SHUBNIKOV–DE HAAS OSCILLATIONS IN $Pb_{0.82}Sn_{0.18}Te$ SINGLE CRYSTALS

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(Received September 3, 2019)

Abstract

Lead–tin telluride single crystals have been prepared by gas-phase synthesis. Shubnikov–de Haas effects in magnetic fields up to 12 T at low temperatures of 2.1 and 4.2 K have been studied. Parameters of the charge carrier energy spectrum have been determined. It has been found that an increase in the charge carrier concentration leads to an increase in the cyclotron effective mass, Fermi surface cross section, and relaxation time.

1. Introduction

Intense interest in studying the properties of narrow-gap semiconductors, particularly, lead–tin telluride single crystals is attributed to the wide possibilities of practical use of these materials as detectors and sources of radiation in the infrared spectral region, thermoelectric cells, strain gauges, etc. The scientific interest in these materials is primarily associated with their unusual galvanomagnetic, thermomagnetic, and magnetooptic properties [1].

The Shubnikov–de Haas (SdH) effect is a universal and powerful tool for studying the energy spectrum of degenerate electronic systems in metals, semimetals, alloys, and doped semiconductors. It was found that particularly suitable objects for the observation of this effect are $A^{III}B^{V}$ and $A^{II}B^{IV}$ group semiconductors and narrow-gap semiconductors.

The high content of information on the electronic system parameters is responsible for the widespread use of the SdH effect [2].

To obtain reliable experimental results, severe requirements are imposed on the quality of the samples under study: the volume distribution of the components should be uniform, while the amount of mechanical defects should be minimal. The most effective method for synthesizing homogeneous $Pb_{1-x}Sn_xTe$ single crystals is the gas-phase growth technique. To provide the growth of single crystals from the gas phase, we have developed a special technology using high-purity Pb, Sn, and Te of the OSCh-0000 grade as starting materials (Te was purified by multiple zone recrystallization). Microstructural and spectral studies and the Hall coefficient measurements confirmed the high quality of the synthesized $Pb_{1-x}Sn_xTe$ ($x = 0.18$) single crystals.

2. Results and Discussion

Determination of crystal parameters from experimental data on the SdH effect

In a quantizing magnetic field, taking into account the spin splitting of the levels for the Kane's dispersion law, the charge carrier spectrum (at $H \parallel z$) has the form [3]

$$\varepsilon(1+\frac{\varepsilon}{E_g}) = (n+\frac{1}{2}) * \eta\omega_c + \frac{P_z}{2m_c} + g\beta H / 2 \quad (1)$$

where n = 0,1,2... is the Landau level number, E_g is the band gap, $\beta = \frac{e\eta}{2m_0}$, P_z is the projection of the quasi-momentum vector onto the direction of magnetic field H, and ε is the charge carrier energy. This dispersion law is valid in the case of $m_c >> m_0$, which holds true in the case under consideration.

In experimental terms, the study of magnetoresistance oscillations provides the determination of a number of parameters of the energy spectrum of charge carriers. Quantum levels were determined from the ratio

$$n = k\frac{H_{n+k}}{H_n - H_{n+k}}, \quad (2)$$

where H_i is the magnetic field magnitude at the i maximum of magnetoresistance. Oscillation period was calculated by the following formula:

$$\frac{1}{H_{n+1}} - \frac{1}{H_n} = \Delta[\frac{1}{H}].$$

The experimental $n(1/H)$ dependence was used to calculate the slope and determine the SdH oscillation frequency.

$$F = \frac{\Delta n}{\Delta\frac{1}{H}}.$$

In the Kane's approximation, the frequency of magnetoresistance oscillations is as follows:

$$F_i = F\frac{1+2\frac{\varepsilon_F}{E_g}}{1+\frac{\varepsilon_F}{E_g}}, \quad (3)$$

where F is the oscillation frequency in the case of the parabolic dispersion law. Oscillation period is determined by the area of the extreme sections of the Fermi surface:

$$S_{экст.} = \frac{2\pi e}{\eta}\frac{1}{\Delta[\frac{1}{H}]} = \frac{2\pi e}{\eta}F \quad (4)$$

Cyclotron masses were determined from the temperature dependence of the SdH oscillation amplitudes, in accordance with the formula

$$m_c = \frac{e\eta H}{2\pi^2 kTc} * Arch\left[\frac{B(T_1, H_n)}{B(T_2, H_n)}\right], \quad (5)$$

$B(T,H)$ is the oscillation amplitude where at temperature T and in field H. ($T_2 = 2T_1$) Fermi energy can be calculated from the following relationship: $\varepsilon_F = (n+\frac{1}{2})\frac{e\eta H_n}{m_c}$. For the case of an

anisotropic Fermi surface, the charge carrier concentration can be calculated by the following formula:

$$\frac{p}{M} = \frac{1}{3\pi^2}\left(\frac{2e}{\eta}\frac{1}{\Delta[\frac{1}{H}]}\right)^{3/2}\frac{\left[k\cos^2\Theta + \sin^2\Theta\right]^{3/4}}{k^{1/4}}, \quad (6)$$

where M is the number of equivalent extrema in the Brillouin zone, p is the charge carrier concentration, $k = \frac{m_{\|}}{m_{\perp}}$, and Θ is the angle between the major axis of the ellipsoid and the direction of the magnetic field.

Dingle showed that the broadening of the Landau levels due to electron scattering is equivalent to an increase in temperature by the value of $T_D = \frac{\eta}{\pi k_0 \tau}$, where τ is the relaxation time.

The Dingle temperature, which characterizes the smearing of the Landau levels and determines the amplitude of quantum oscillations, can be calculated by the formula

$$T_D = \frac{e\eta}{2\pi^2 k_0 m_c} tg\alpha, \quad (7)$$

where α is the slope of the dependence of the SdH oscillation amplitude on the reciprocal magnetic field.

With an increase in the magnetic field, additional maxima associated with the spin splitting of the Landau levels appear on the oscillating resistance curve; therefore, the g-factor can be calculated:

$$g = \frac{\frac{1}{H_k} - \frac{1}{H_{k+1}}}{\frac{1}{H_k^s} - \frac{1}{H_{k+1}^s}} = \frac{\Delta[\frac{1}{H}]}{\Delta[\frac{1}{H^s}]} \quad . \quad (8)$$

Figure 1 shows the field dependence of the transverse magnetoresistance of $Pb_{0.82}Sn_{0.18}Te$ in magnetic fields up to 12 T at a temperature of 2.1 K.

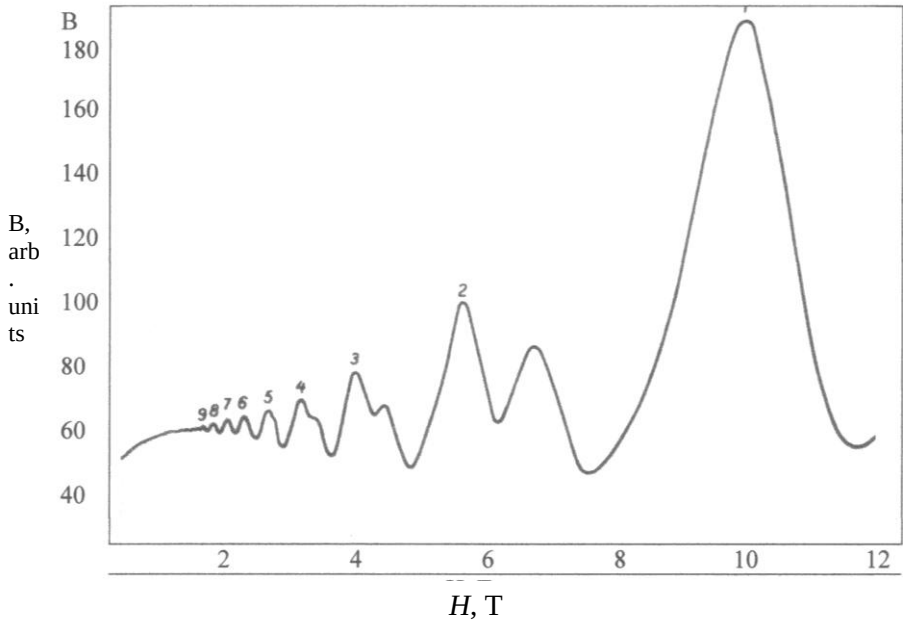

Fig. 1. Field dependence of the transverse magnetoresistance of $Pb_{0.82}Sn_{0.18}Te$ (sample 2)
The observed SdH oscillations are periodic in a reciprocal magnetic field 1/*H* (Fig. 2).

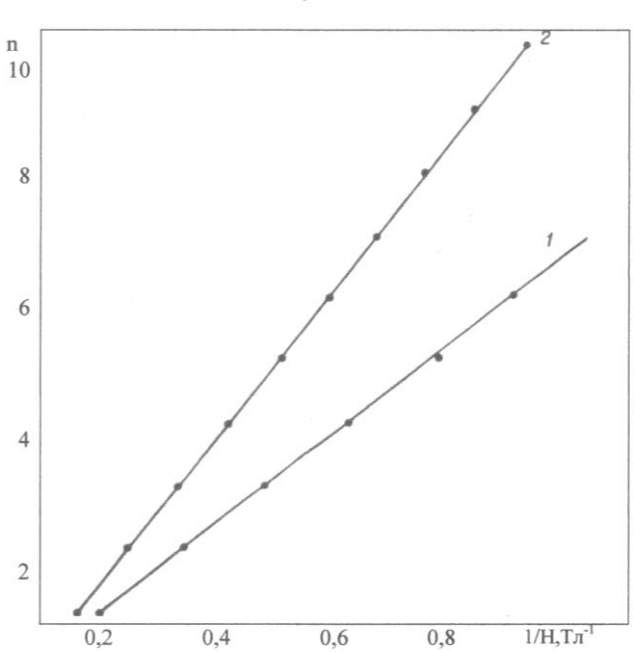

Fig. 2. Dependence of the quantum number of the SdH oscillations on reciprocal magnetic field 1/*H*.

Table 1. Parameters calculated from the field dependence of the transverse magnetoresistance of two $Pb_{0.82}Sn_{0.18}Te$ samples in magnetic fields up to 12 T at two temperatures of 4.2 and 2.1 K

Sample	p, 10^{17} cm^{-3}	$\frac{m_c}{m_0}$	S, 10^{-13} cm^{-2}	T_D, K		g		ε_F, eV	τ, 10^{-12} s		F, 10^5 G
				4.2 K	2.1 K	4.2 K	2.1 K		4.2 K	2.1 K	
1	9.6	0.07	1.12	6.4	6.0		9.1	0.057	0.38	0.405	0.304
2	4.8	0.031	0.29	11.4	10.1	5.5	12.2	0.03	0.21	0.24	1.17

3. Conclusions

Based on the effect of Shubnikov de Haas were calculated the electronic system parameters of two $Pb_{0.82}Sn_{0.18}Te$ samples in magnetic fields up to 12 T at two temperatures of 4.2 and 2.1 K.

The derived data show that an increase in the charge carrier concentration leads to an increase in the cyclotron effective mass magnitude, the Fermi surface cross section, and the relaxation time.

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