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Electrophysical properties of $Sm_xPb_{1-x}Te$ solid solutions

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Abstract. The electrophysical properties of $Sm_xPb_{1-x}Te$ ($x \le 0.08$) solid solutions have been investigated. The electric conductivity, Hall coefficient and Hall mobility of charge carriers in the temperature range 80 to 800 K have been measured. The mechanism of charge carrier scattering in solid solutions has been ascertained. It is established that increase of samarium content and simultaneous participation of interacting Sm^{2+} and Sm^{3+} ions in the transfer process lead to decrease in electric conductivity. The change of conductivity type from *p*- to *n*-type means that obtained solid solutions are partly compensated semiconductors.

Keywords: solid solution, electric conductivity, Hall coefficient, Hall mobility, mechanism of scattering.

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1. Introduction

The narrow-gap semiconductors of $A^{IV}B^{VI}$ group are unique materials due to their physical properties, variety of effects observable in them and possibilities of practical use. The high faultiness of their structure is one of important disadvantages of lead telluride. The concentration of vacancies and interstitial atoms achieves 10^{18}-10^{19} cm^{-3} when using standard methods of synthesis. Doping is one of the main methods to control the concentration of free charge carriers in semiconductors. The use of this method in application to solid solutions based on lead telluride allows us not only change the concentration of electrons and holes, but leads to appearance of principally new properties not inherent to initial material. The stabilization effect for the Fermi level is observed if its position is defined by only alloy composition and doesn't depend on the concentration of doping impurities and lattice defects, when PbTe doping with some rare-earth elements (Yb, Gd) takes place [1].

The aim of the work is to study samarium influence on electrophysical properties of lead telluride.

2. Experimental technique

The samples were obtained by direct alloying the initial components in vacuum-processed silica ampoules. The homogenizing annealing of the obtained one-phase samples was carried out in the medium of spectroscopically pure argon at 800 K for five days. The compositions of synthesized alloys correspond to the values x = 0.00; 0.02; 0.04; 0.08. The introduction of samarium impurity into lead telluride essentially changes its electrophysical properties, and the change of the conductivity from *p*- to *n*-type was observed in the investigated sample. The electric conductivity σ and Hall coefficient R at direct current and electromagnet magnetostatic field were measured [2]. The thermoelectromotive force α is measured in steady-state condition by the compensation method using the technique described in [2]. The measurement inaccuracy did not exceed 2.7 %.

3. Results and discussion

The curves of the temperature dependence for the electric conductivity σ are given in Fig. 1. As seen from the figure, the electric conductivity of solid solutions $Sm_xPb_{1-x}Te$ changes in a different manner with respect to the substituting ion Sm^{3+}, which depends on the substitution type and x value. The character of $\sigma(T)$ dependence in extrinsic conductivity range (80-200 K) is determined by the composition of solid solution. The further temperature increase leads to a strong decrease in the electric conductivity σ. Moreover, the rate of σ decrease depends on composition of solid solution $Sm_xPb_{1-x}Te$; the increase of samarium content in solid solution is accompanied by the corresponding increase of the activation energy for charge carriers from 0.03 up to 0.14 eV. The depletion range of charge carriers shifts to the side of more high temperatures (Fig. 1, curve 4). The intrinsic conductivity range begins at enough low temperatures ($T \ge 500$ K). The thermal width of the

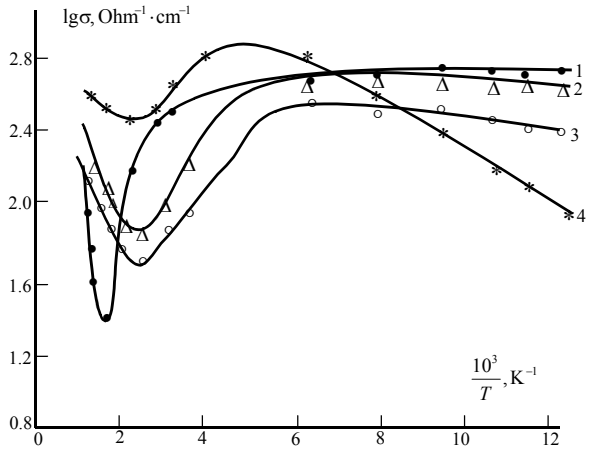

Fig. 1. The reverse temperature dependence of the electric conductivity σ for solid solutions $Sm_xPb_{1-x}Te$ at $x = 0.00$ (*1*); 0.02 (*2*); 0.04 (*3*); 0.08 (*4*).

forbidden band defined by $\lg\sigma = f(10^3/T)$ dependence increases from 0.22 up to 0.34 eV with the increase of samarium content in solid solution. This proves the fact that "self-compensation" also takes place along with "self-doping" in these solid solutions.

It is known that the coexistence of electrons and polarization sphere of lattice ions take place in rare-earth chalcogenide elements. Any polaron relaxations or polaron displacements along lattice take place in the charge exchange process between neighbor Sm^{3+} ions. Consequently, at increase of Sm^{3+} quantity and Sm^{2+} ions connected with it, the polaron displacements or relaxation decrease because of bond strengthening between samarium ions that gives the additional decrease of electric conductivity in the impurity region (Fig. 1).

The Hall coefficient *R* temperature dependences of solid solutions $Sm_xPb_{1-x}Te$ are given in Fig. 2. As seen from the figure, the Hall coefficient *R* increases at weak substitution of Pb atoms by Sm ones, i.e., the charge carrier concentration decreases. At further increase of samarium content, *R* changes the sign from the positive to negative one. The change of the charge carrier sign is confirmed by α thermoelectromotive force measurements for each from solid solution composition. The sign change effect takes place in solid solutions of $x = 0.04$ composition.

The curves of temperature dependences for the Hall mobility of charge carriers μ in $Sm_xPb_{1-x}Te$ solid solutions are given in Fig. 3. As seen from the figure, the change of the μ value with temperature increase has a complex character in the dependence on samarium content. The minima of μ(*T*) are observed practically in all compositions of solid solutions (with exception of the composition $x = 0.04$) at relatively high temperatures ($T = 250$-500 K). The μ(*T*) strong increase at further temperature increase shows appearance of hopping mechanism features in the given solid solutions, although according to classical laws the hopping

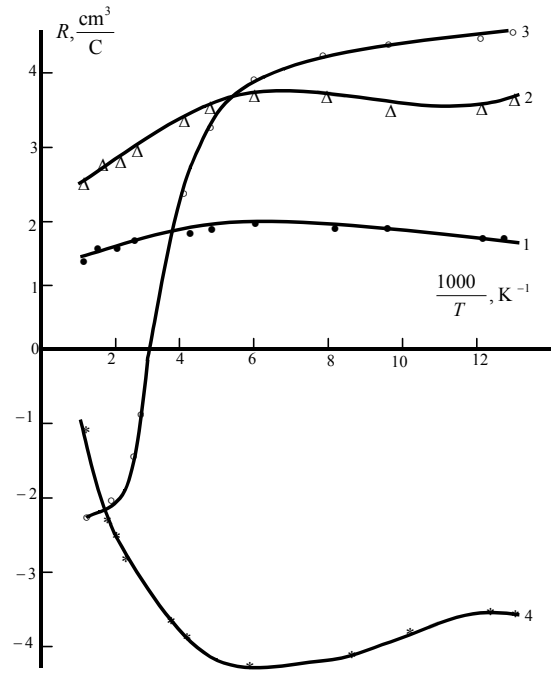

Fig. 2. The reverse temperature dependence of the Hall coefficient *R* for the solid solutions $Sm_xPb_{1-x}Te$ at $x = 0.00$ (*1*); 0.02 (*2*); 0.04 (*3*); 0.08 (*4*).

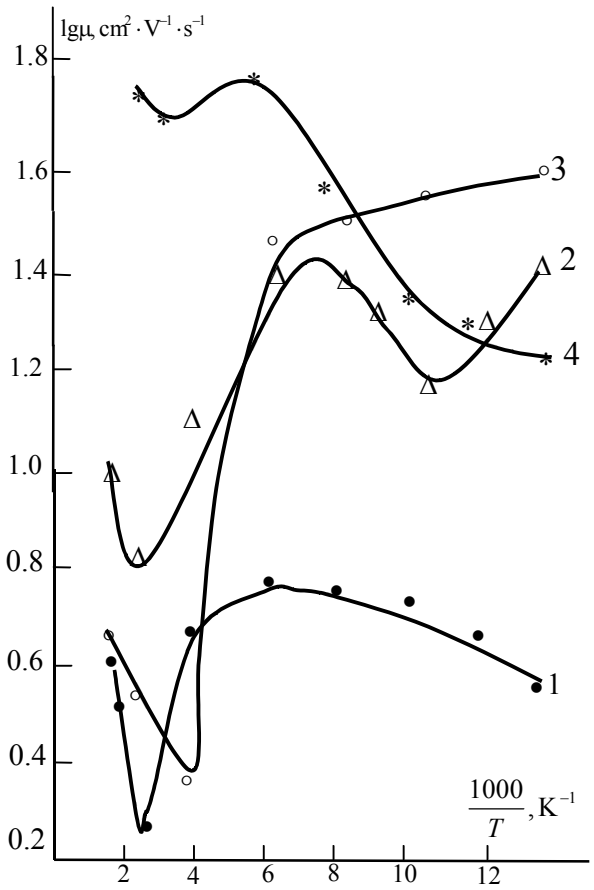

Fig. 3. The reverse temperature dependence of the Hall mobility for charge carriers μ in solid solutions $Sm_xPb_{1-x}Te$ at $x = 0.00$ (*1*); 0.02 (*2*); 0.04 (*3*); 0.08 (*4*).

mechanism should appear at relatively low temperatures [5]. Note that the conductivity of solid solution at given temperature is determined by the presence of charge carriers of different types, i.e., solid solutions have the properties of partly compensated semiconductor. In the given case, the general scattering mechanism is defined by relative contributions of separate scattering mechanisms. It is obvious that $\mu(T)$ dependence for each composition is established by the ratio of different scattering mechanisms for charge carriers [1]. The temperature dependence of the Hall coefficient (Fig. 2) proves the fact of simultaneous participation of charge carriers of different types in conductance.

The inversion takes place in solid solution beginning with $x = 0.04$ at $T = 380$-400 K. The given fact proves the discussions about variety of scattering mechanisms in solid solutions. The complexity of the dependence $\mu(T)$ allows us to make only qualitative conclusions about the dispersion mechanism for charge carriers in solid solutions. The scattering caused by polarized and acoustic phonons are the dominant ones in scattering mechanism for charge carriers at temperatures 250-800 K. The features of the hopping mechanism based on neutral impurity centers appear with temperature increase.

In the case $x = 0.04$, the qualitative change of the Hall mobility temperature dependence in the temperature range 80-450 K is observed. Probably, beginning with this samarium concentration in solid solution the essential increase in the number of delocalized states takes place.

4. Conclusions

The simultaneous decrease of conductivity, increase of the Hall mobility and change of charge carrier sign prove the fact that polaron centers appearing at formation of solid solutions $Sm_xPb_{1-x}Te$ play the active role in electric conductance. The scattering mechanism character depends on the samarium content in solid solution. At $x = 0.08$, the qualitative change of Hall charge carrier mobility dependence in the temperature range 80-450 K takes place. The scattering by polarized acoustic phonons is the main one in the scattering mechanism for charge carriers along with dispersion by acoustic phonons in solid solutions $Sm_xPb_{1-x}Te$ unlike to pure lead telluride.

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