation energy. It can be assumed that the factor σ0 is less than σM. this suggests that in the crystallites themselves there is a fluctuation of the energy zones of a smaller scale than at the boundaries of the crystallites [12]. Scattering of carriers on the humps of such small-scale fluctuations leads to a dispersion of their mean free path and a decrease in the mobility in the crystallites themselves. In this regard, in σ0<<σM. The permittivity of a substance is determined by the e ε=1+4πX_e, where , X_a=P/E is the electrical susceptibility, which is determined by the internal properties of the substance and depends on the polarizability of each atom. The total dipole moment (Ṗ) of a unit volume of a crystallite depends on the values of the dipole moment of the atoms, and the number and geometric arrangement. The combination of atoms into a molecule and the formation of crystallites can change the electronic structure and hence the polarizability.

PbTe-Te, PbTe-Pb films are heterogeneous systems consisting of PbTe, Te, Pb. Lead telluride and lead have a cubic lattice, while telluride has a hexagonal one [13]. Therefore, PbTe-Te films with excess superstoichiometric Te are a system consisting of tare-shaped (PbTe) and ellipsoidal (Te) formations, and PbTe - Pb - only tare-shaped. in the structures of PbTe, Pb, Te atoms there are weakly bound valence electrons. Therefore, atoms are easily deformed by an electric field. The electric field causes a relative displacement of free carriers in crystals. Crystallites can have an electric dipole moment if the "centers of gravity" of the positive and negative charges do not coincide. The high value of the effective permittivity ε_{eff}^{*} in the microwave range is associated with the establishment of full polarization in all regions of the film. An increase in ε_eff^* with an increase in the Te addition is due to an increase in the number of ellipsoidal inclusions, which have a large dipole moment. Small values of ε_eff^* in the IR frequency range - by establishing a weak polarization due to the difference in relocation times [14]. The absorption coefficient (the imaginary part of the permittivity) is determined by the electronic transitions that occur when light interacts with a semiconductor. The dependences of the calculated values of $J_m\varepsilon_{eff}^{*}$ and the experimental values of the emission coefficient on the light energy are similar for all films under consideration. This shows that the experimentally observed change in the absorption spectra of PbTe-Te and PbTe-Pb films is due to a change in their effective permittivity depending on the volume fraction of superstoichiometric Te and Pb. It is known that at the boundary of two media with different polarization ($\dot{P}1$, $\dot{P}2$) the electric field strength jump is equal to their difference ($\Delta\dot{P} = \dot{P}1 - \dot{P}2$). In other words, the interface between two media, on which the polarization changes by a certain magnitude, has the same effect on the magnitude of the electric field as does the surface of the body on which the real charge is located. Consequently, in the case of uniform polarization, a surface charge with a density σ equal to ΔP per unit area is formed at the crystallite boundary, which leads to a change in the height of intercrystallite barriers in PbTe – Te films. The sublinear current-voltage characteristic in PbTe – Te films can be explained by the modulation of structural barriers by polarization ones: with an increase in the applied voltage, the barriers at the boundaries of crystallites increase nonlinearly, which leads to an increase in the resistance of the films to the field.

CONCLUSION

Comparison of the experiment with the qualitative results of the present work shows satisfactory agreement. It can be concluded that the features of the kinetic effects in polycrystalline PbTe films of nonstoichiometric composition are due to the inhomogeneity of the potential relief of the films.

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