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THERMOELECTRIC PROPERTIES OF VAPOUR-PHASE CONDENSATES BASED ON DOPED LEAD TELLURIDE *SnTe*:*Bi*

Thermoelectric properties of vapour-phase condensates based on doped tin telluride SnTe:Bi of different composition obtained in open vacuum on glass ceramic and mica substrates are investigated. It is shown that thin films on fresh (0001) cleavages of muscovite mica with the content of ~ 0.3 mol.% Bi are characterized by maximum values of thermoelectric power ~ 42 $\mu W/K^2cm$.

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

Introduction

Tin telluride is widely used in semiconductor engineering. It also offers great promise as thermoelectric material for medium-temperature range (500 – 750 K) [1, 2, 3]. Preparation of thin film material extends considerably the limits of practical application. The problem of temporal stability of electrical parameters remains to be solved. Moreover, on exposure to air, a layer enriched with *p*-type conductivity carriers is formed on the film surface due to the acceptor effect of oxygen [4].

This paper studies the thickness dependences of thermoelectric parameters of films based on pure and bismuth doped *SnTe* obtained from the vapour phase on glass ceramic and mica substrates.

Experimental procedure

Films for investigation were prepared by vapour deposition of synthesized *SnTe* material in vacuum onto the substrates of fresh (0001) cleavages of muscovite mica and glass ceramic. The temperature of evaporator was T_{ev} = 870 K, and substrate temperature T_{sub} = 470 K. Film thickness was assigned by deposition time within (5 – 480 s) and measured by interference microscope MII-4.

The electric parameters of the films were measured in the air at room temperatures in constant magnetic fields on the elaborated automated installation assuring both the process of electric parameters measurement and recording and primary data processing, with the possibility of constructing the plots of time and temperature dependences. The sample being measured had four Hall and two current contacts. As the ohmic contacts, silver films were used. Current through the samples was ≈ 1 mA. Magnetic field was directed perpendicular to the surface of films at induction of 1.5 T.

The results of investigation and the thickness dependences of electric conductivity σ, the Hall concentration of current carriers n_H and the Seebeck coefficient *S* are represented in Figs. 1 – 2.

Analysis of the results of investigation

The introduction of *Bi* leads to donor effect in tin telluride which is manifested in decreasing hole concentration in the bulk of the films. The results of investigation of thermoelectric parameters of vapour-phase condensates based on doped tin telluride for different compositions are given in the Table. With increasing content of doping impurity, the thermoelectric power is first increased, and then drastically decreased, which is due to overrunning of *Bi* solubility region in *SnTe*. Maximum thermoelectric power is achieved with impurity content about 0.3 mol.%, but for condensates prepared on fresh (0001) cleavages of muscovite mica it is much higher than for samples on glass ceramic.

Table

Thermoelectric parameters of vapour-phase condensates based on doped tin telluride of different composition

mol.% *Bi*	σ, Ω^{-1}cm^{-1}	μ, cm^2/V·s	*n*, cm^{-3}	*S*, μV/K	$S^2\sigma$, μW/K^2·cm
Films 0.1 μm thick on fresh (0001) cleavages of muscovite mica					
0	2790	32	$5.44\cdot10^{20}$	55	8.4
0.3	3900	146	$1.67\cdot10^{20}$	90	31.2
1.5	3904	278	$8.78\cdot10^{19}$	65	16.3
2	852	56	$9.56\cdot10^{19}$	131	14.6
Films 0.5 μm thick on fresh (0001) cleavages of muscovite mica 0.5 μm					
0	1414	61	$1.44\cdot10^{20}$	31	1.3
0,3	2780	221	$7.87\cdot10^{19}$	54	8.1
1,5	5501	318	$1.08\cdot10^{20}$	56	17.5
2	674	68	$6.18\cdot10^{19}$	123	10.2
Films 2 μm thick on fresh (0001) cleavages of muscovite mica					
0	1156	74	$9.71\cdot10^{19}$	20	0.5
0,3	2570	242	$6.63\cdot10^{19}$	44	4.9
1,5	5800	323	$1.12\cdot10^{20}$	55	17.7
2	641	71	$5.62\cdot10^{19}$	121	9.3
Films 0.05 μm thick on glass-ceramic substrates					
0	4815	19	$1.55\cdot10^{21}$	64	19.8
0.3	5776	102	$3.54\cdot10^{20}$	62	22.3
1.5	1390	82	$1.05\cdot10^{20}$	80	8.8
Films 0.3 μm thick on glass-ceramic substrates					
0	1844	47	$2.44\cdot10^{20}$	34	2.1
0.3	4129	257	$1.01\cdot10^{20}$	30	3.7
1.5	4398	170	$1.62\cdot10^{20}$	15	0.9
Films 1 μm thick on glass-ceramic substrates 1 μm					
0	1428	60	$1.48\cdot10^{20}$	19	0.5
0.3	3899	289	$8.43\cdot10^{19}$	23	2.1
1.5	4819	174	$1.73\cdot10^{20}$	12	0.7

Figs. 1 – 2 show the thickness dependences of thermoelectric parameters of vapour-phase *SnTe* condensates with the content of bismuth 0.3 mol.%. It is seen that with reduction of condensate thickness *d*, irrespective of composition, conductivity grows considerably, and for thicknesses more than $d \approx 0.5$ μm it is practically unvaried. This is related to growth of the concentration of current carriers in the range of small film thicknesses, due to the acceptor effect of surface-adsorbed oxygen. And current carrier concentration for pure telluride is higher than for doped one due to the donor effect of bismuth. With decreasing thickness of films prepared on mica substrates, the Seebeck coefficient is increased as well, which results in considerable increase of thermoelectric power (Fig. 1, *d*).

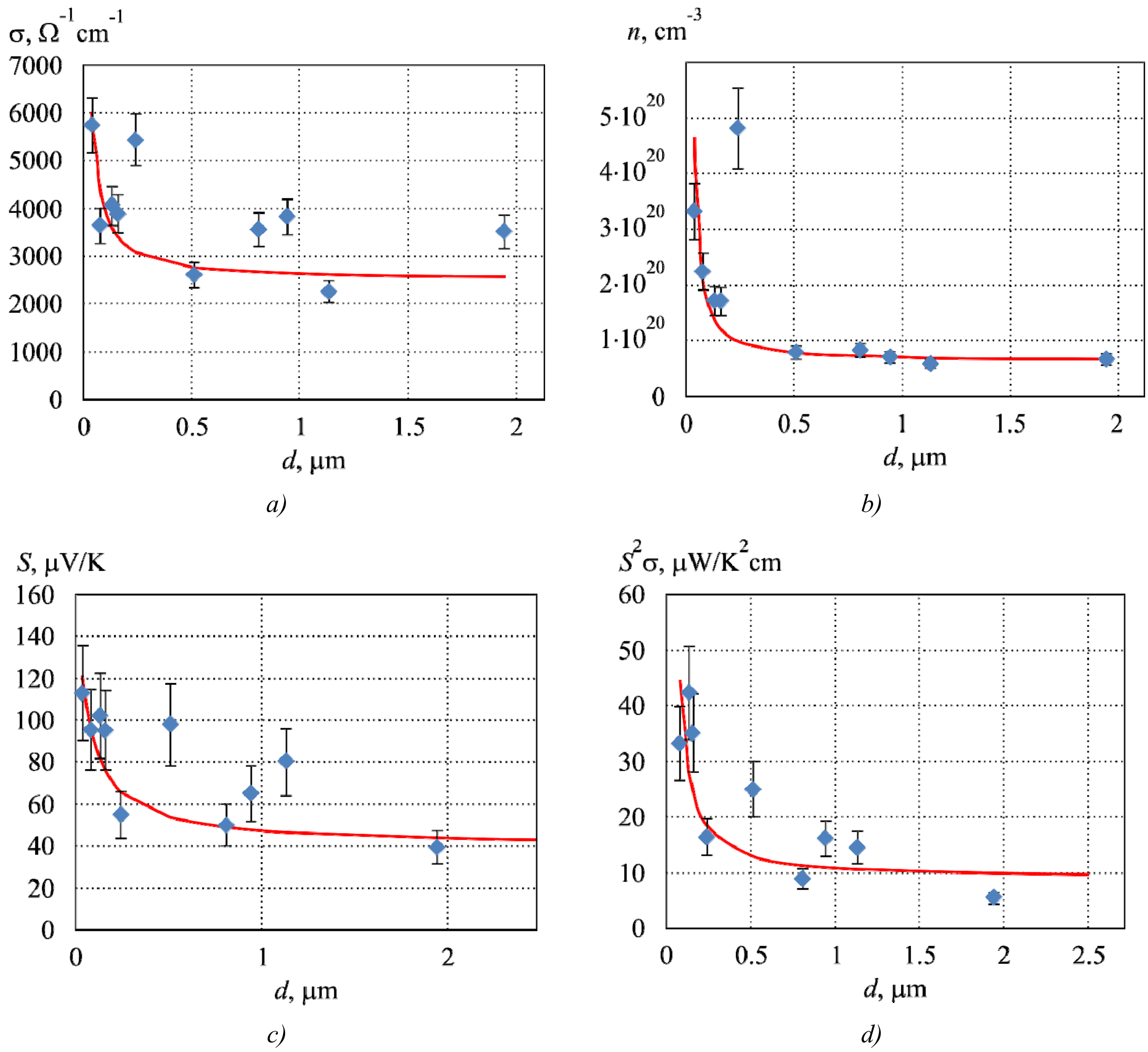

Fig. 1. Dependences of electric conductivity σ (a), the Hall concentration n (b), the Seebeck coefficient S (c) and thermoelectric power $S^2\sigma$ (d) on thickness d of SnTe:Bi films on fresh (0001) cleavages of muscovite mica. The content of Bi is 0.3 mol.%.

Films prepared on fresh (0001) cleavages of muscovite mica are characterized by considerably higher thermoelectric power due to double Seebeck coefficient than samples prepared on glass ceramic (Figs. 1 – 2, *d*), owing to better structural order at the cost of orientation effect of the substrate. For condensates obtained on glass ceramic substrates the thickness dependences of the Seebeck coefficient and thermoelectric power have a distinct maximum in the range of thicknesses ~ 0.6 μm (Fig 2, *c*, *d*) which is due to manifestation of size effects with small condensate thicknesses.

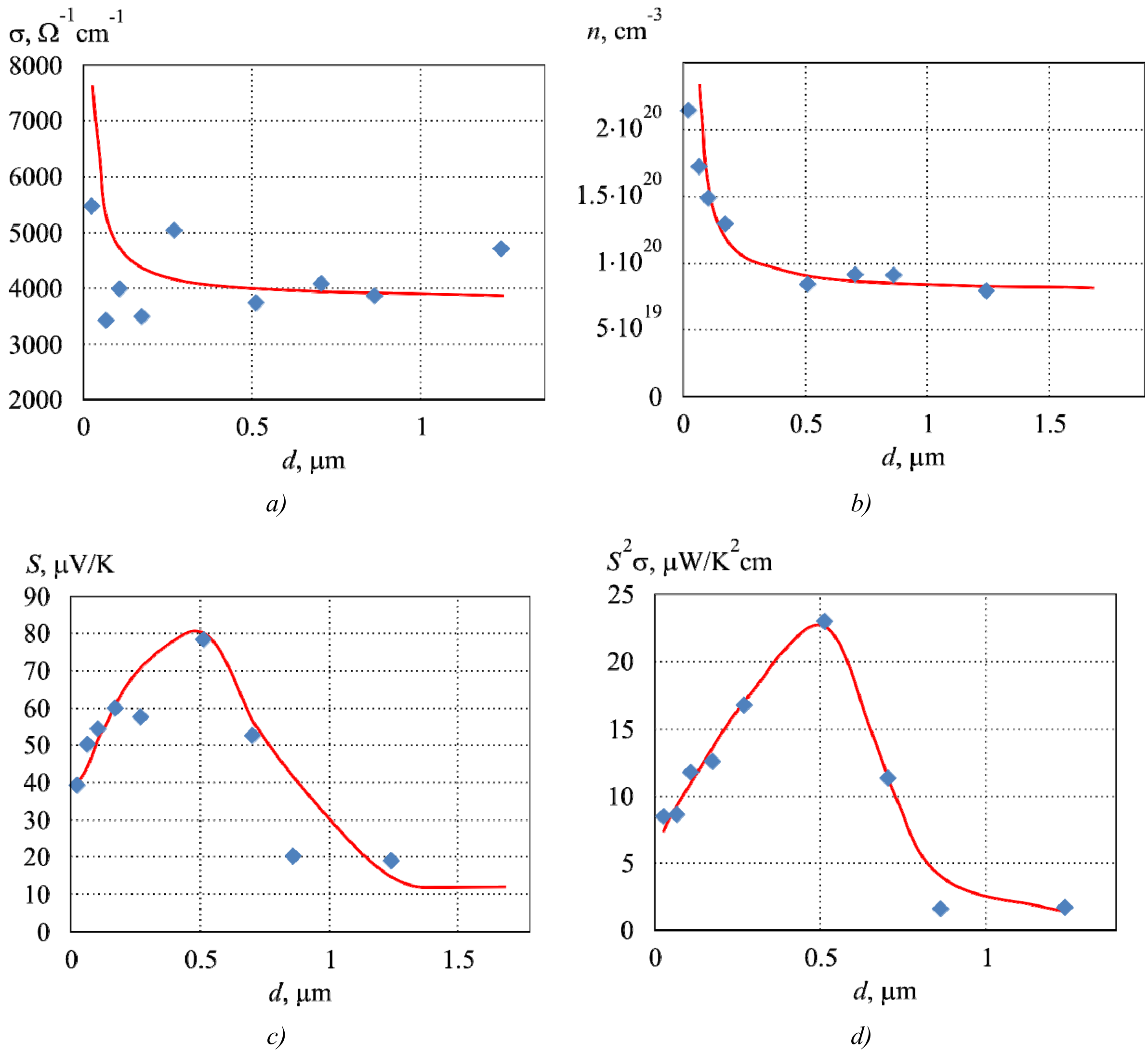

Fig. 2. Dependences of electric conductivity σ (a), the Hall concentration n (b), the Seebeck coefficient S (c) and thermoelectric power $S^2\sigma$ (d) on thickness d of SnTe:Bi films on glass-ceramic substrates. The content of Bi is 0.3 mol.%.

On the whole, high conductivity values combined with considerable Seebeck coefficient value of *SnTe*:*Bi* films yield thermoelectric material of *p*-type conductivity which is promising for construction of film micromodules for thermoelectric power conversion.

Conclusions

1. Thermoelectric properties of vapour-phase thin films of lead telluride doped with bismuth, prepared by vapour-phase methods on glass-ceramic and mica substrates have been studied.
2. It has been shown that *p*-type *SnTe* thin films have improved thermoelectric parameters as compared to the bulk samples.
3. Doping of tin telluride with bismuth, despite some reduction of conductivity allows improving thermoelectric power due to the Seebeck coefficient increase.

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