

PECULIARITIES OF QUANTUM OSCILLATIONS OF LONGITUDINAL HALL EFFECT IN HIGH MAGNETIC FIELDS IN BISMUTH BICRYSTALS

F.M.Muntyanu, A.Gilewski, K.Nenkov, A.Zaleski, T.Palewski

International Laboratory of High Magnetic Fields and Low Temperatures, Wroclaw, Poland

V.Chistol

Technical University of Moldova, Chisinau, Republic of Moldova

E-mail address: muntean_tedor@yahoo.com

Abstract: We report the results of longitudinal Hall effect (LHE) study in Bi bicrystals with nano-width superconducting crystallite interfaces (CIs), converted by magnetic field or current in normal state, in order to elucidate the high field (up to 40T) peculiarities of quantum oscillations. At $B > 2T$ directed along CIs plane two new harmonics of oscillations as well as a number of quantum Hall quasi-plateaus have been observed. It was found that the detected quasi-plateaus disappeared at magnetic field reversal. This indicates that in bicrystals there are spin - oriented carriers located in spectrum of Landau levels.

1. Introduction

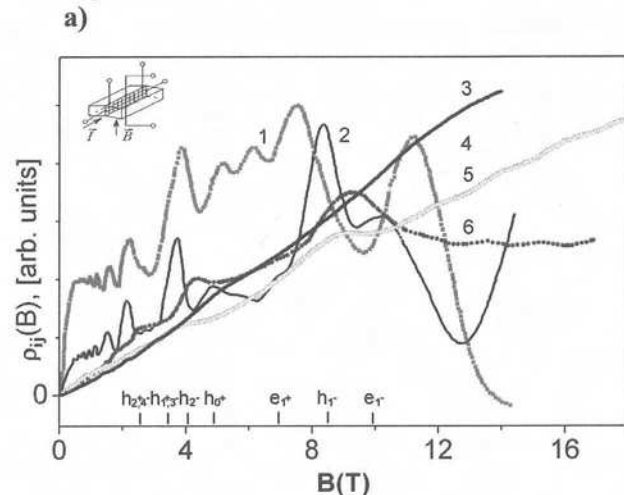
The bismuth bicrystals are very interesting object of research from many points of view, but especially to the fact, that in Bi occurs phase transitions of Dirac electrons with novel quantum properties in high magnetic fields [1-3]. Moreover, while ordinary rhombohedral Bi is not a superconductor, the CIs of bicrystals exhibits superconducting properties, for some samples $T_{onset} \sim 21K$ [4] that is much more, than in ultrathin amorphous or granular Bi films and nanoparticles. In the current experiments the LHE was registered at low temperatures and in magnetic fields up to 40 T, directed along the CI plane near the trigonal C_3 axis of crystallites. The LHE was chosen as the preferential method because it seems to be one of the most sensitive transport effect to detect the quantum oscillation in bicrystals. Contact electrodes for LHE investigations were soldered by electro-spark welding. Two types of bicrystals were investigated: small crystallite disorientation angle (SDA) and large crystallite disorientation angle (LDA). The measurements were made in the International Laboratory of High Magnetic Fields and Low Temperatures (Wroclaw, Poland).

In this report we identify high-fields features of spin-oriented carriers located in spectrum of Landau levels which significantly affect the LHE behavior at the particular orientation of the magnetic fields along CIs plane.

2. Results and discussion

After extensive research of both SDA and LDA bicrystals, we established that in a magnetic field directed along the C_3 axis of crystallites the spectrum of LHE quantum oscillations (see Fig.1a,b) of SDA bicrystals of inclination type is complex and contains frequencies from the Fermi surface (FS) of crystallites and interfaces [5]. Above 2 T, the oscillation peaks take an unusual configuration, and their position is essentially shifted from the oscillation maxima of Hall resistivity of elemental Bi in both bicrystals and single crystalline samples [6]. Between the peaks, along with minima in magnetoresistance, a number of quantum Hall quasi-plateaus (~ 3 T, ~ 6 T, ~ 15 T) were found including two below the carrier quantum limit and one centred at 15 T after quantum limit for the holes. If Hall potential contacts are adjusted outside of CI or magnetic field is reversed, the quasi-plateaus disappear and

the oscillation peaks assume their conventional shapes. In addition to the known frequencies of quantum oscillations of Bi, finding explanation in the one-particle picture, two new harmonics are observed in our bicrystals since 2-2.5 T (first frequency) and 10 T (second frequency), respectively. Their periods of oscillation characterize larger than in single crystalline Bi cross-sectional areas of the FS and are related to the central and adjacent layers of interfaces. At least one of the harmonics in bicrystals with a higher superconducting transition temperature defines extremal cross-sectional areas of Fermi surface which is almost 70 times higher than that of FS of crystallites. We've also found: (i) In SDA bicrystals of an inclination type, the first harmonic became visible in magnetic fields (~ 2 T) since the anomalies of LHE quantum oscillations can be identified; (ii) The quantum Hall quasi-plateaus and changing of the shapes of oscillation peaks are clearly pronounced only in SDA bicrystals of inclination type, while the new harmonics occur in all investigated bicrystals; (iii) Because of the increased strength of disorder and high density of dislocations in LDA bicrystals [5] the localised states in the spectrum of Landau levels do not appear and the presence of non-interacting carriers seems to be problematic. Another interesting feature of the development of quantum Hall quasi-plateaus (including the one at 15 T) is their disappearance if magnetic field reverse, therefore indicating that in SDA bicrystals the flow of Dirac fermions along the CI plane is sensitive to the direction of the magnetic field.



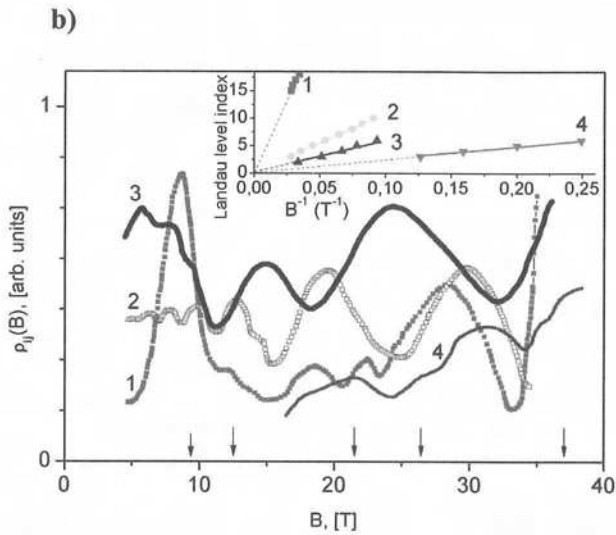


Fig.1. The quantum oscillations of magnetoresistance $\rho_{ii}(B)$ and longitudinal Hall effect $\rho_{ij}(B)$ in Bi bicrystals of inclination (a) and twisting (b) types. (a) (1) $\rho_{ii}(B_i^+)$, 4,2 K, $\theta_1 = 4^\circ$; (2) $\rho_{ij}(B_i)$, 2,1 K, $\theta_1 = 5^\circ$; (3) $\rho_{ij}(B_i)$, 4,2 K, $\theta_1 = 4^\circ$; (4) $\rho_{ij}(B)$, 2,1 K, $\theta_1 = 5^\circ$; (5) $\rho_{ij}(B_i)$, 4,2 K, $\theta_1 = 7^\circ$; (6) $\rho_{ij}(B_i)$, 4,2 K, $\theta_1 = 8^\circ$. The marks denote the position of oscillation peaks in Bi single crystals. (b) (1) $\rho_{ij}(B_i)$, 1,5 K, $\theta_1 = 5^\circ$, $\theta_2 = 5,5^\circ$; (2) $\rho_{ij}(B_i)$, 4,2 K, $\theta_1 = 62^\circ$, $\theta_2 = 2^\circ$; (3) $\rho_{ij}(B_i)$, 1,6 K, $\theta_1 = 3^\circ$, $\theta_2 = 5^\circ$; (4) $\rho_{ij}(B)$, 4,2 K, $\theta_1 = 29^\circ$, $\theta_2 = 11^\circ$. The monotonic part of $\rho_{ii}(B)$ and $\rho_{ij}(B)$ has been subtracted. The marks denote [6] the position of Nernst oscillation peaks in Bi at $B > 10$ T. Inset: The B^{-1} position of the Hall peaks versus their Landau level index: (1, 2) for the oscillation curve 4; (3, 4) for the oscillation curve 2.

Very recently in [7] also was shown that the flow of Dirac fermions along the trigonal axis is extremely sensitive to the orientation of in-plane magnetic field. All

these issues apparently indicates a possible experimental manifestation of valley – nematic Fermi liquid state in bismuth in high magnetic fields, at which the formation of the domains of pseudospin polarization occurs, preventing [7,8] the macroscopic vally and nematic ordering.

Conclusions

As a consequence of LHE investigations in Bi bicrystals at low temperatures and in high magnetic fields were revealed two new harmonics of oscillations attributed to Fermi surface of adjacent and central layers of crystallite interface. Also was observed a number of quantum Hall quasi-plateaus, which disappeared if magnetic field reversed. We conclude that in Bi bicrystals there are domains of pseudospin polarization depending on direction of the magnetic field.

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