Quantum oscillations of Bi and alloy BiSb magnetoresistance in magnetic fields up to 33 T

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Abstract

The special quantum oscillations of bismuth magnetoresistance have been considered. In contrast to Shubnikov-de Haas (SdH) oscillations observed at temperature less than 4K, the oscillations were detected in the temperature range 6-65 K and were referred to as “high-temperature” oscillations (HTO). The results of joint studies of SdH oscillations and HTO of the magnetoresistance for pure Bi and alloy Bi$_{1-x}$Sb$_x$ (x=2.6 at.%) in stationary magnetic field up to 33 T are presented. It was found that SdH oscillations and HTO reached its quantum limit at the same value of magnetic field. The analysis of the experimental data verified one of two alternative models of HTO.

Key words: bismuth; magnetoresistance; quantum limit

A new type of quantum oscillations of static conductivity of bismuth in a magnetic field has been considered. These oscillations are periodic in reciprocal magnetic field and are characterized by a frequency higher than that of Shubnikov-de Haas (SdH) oscillations. In contrast to SdH oscillations observed at temperature $T \leq 4$ K, the oscillations were detected in the temperature range 6-65 K and were referred to as “high-temperature” oscillations (HTO) [1]. HTO are investigated on bismuth samples of various quality, in compensated alloys Bi$_{1-x}$Sb$_x$ and in not compensated alloys Bi$_{1-x}$(Sb,Te, Sn)$_x$. The thermo-emf HTO in a magnetic field has also been studied. HTO differ basically from SdH oscillations in peculiar temperature dependence: the HTO amplitude rapidly attains its peak value at $T \approx (10-12)$ K and then decreases slowly upon heating. It was found [2] that the existence of a peak on the HTO amplitude temperature dependence is determined by frequency intergroup electron-hole transitions associated with inelastic scattering by acoustic phonons. The characteristic feature of HTO distinguishing them from other quantum oscillations in a magnetic field is the independence of the HTO frequency $F$ of the Fermi energy $\epsilon_F$. It was found that $F_{HTO} \propto \epsilon_F^e + \epsilon_F^h = \epsilon_p$ (e$^e$ and e$^h$ are the Fermi energy of electrons and holes and $\epsilon_p$ is of the energy bands overlapping region).

Recently two alternative models tried to explain qualitatively of the HTO nature.

1. HTO arise due to the electron-hole transitions near the boundaries of the energy bands [3]. Every time the Landau subband extremum for the hole (electron) band of the spectrum appears near the bottom of the conduction (valence) band, the collision frequency suffers a discontinuity because the density of electron states below the bottom of the conduction band is equal to zero. Authors [3] suppose that in the temperature region $T \ll \epsilon_F/k_B$ the number of unoccupied states below the Fermi level (and the number of occupied states above $\epsilon_F$) is not exponentially small but one is determined by the broadening of the energy levels due to relaxation processes (both elastic and inelastic).

2. Oscillations of conductivity are a result of electron-hole transitions close to a Fermi level [4]. The necessary condition for HTO appearance is that the effective electron and hole masses must be commensurable ($km^*_{e} = k'm^*_{h}$ with integers k and k'). In this case the appropriate extrema of electron and hole
Landau subbands have a simultaneous tangent in the vicinity of the Fermi level.

It seems that for final conclusions concerning the HTO physical nature it is necessary to a set of joint measurements of SdH hole oscillations and hole HTO in a Bi and alloy BiSb in strong magnetic fields up to 30-40 T. SdH hole oscillations reached its quantum limit when magnetic fields is so high. Under these conditions according to the hole HTO behavior it will be possible to obtain the appropriate conclusions on their nature.

The measurements of SdH oscillations and HTO were made in stationary magnetic fields up to 33 T on pure Bi and alloy BiSb in strong magnetic fields up to 30-40 T. SdH hole oscillations reached its quantum limit when magnetic fields is so high. Under these conditions according to the hole HTO behavior it will be possible to obtain the appropriate conclusions on their nature.

In the experiments under consideration the quantum limit $M_{\Omega_c} > \epsilon_{F}^e$ (or $\epsilon_{F}^h$) at high magnetic fields is realized for different ratio between spectral parameters of electrons and holes in bismuth and $B_{1-x}Sb_x$.

The HTO behavior of HTO is typical of the oscillation mechanism proposed in [4]. According to [4], the HTO are nominally the SdH oscillations but with due regard for interband transitions nearby the Fermi level followed by a change of sign of the effective mass. In this case it is reasonable that the quantum limit for SdH oscillations of both electrons and holes is bound to show itself also in HTO in the same way. It is particularly remarkable that the last minimum of HTO, which are a factor of two.

These researches were carry out in collaboration with National High Magnetic Laboratory in framwork of the NIS/NHMFL program.

References