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THERMOELECTRIC PROPERTIES OF THIN FILMS BASED ON STIBIUM-DOPED TIN TELLURIDE

The thermoelectric properties of thin films based on stibium-doped tin telluride with stibium content 2 at. % produced in open vacuum at different deposition temperatures on fresh chips (0001) of mica are investigated. It is established that samples of thickness close to 1.5 μm have maximum thermoelectric power 25 μW/K2cm, which is much better as compared to that of pure tin telluride.

Key words: thin films, tin telluride, doping, thermoelectric properties.

Introduction

Tin telluride is widely used in semiconductor technology. Moreover, it is also a promising thermoelectric material for medium-temperature range (500 – 750) [1 – 4]. Preparation of thin-film material largely expands the scope of application. Due to introduction of doping impurities the thermoelectric properties of material can be modified over wide range.

This paper is concerned with the thickness dependences of thermoelectric parameters of films based on stibium-doped tin telluride vapor-phase deposited on mica substrates.

Experimental procedure

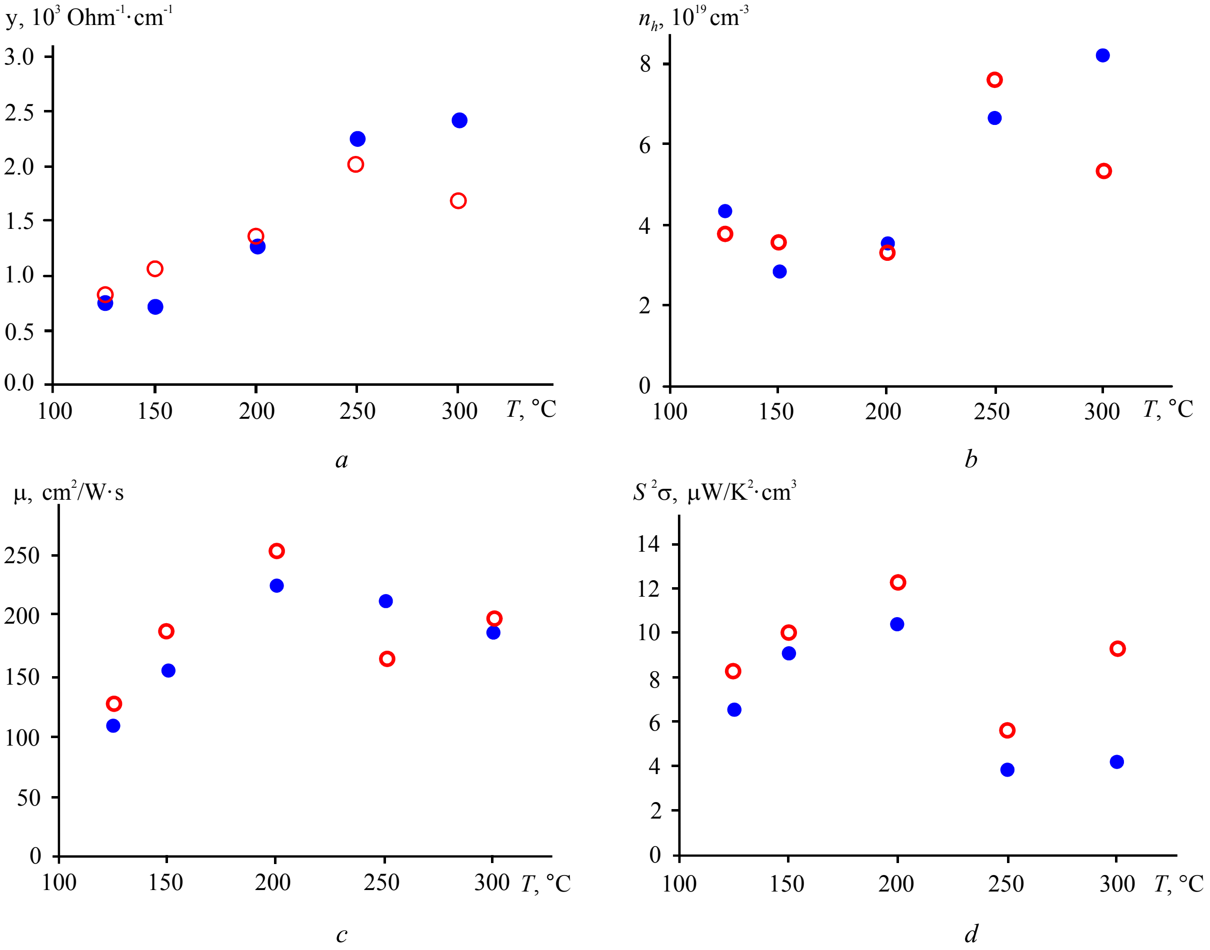
Films to be investigated were prepared by vapor deposition of synthesized material *SnTe* in vacuum on the substrates of fresh chips (0001) of muscovite mica and glass ceramics. The evaporator temperature was $Te = 600\ ^{o}$C, and substrate temperature varied in the range of $Ts = 150 – 300$ °C. The thickness of films was assigned by deposition time within (45 – 240) s and measured with the aid of a micro interferometer MII-4.

The electric parameters of films were measured in the air at room temperatures in constant magnetic fields on the developed automated plant that provides for measuring the electric parameters, as well as recording and primary processing of data with the possibility of constructing the plots of temporal and temperature dependences. The measured sample had four Hall and two current contacts. As the ohmic contacts, silver films were used. Current through the samples was ≈ 1 mA. A magnetic field was directed perpendicular to the surface of films at the induction of 1.5 T.

The results of investigations and the dependences of the electric conductivity σ and the Hall concentration of charge carriers n_h and the Seebeck coefficient S on the surface temperature and thickness are represented in Figs. 1 – 3.

Investigation results and their analysis

As can be seen from Fig. 1, the deposition temperature has a considerable impact on the thermoelectric parameters of material under study. The electric conductivity and the Hall concentration of charge carriers increase with a rise in deposition temperature, and the thermoelectric power has a clear peak at deposition temperature 200 °C. With a rise in *Ts*, mobility grows up to temperatures 200 °C, and with a further increase in temperature, it is somewhat reduced. This is due to structural perfection of condensate. With a rise in deposition temperature, due to improved self-organization, material structure is better ordered, which reduces the impact of grain-boundary scattering mechanism. With a further increase in substrate temperature, the processes of condensate re-evaporation are considerably accelerated and thermoelectric parameters of material are somewhat degraded.



a *b*

c *d*

Fig. 1. Dependences of the electric conductivity σ (a), the Hall concentration n_h (b), charge carrier mobility μ (c) and the thermoelectric power $S^2\sigma$ (d) on the deposition temperature of films produced on fresh mica chips. Derivation time, s: ● – 120, ○ – 240.

With regard to a clear peak of thermoelectric power, subsequent studies versus condensate thickness were performed for samples produced at *Ts* = 200 °C.

The electric conductivity of films and the Hall concentration of charge carriers drastically increase in the area of low thicknesses. This is due to the acceptor action of oxygen. On the contrary, the Seebeck coefficient is reduced in the area of low film thicknesses. Therefore, for the thermoelectric power ($S^2\sigma$) a clear peak is observed in the area of thicknesses 1.5 μm (Fig. 3).

To determine the surface effect, the thickness dependences of thermoelectric parameters for films produced on different substrates were investigated (Fig. 2). Parameters of near-surface layers were estimated by means of Petritz's model. A thin film in this model is composed of two layers: near-surface (I) (surface charge region) of thickness d_s, with current carrier concentration n_s, and their mobility μ_s, and bulk (II), which is characterized by similar values d_b, n_b, μ_b, connected in parallel. The thickness of the film is $d = d_s + d_b$.

In this case according to [5]:

$$\sigma = \frac{\sigma_s d_s + \sigma_b d_b}{d}; \tag{1}$$

$$R = \frac{R_s \sigma_s^2 d_s + R_b \sigma_b^2 d_b}{\left(\sigma_s d_s + \sigma_b d_b\right)^2} d; \tag{2}$$

$$S = \frac{\sigma_s d_s S_s + \sigma_b d_b S_b}{\sigma_s d_s + \sigma_b d_b}. \tag{3}$$

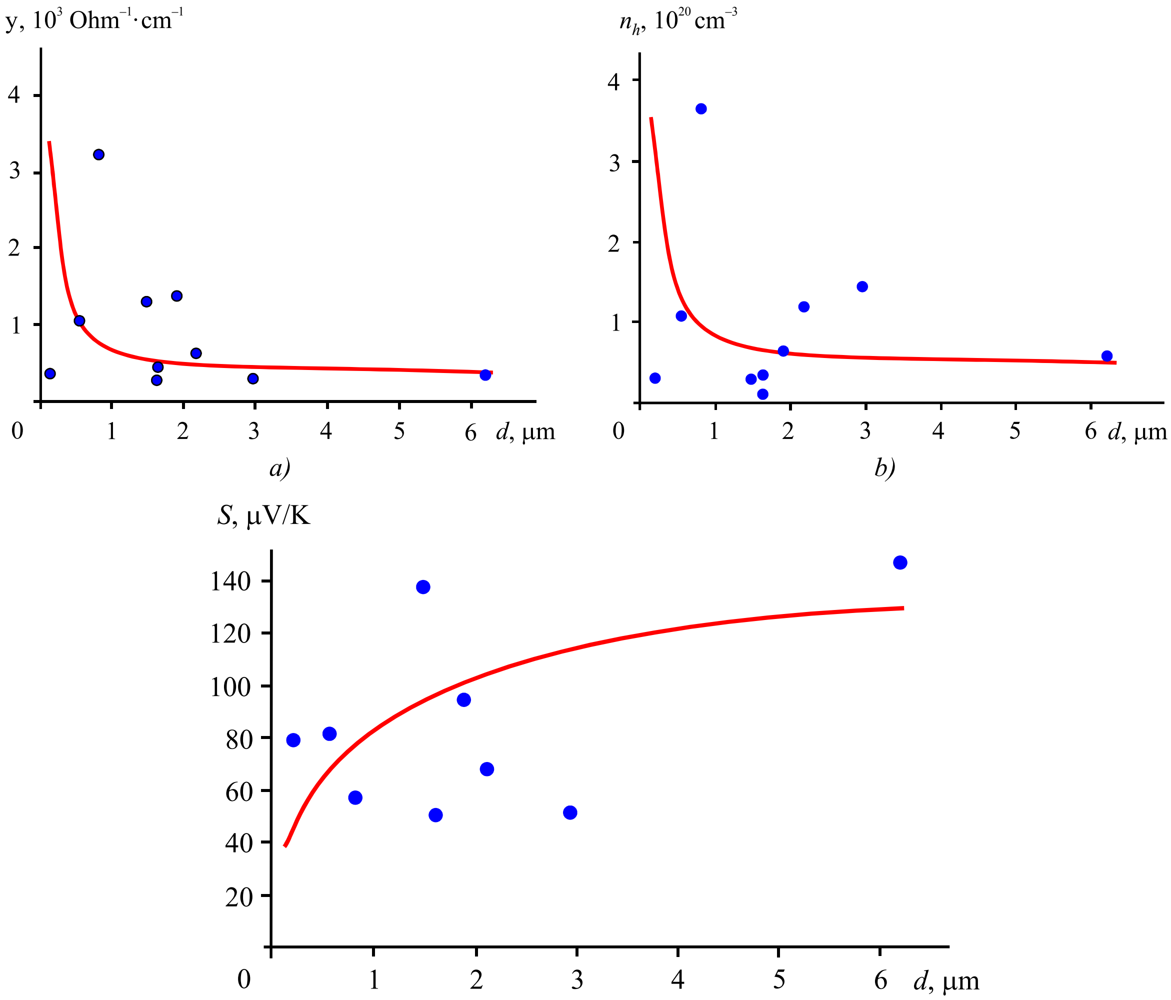
On condition of known experimental values of σ, *R*, μ and the bulk σ_b, R_b, μ_b and *d*, from these relationships one can approximately determine parameters of near-surface layers σ_s, R_s, μ_s respectively, the values of which are listed in the table. It is seen (Fig. 2 – solid lines) that calculated curves describe adequately the experimental results with the defined values of near-surface electric parameters d_s, σ_s, R_s, n_s, μ_s (Table 1).

Table 1

Parameter values of near-surface layer (*s*) and bulk (*b*) of *SnTe*: *Sb* films calculated according to a two-layer Petritz's model

	Parameters
d_s, μm	0.13
σ_s, Ohm^{-1}cm^{-1}	3100
σ_b, Ohm^{-1}cm^{-1}	300
R_s, cm^{3}C^{-1}	0.013
R_b, cm^{3}C^{-1}	0.15
n_s, cm^{-3}	4.81 10^{20}
n_b, cm^{-3}	4.17 10^{19}
μ_s, cm^{2}V^{-1}s^{-1}	40.3
μ_b, cm^{2}V^{-1}s^{-1}	45
S_s, μV/K	80
S_b, μV/K	150

Conspicuous are considerable values of near-surface electric conductivity and the Hall concentration of carriers, the Seebeck coefficient $S_s \approx 80$ μV/K (Table 1), which creates prospects for using *SnTe*:*Sb* as *p*-type legs in thin-film thermoelements.



a) *b)*

c)

Fig. 2. Dependences of the electric conductivity σ (a), the Hall concentration n_h (b) and the Seebeck coefficient S (c) on the thickness d of SnTe:Sb films on mica substrates. Dots are for experiment, solid line – calculation according to Petritz's model.

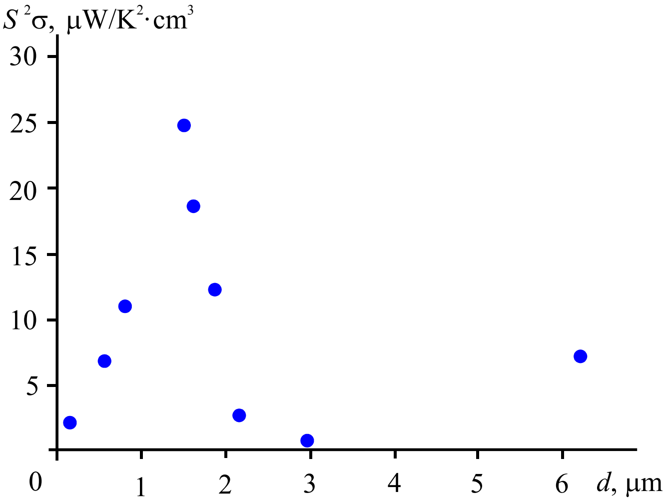


Fig. 3. Dependence of the thermoelectric power $S^2\sigma$ on the thickness d of SnTe:Sb films on mica substrates.

Conclusions

1. The thermoelectric properties of *Sb* doped tin telluride thin films produced by vapor-phase methods on mica substrates are studied. It is established that samples of thickness close to 1.5 μm have maximum thermoelectric power 25 $\mu W/K^2 cm$, which is much better as compared to that of pure tin telluride.
2. The thermoelectric parameters of near-surface layers are determined. It is shown that *p*-type *SnTe* films have improved thermoelectric parameters as compared to the bulk samples.

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