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Classical Size Effects in Sb Doped SnTe Thin Films

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The possibility of obtaining strongly degenerate (> 4×10^{20} cm^{-3}) SnTe thin films (d = 200 - 2000 nm) with p-type conductivity by thermal evaporation in vacuum of SnTe crystals doped with Sb, with subsequent condensation onto as (0001) mica and sytal substrates, was established. The thickness dependences of electro-physical properties of thin films were obtained. In this region of thickness there was growth of the carrier mobility with thickness, which is attributable to manifestation of classical size effect and interpreted in the framework of Fuchs-Sondheimer theory. These measurements show little correlation between the length of free path of charge cattiers and the lateral diameter of surface objects.

Key words: tin telluride, thin film, thickness, size effect.

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Introduction

As is known, IV-VI semiconductors are very wide applied in many fields of science and technology [1]. Tin telluride (SnTe) has proved itself as material used in thermoelectric power converters (thermal generators) [2]. Efficient use of SnTe is possible at high concentrations of charge carriers (p ~ 10^{20} cm^{-3}) which do not seem possible to be obtained due to deviations from stoichiometry. In this connection, SnTe is doped with different impurities. Introduction of stibium and bismuth into SnTe lattice allows achieving concentration values up to ~ 10^{20} - 10^{21} cm^{-3} [2]. Increase in thermoelectric figure of merit of material which is in a low-dimensional state was experimentally shown for superlattices based on IV-VI compounds [3, 4]. With practical application of thin films, it is important to take into account the influence of size effects (classical and quantum) that can change drastically the kinetic properties of material [5].

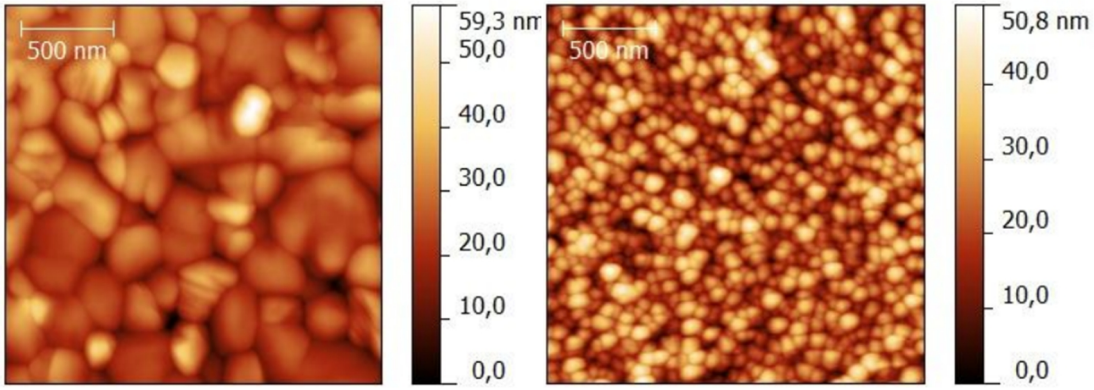
For Bi doped PbTe films obtained by thermal evaporation in vacuum of crystals of stoichiometric PbTe with electron concentration n ~ 10^{20} cm^{-3}, there was increase in the electric conductivity and mobility with growth of film thickness, which was attributed to manifestation of classical size effect (ClSE) [6].

Few works are concerned with the investigation of the thickness dependences of thermoelectric properties of SnTe films with a high degree of electron gas degeneracy. In [7] autors showed that Bi-doped SnTe films show a classical dependence of electro-physical (EP) properties on film thickness. The purpose of this paper is to study in more detail the influence of thickness d of Sb-doped SnTe films with a high degree of hole gas degeneracy (p ~ $4\cdot10^{20}$ cm^{-3}) on their EP properties at room temperature.

The length of free path and probability of elastic scattering are the most important parameters of transport process for free charge carriers in a thin film. A number of methods for their determination, including determination from the mobility-thickness characteristic, are well known. In this work, the specularity parameter and length of free path of charge carriers in stibium doped tin telluride thin films deposited on mica and sytal from the mobility-thickness characteristics were determined.

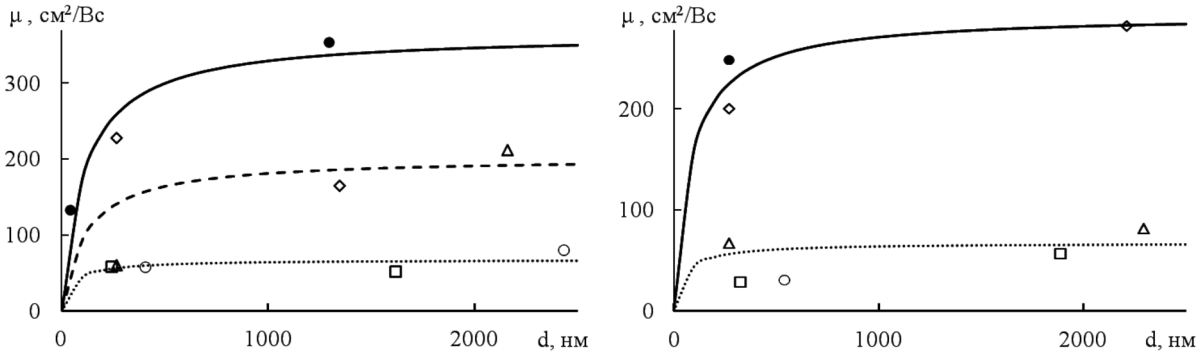
I. Procedure

SnTe films with thicknesses d = 200 - 2000 nm were obtained by the method of thermal evaporation in vacuum (10^{-5}-10^{-6} Pa) of SnTe crystals doped with 1 at. % Sb, with subsequent condensation onto (0001) mica and sytal surfaces, maintained at temperature of 125 - 300 ^{0}C. The thickness d of the films was controlled with the aid of micro-interferometer MII-4. Surface morphology and average roughness were studied by means of atomic force microscope (AFM) Nanoscope 3a Dimention 3000, the images were obtained in the air in contact mode.



(a) *(b)*

Fig. 1. AFM-topography of films surface with thickness d nm: (a) 200 and (b) 2000.



(a) *(б)*

Fig. 2. The theoretical calculation and experimental mesurements of the dependence of the free carrier mobility μ in (a) mica and (b) sytal on the thickness of films deposited at temperature in ^{0}C: 125 - ○, 150 - □, 200 - Δ, 250 - ●, 300 - ◊.

The electric conductivity σ and the Hall coefficient R_H were measured by standard dc method with an error not exceeding 5 %. As material for soldering of contacts, use was made of indium. The Hall concentration of charge carriers p was calculated on the assumption of one sort of carriers by the formula $p = r/R_H \cdot e$, where the Hall factor r = 1, e is electron charge. The Hall mobility μ_H was calculated as $\mu_H = R_H \sigma$. The type of charge carriers was determined by the sign of R_H.

Dependences μ on the thickness of films were calculated in the framework Fuchs-Sondheimer theory with the use of Excel.

II. Results

Measurements of R_H have shown that the films possess p-type conductivity over the entire range of studied thicknesses, just as SnTe<Sb> crystal which was used as a charge for preparation of films. For the crystal the following values of kinetic coefficients were obtained: σ = 4600 $(Ohm \cdot cm)^{-1}$, p = 4 10^{20} cm^{-3}, $_H$ = 100 $cm^2/(V \cdot s)$. The hole conductivity type and high values of carrier concentration result from the introduction of stibium into SnTe lattice and agree with the data reported in the literature [6].

The results of AFM investigation of the films surface are given in Fig. 1. As is seen, the surface of the films has asperities. The height of asperities was ≈ 50 nm, the base width did not exceed 200 ÷ 300 nm for films with thickness 200 nm and 20 ÷ 50 nm for films with thickness 2000 nm The average distance between the asperities was equal the base width.

Smooth growth of μ with thickness in the area of $d >$ 200 nm can be related to manifestation of classical size effect. Taking into account high degree of electron gas degeneracy in the films, an attempt was made to describe the results in the framework of Fuchs- Sondheimer theory.

As a model, Fuchs-Sondheimer theory considers a metal with a spherical Fermi surface and isotropic carrier mean free path l independent of film thickness d. Specularity parameter p is introduced which determines the share of electrons elastically reflected from the surface, equal for both surfaces, independent of d, the trajectory and incidence angle of electrons on the surface. With fully diffused scattering $p = 0$, and with fully specular $p = 1$. In the approximation of thin films ($d \sim l$) the expression for μ is of the form [26, 27]:

$$m_H = \frac{m_\infty}{1 + \frac{3}{8}(1 - p)\frac{l}{d}}, \qquad d \sim l \qquad (1)$$

where μ_∞ is the values of μ in a sample of infinitely large thickness.

Using formula (1), the theoretical dependences (d) were constructed (Fig. 2) and the value (1 - p)l were determined whereby the best agreement is observed between the experimental data and the theoretical curve, determined by the lowest value of mean-square

deviation.

It turned out that dependence (d) is best described at (1 - p)l are 140 and 300 nm for mica substrate temperature 125 – 150 and 200 – 300 ^{0}C respectively. Note that for films deposited on sytal these parameters are 140 and 220 nm for the same temperatures. It can be seen that the calculated values of (1 - p)l in SnTe<Sb> films on sytal proved to be slightly lower films on mica.

Conclusions

The method of thermal evaporation in vacuum of the doped Sb of SnTe crystals was used to grow thin films p-type conductivity of thicknesses d = 200-2000 nm on mica and sytal substrates. By the method of atomic force microscopy it was established that the surface has asperities, grain structure is not manifested.

Increase in μ with film thickness in the area d > 200 nm was discovered, which is attributed to manifestation of ClSE. Interpretation of $\mu(d)$ dependences was given in the framework of Fuchs-Sondheimer theory.

It is established that the base widths of objects on film surface with the lenghts free path of charge carriers are correlated.

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Класичний розмірний ефект в тонких плівках SnTe легованого Sb

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Встановлена можливість отримання сильно дефектних (4×10^{20} см$^{-3}$) тонких плівок (d = 200 - 2000 нм) SnTe з р- типу провідності шляхом термічного випаровування в вакуумі кристалів SnTe легованого Sb, з подальшою конденсацією на поверхні (0001) слюди і ситалі. Отримано товщинну залежність електрофізичних властивостей тонких плівок. У цій області товщини спостерігалося зростання рухливості носіїв з товщиною, що обумовлено проявом класичного розмірного ефекту і інтерпретується в рамках теорії Фукса-Зондхеймер. Ці виміри показали слабку кореляцію між довжиною вільного пробігу носіїв заряду і латеральним діаметром поверхневих об’єктів.

Ключові слова: телурид олова, тонка плівка, товщина, розмірний ефект.