# NEW REVERSAL EFFECT IN InSb

D.G. Andrianov, N.B. Brandt, E.R. Ioon, V.M. Fistul', and S.M. Chudinov
Moscow State University

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Beats and a reversal effect were observed in one and the same narrow interval of carrier density in an investigation of Shubnikov-de Haas oscillations in n-InSb doped with Te. The reversal effect consists of a qualitative change in the picture of the oscillations when the magnetic field is reversed. Possible causes of the indicated effects are discussed.

1. The Shubnikov - de Haas (SdH) oscillations of single-crystal samples of n-InSb doped with Te, with a carrier density $\sim 10^{18}$ cm$^{-3}$, were investigated in detail in a magnetic field up to 60 kOe at 4.2°K. A standard procedure was used to plot the oscillations of the magnetoresistance $\rho(H)$ and of its derivative $\partial\rho/\partial H = f(H)$. All measurements were made with $\vec{H}$ perpendicular to the current flowing through the sample.

2. In samples with carrier density in the narrow interval $8.13 \times 10^{17} < n < 1.1 \times 10^{18}$ cm$^{-3}$ we observed beats of the SdH oscillations and a unique reversal effect, wherein the character of the oscillatory dependences was qualitatively altered when the magnetic field direction was reversed. Commutation of the field H was accompanied by vanishing, appearance, or strong shifts of the nodes of the beats, and also by a change in the amplitude and phase of the oscillations (Figs. 1 and 2).

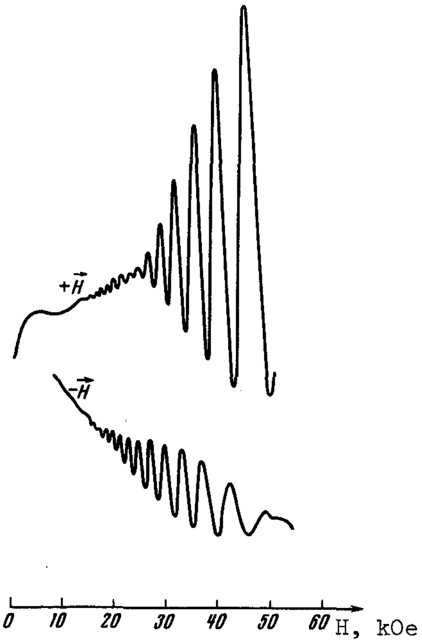

Fig. 1. Oscillations of the derivative of the magnetoresistance $\partial\rho/\partial H$ in the direct ($+\vec{H}$) and reversed ($-\vec{H}$) field in an InSb sample doped with Te with $n = 9.6 \times 10^{17}$ cm$^{-3}$. The angle $\phi$ between the $[00\bar{1}]$ direction and the magnetic field lying in the $(1\bar{1}0)$ plane is equal to 172°.

We note that reversal of the current through the sample leads only to a mirror reversal of the oscillation curve, without a qualitative change in its shape. A change in the value of the current causes a proportional decrease or increase of the oscillation amplitude, without a shift of the beat nodes. The oscillation picture does not depend on which of the faces of the sample the potential contact are placed, and identical plots were obtained with potential contacts located on different sample faces parallel to the (110) and (001) planes.

3. The reversal effect and the beats have the following features: a) there is no reversal effect when the magnetic field vector lies in the (110) plane; b) beats are observed at all orientations of the magnetic field, including orientations in the (110) plane, with the exception of the [001] direction (which is a characteristically unique direction for this crystal); c) when the vector $\vec{H}$ passes through the [001] axis in the planes (100), (010), and $(1\bar{1}0)$ the picture of the oscillations hitherto observed in the direct magnetic field $+\vec{H}$ is now observed in the reversed field $-\vec{H}$, and vice versa. The plots of $\partial\rho/\partial H = f(+\vec{H})$ for the angle $+\phi$ ($\phi$ is the angle between $\vec{H}$ and the $[00\bar{1}]$ direction in the corresponding plane) coincide exactly with the plots of $\partial\rho/\partial H = f(-\vec{H})$ for the

angle $-\phi$. A similar situation is observed also in the (001) plane, but then the role of the [001] axis is assumed by [1$\bar{1}$0]. Figure 3a shows a typical plot of the positions of the beat nodes on the orientation H in the (1$\bar{1}$0) plane and illustrates the magnetic anisotropy of the observed effects.

4. The foregoing data lead to the following conclusions:

1) In a narrow range of the Te impurity density in the InSb crystal, the tetrahedral symmetry relative to the external magnetic field is lost: a) the [001] direction becomes singled out while the directions [100] and [010] remain equivalent; b) the rotational symmetry of the cubic axes and of the diagonals on the faces decreases to first order, with exception of the singled-out axis [110], which retains twofold symmetry[1].

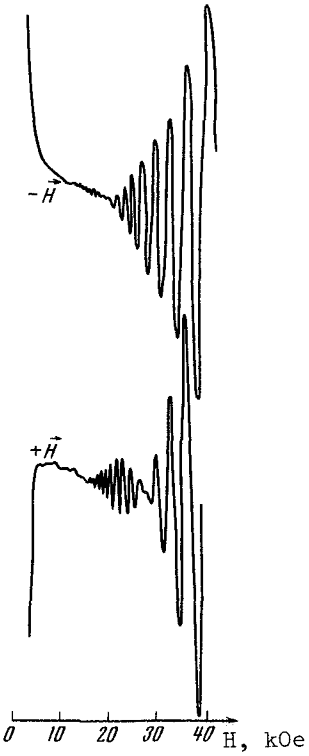

Fig. 2

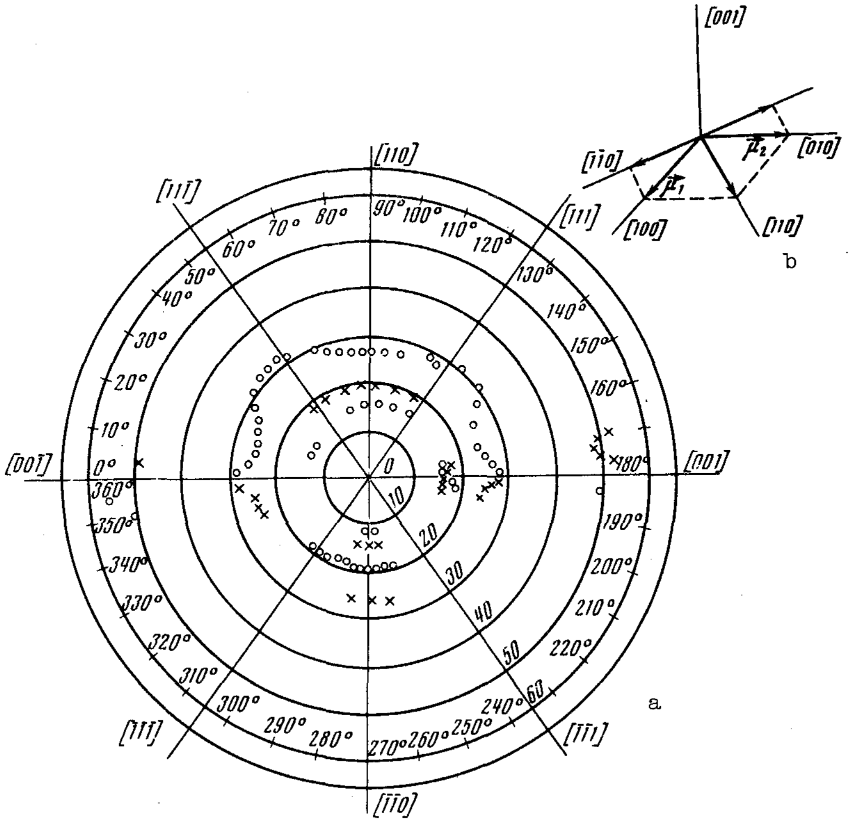

Fig. 3

Fig. 2. Oscillations of the derivative of the magnetoresistance $\partial\rho/\partial H = f(H)$ in the reverse ($-\vec{H}$) and direct ($+\vec{H}$) field in an InSb sample doped with Te with $n = 9.6 \times 10^{17}$ cm$^{-3}$ at $\phi = 80°$.

Fig. 3. a) Polar plot of the positions of the beat nodes in SdH oscillations observed in an InSb sample with $n = 9.6 \times 10^{17}$ cm$^{-3}$ in the direct field $+\vec{H}$ (light circles) and in the reversed field $-\vec{H}$ (crosses) at different orientations of $\vec{H}$. The magnetic field lies in the (1$\bar{1}$0) plane, the angles are measured from the [00$\bar{1}$] axis. The magnetic field intensity is plotted in the radial direction. b) Arrangement of the magnetic moments relative to the crystallographic axes.

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[1] The crystal was grown in the [112] direction.

2) The reversal effect observed in InSb + Te cannot be attributed to singularities in the electron energy spectrum of InSb. The asymmetry of the properties with respect to the sign of the external magnetic field points to the existence of an intracrystalline magnetic field.

It can be assumed on the basis of the obtained data that there exist in the crystal two magnetic moments of equal magnitude, $\vec{\mu}_1$ and $\vec{\mu}_2$, directed along the axes [100] and [010].

On the basis of the concepts universally accepted in magnetism, the [110] direction is that of the ferromagnetic axis, and the direction $[1\bar{1}0]$ perpendicular to it is that of the antiferromagnetic axis (Fig. 3b).

5. The appearance of a unique magnetism in InSb + Te in a narrow interval of Te concentration can be explained by the hypothesis of the appearance of quasilocalized magnetic moment connected with certain virtual (resonant) levels that cause a change in the dispersion law in the conduction band of InSb in the neighboring energy region. Passage of the Fermi level (due to doping or to external pressure) through these resonant levels is accompanied (i) by their virtual filling and the appearance of quasilocalized magnetic moment, and (ii) by a maximum of exchange interaction of the quasilocalized moments via the conduction electrons on the Fermi level, and consequently the appearance of a long-range magnetic order and formation of an intracrystalline field.

6. It can be assumed that an analogous mechanism causes the beats observed in the SdH effect in n-type HgSe and GaSb crystals (in the carrier density interval $1.2 \times 10^{18} < n < 1.5 \times 10^{18}$) [12], and also in Bi doped with Te and Se [3]. The presence of a narrow concentration interval in which the beat effect is observed, and also the existence of this effect in Bi + Te(Se) (whose lattice has an inversion center) casts doubts on the existence of a connection between the appearance of the beats and the absence of an inversion center in crystal lattices of III-V or II-VI compounds.

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