GALVANOMAGNETIC EFFECTS IN $A_2^V B_3^{VI}$

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Abstract: Magnetoresistivity of $A_2^V B_3^{VI}$-based compounds has been investigated ($H \approx 0$–89 kE, $T=0,5$–4.2 K). Oscillation of magnetoresistivity, Shubnikov de Gaas oscillation has been observed at high magnetic fields ($H > 30$ kE). The charge carrier concentration and area of extreme cross section of Fermi surface by plane, perpendicular to magnetic field have been evaluated from oscillation period.

$A^5_2 B^6_3$-based compounds are used as high effective thermoelectric transformers [1]. Recently, the interest to these compounds increases due to the perspectives of widening of working temperature range and increase of thermoelectric efficiency of $A_2^5 B_3^{VI}$ compounds, doped by different impurities [2–6]. Therefore the investigation of fundamental characteristics of these compounds is not only extended our representation on band structure, also has a practical meaning.

In the present work the results of investigations of galvanomagnetic effects in layered $A^5_2 B_3^{VI}$ compounds which have rhombohedral structure and crystallize in sp.gr. $D_3d$ ($R \bar{3}m$) [1], are given. The layers in $A^5_2 B_3^{VI}$ compounds consist of five monoatomic hexagonal grids alternating in sequence in $B(1)$-$A$-$B(2)$-$A$-$B(1)$. Atom $B(2)$ has 6 nearest atoms $B(1)$. The bond between $B(1)$-$A$-$B(2)$-$A$-$B(1)$ layers-quinquets is of weak Van-der-Vaal type, but in layers of $B(1)$-$A$ and $A$-$B(2)$ bonds have covalent character with small fraction of ionic bond.

Single crystals under investigation have been grown by Bridgman method from components with stoichiometric relationship. It is known, that by synthesis of $A_2^5 B_3^{VI}$ compounds from the melt of stoichiometric structure are characterized by presence of a significant amount of own points defects conditioned by transition of $A$ atoms into the position of $B$ atoms. These antistructural defects are the acceptors. Concentration of holes is $p\sim 10^{19}$ cm$^{-3}$.

Investigations have been carried out in temperature range 0.5–300K and magnetic field up to 8 Tl. At galvanomagnetic investigations the sample is placed in the centre of superconductive solenoid. Measurements are carried out by selective method under the alternating current by 20 Hz frequency. The current magnitude does not exceed 1mA. The current is directed along the layer plane, magnetic field is perpendicular to layer plane.

1. Theory
As it is known, at strong magnetic field ($\mu B > 1$, $\mu$-mobility of carriers is quanted on the plane perpendicular to magnetic field and takes discrete magnitudes (Landau levels). At definite conditions it is possible to observe these oscillations experimentally. These conditions are so:
1) $\hbar \omega_c >> kT$ - energy distance between Landau levels must be exceed many times thermal expansion of distribution of charge carriers on energy near Fermi level,

$$\omega_c = \frac{eH}{m^*_c c}$$

here $\omega_c$ cyclotron frequency,

2) $\omega_c \tau >> 1$ – broadening of Landau levels must be little many time than the distance between the levels,

3) $\zeta > \hbar \omega_c$ - to observe the oscillation it is necessary Fermi level to be above for some Landau levels. At the same time in aggregate with the first condition, this condition provides fulfillment of a condition of strong degeneration.

As for as Landau levels are placed equidistantly, then observed oscillation of kinetic characteristics (in peculiar, magnetoresistivity) is periodical in reverse magnetic field (with the period $2\pi = \frac{2\pi m^*_c}{eH}$). The investigation of magnetoscillation effects are comfortable, therefore some characteristic magnitudes depend only on form of izoenergy surfaces in space of reverse lattice and are unsensitive to dissipation mechanism.

For example, from the $p$ period of magnetoresistivity oscillation one can determine $n$ the concentration of charge carriers. Generally the oscillation period for secluded Fermi surface of arbitrary form is determined by the equation [7].

$$p = \frac{2\pi m^*_c}{eH}$$

here, $S_F$ – extreme square of cross of Fermi surface $\rightarrow \varepsilon(k) = \mu_F$ by plane, perpendicular to direction of magnet field.

In frameworks of sixellipsoidal model of Drebl-Volf for ellipsoid, centered on reflection plane, referred to center of a zone, dependence of energy with wave vector $\varepsilon(k)$ is described by:

$$\varepsilon(k) = \frac{\hbar^2}{2m_0} \sum_{i,j} \alpha_{ij} k_i k_j$$

(2)

Here, $\alpha_{ij}$ - tenzor components of reverse effective mass $\alpha_{ij} = m_{ij}$, $k_1$ axis is perpendicular to reflection plane, $k_2$ axis is parallel to crystallography $C_1$ axis, $k_3$ axis is directed along tetrahedral $C_3$ axis. Then oscillation period [8]:

$$p = \frac{eH}{m_0 c \mu_F} \left[ (\alpha_{22} \alpha_{33} - \alpha_{23}^2) \cos^2 \alpha + \alpha_{11} \alpha_{33} \cos^2 \beta + \alpha_{11} \alpha_{22} \cos^2 \gamma + 2 \alpha_{12} \alpha_{23} \cos \beta \cos \gamma \right]^{1/2}$$

(3)

In the case of magnet field is directed along $C_3$ tetrahedral axis (in the case Bi$_2$Te$_3$ is perpendicular to layers), then $\alpha = \beta = 90^0$, $\gamma = 0$, from (3) it is follow, that oscillation period is
\[ P\left( \frac{1}{H} \right) = \frac{e\hbar}{m_0 c \mu_F} \sqrt{\alpha_{11} \alpha_{22}} \]  

(4)

For sixellipsoidal model with square law of dispersion, Fermi level [9,10]:

\[ \mu_F = \frac{\hbar^2}{2m^*} \left( \frac{3\pi^2 n}{K_F} \right)^{2/3} \]  

(5)

here, \( n \) – full hole concentration, \( k_e \) - number of ellipsoids,

\[ m^* = \frac{m_0}{\sqrt{3\alpha_{11} (\alpha_{22}\alpha_{33} - \alpha_{23}^2)}} \]  

(6)

Thus, oscillation period is:

\[ P\left( \frac{1}{H} \right) = \frac{2e \sqrt{\alpha_{11} \alpha_{22}}}{\hbar \left( \frac{3\pi^2 n}{K_F} \right)^{2/3} \sqrt{3\alpha_{11} (\alpha_{22}\alpha_{33} - \alpha_{23}^2)}} \]  

(7)

Respectively, carrier concentration is determined as

\[ n^{2/3} = \frac{2e \sqrt{a_{11} a_{22}}}{P(1/H) \hbar \left( \frac{3\pi^2}{k_F} \right)^{2/3} \sqrt{3a_{11} (a_{22} a_{33} - a_{23}^2)}} \]  

(8)

2. Results of investigations and their discussion

We reveal, that in \( A^2B_3 \) –based compounds the magnetresistivity oscillation is observed on magnetic field dependence of magnetresistivity in the range of high magnet field (\( H > 30kE \)) at low temperature. By the special program prepared by us, oscillation part of magnetresistivity was secured, it is periodical in reverse magnet field.

As for as, at orientation of magnet field along \( C_3 \) axis all six ellipsoids of Fermi surface are sited symmetrically and have same extreme cross section by plane, perpendicular to magnet field, on fig.1 and 2 oscillation of one period is observed.
Figure 1. Oscillation part of magnetoresistivity, shown in reverse magnet field for two different samples of Bi$_2$Te$_3$ single crystal.

In fig.1 oscillation part of magnet resistivity for two samples of Bi$_2$Te$_3$ single crystals is shown. Oscillation period of magnetresistivity in Bi$_2$Te$_3$ single crystal was within (3÷3.5)·10$^{-6}$ E$^{-1}$. To take account in (8) tensor components of reverse effective mass are $a_{11}=2.8$; $a_{22}=20.8$; $a_{23}=4.65$ and $a_{13}$=-1.05 [11], then determined value of charge carrier concentration appears to be equal (6.5÷8)·10$^{18}$ cm$^{-3}$.

Area of extreme cross section of Fermi surface by plane perpendicular to magnetic field is $S=(28÷32)$·10$^{12}$ cm$^{-2}$.

Figure 2. Oscillation part of magnet resistivity, shown in reverse magnet field for two different samples of Sb$_2$Te$_3$ single crystal.
In fig. 2 oscillation part of magnetoresistivity for two samples of Sb$_2$Te$_3$ single crystals is shown. It is shown from the figure the oscillation period of magnetoresistivity in these crystals appear to be less than in Bi$_2$Te$_3$ and is $(1.7±1.9)\cdot10^7$ cm$^{-1}$. From (8) calculated value of charge carrier concentration is $(1.6±1.9)\cdot10^{19}$ cm$^{-3}$. Area of extreme cross section of Fermi surface by plane perpendicular to direction of magnetic field and is $S=(50±57)\cdot10^{12}$ cm$^2$. It is necessary to note the charge carrier concentration in Bi$_2$Te$_3$ and Sb$_2$Te$_3$ determined by Hall measurement, appears to be more, than the charge carrier concentration calculated by Shubnikov-de Gaas oscillation period in high magnet fields, in account of, six-ellipsoidal model of zone structure. Probably, it testifies for the existence of subband in valence band with the large effective mass, sited below the valence band top. Energy of holes in this band isn’t quanted and this band doesn’t give contribution to period of quant oscillation, whereas each bands give contribution to Hall effect. Authors of [12] investigated p-Bi$_2$Te$_3$ samples, supposed same disagreement by the existence of subband with the holes of large effective mass $m^*_p=2.4m_0$, sited below than upper subband on $\sim20$ meV.

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