Electrophysical properties of Sm$_x$Pb$_{1-x}$Te solid solutions

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Abstract. The electrophysical properties of Sm$_x$Pb$_{1-x}$Te (x ≤ 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.

Manuscript received 09.02.09; accepted for publication 18.03.09; published online 20.03.09.

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 $\sigma$ and Hall coefficient $R$ at direct current and electromagnet magnetostatic field were measured [2]. The thermoelectromotive force $\alpha$ 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 $\sigma$ are given in Fig. 1. As seen from the figure, the electric conductivity of solid solutions Sm$_x$Pb$_{1-x}$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 $\sigma$. Moreover, the rate of $\sigma$ decrease depends on composition of solid solution Sm$_x$Pb$_{1-x}$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 ($T \geq 500$ K). The thermal width of the
The curves of temperature dependences for the Hall mobility for charge carriers \( \mu \) in solid solutions \( \text{Sm}_x\text{Pb}_{1-x}\text{Te} \) solid solutions are given in Fig. 3. As seen from the figure, the change of the \( \mu \) value with temperature increase has a complex character in the dependence on samarium content. The minima of \( \mu(T) \) are observed practically in all compositions of solid solutions (with exception of the composition \( x = 0.04 \)) at relatively high temperatures \( (T = 250-500 \text{ K}) \). The \( \mu(T) \) strong increase at further temperature increase shows appearance of hopping mechanism features in the given solid solutions, although according to classical laws the hopping

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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 \( \text{Sm}_x\text{Pb}_{1-x}\text{Te} \) 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 \( \text{Sm}_x\text{Pb}_{1-x}\text{Te} \) unlike to pure lead telluride.

References