Quantum corrections to the galvanomagnetic coefficients of quasi-two-dimensional electrons of InSb/GaAs heteroepitaxial structures

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The logarithmic corrections to the temperature dependence of the conductivity and that of the Hall coefficient have been found experimentally for the first time for quasi-two-dimensional electrons at a *p*-InSb/*i*-GaAs heterojunction. The observed anomalies are attributed to important spin-orbit effects on kinetic phenomena at liquid-helium temperatures.

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There have been theoretical predictions[1–3] of quantum corrections to the components of the conductivity tensor in a magnetic field under weak-localization conditions. In the case of a two-dimensional electron gas, the corrections have a logarithmic temperature dependence, and the contribution from electron-electron interactions under impurity scattering conditions gives rise to the following relations for the surface conductivity[1]:

$$\Delta\sigma^A_{xx} = A\frac{e^2}{2\pi^2\hbar}\ln T\tau, \tag{1}$$

$$\Delta\sigma_{xy} = 0\,. \tag{2}$$

The corresponding relations for the contribution of electron localization are

$$\Delta\sigma^B_{xx} = B\frac{e^2}{2\pi^2\hbar}\ln T\tau, \tag{3}$$

$$\frac{\Delta\sigma_{xy}}{\sigma_{xy}} = \frac{2\,\Delta\sigma_{xx}}{\sigma_{xx}}\,. \tag{4}$$

Using the familiar expression for the Hall coefficient in classically weak magnetic fields, $R_H \sim \sigma_{xy}/\sigma^2_{xx}$, and relations (1)–(4), we can show that

$$\frac{\Delta R_H}{R_H}\bigg/\frac{\Delta\sigma_{xx}}{\sigma_{xx}} = -2\frac{\Delta\sigma^A_{xx}}{\Delta\sigma^A_{xx}+\Delta\sigma^B_{xx}} = -2\frac{A}{A+B}, \tag{5}$$

where $B = \alpha p$ (p is the exponent in the temperature dependence of the relaxation time for the phase of the electron wave function: $\tau_\varphi \sim T^{-p}$).

According to Ref. 4, the coefficient is $\alpha = 1$ for a simple energy band without spin-orbit effects, and if there is a strong spin-orbit relaxation in the quasi-two-dimensional case, then $\alpha = -1/2$.

It can be seen from (5) that the effects of the spin-orbit interaction should lead to the inequality

$$\gamma = \left| \frac{\Delta R_H}{R_H} \Big/ \frac{\Delta \sigma_{xx}}{\sigma_{xx}} \right| > 2, \quad (\text{ since } A>0;\ 1 \leqslant p \leqslant 3).$$

In the absence of spin-orbit effects, we would have $0 \leqslant \gamma \leqslant 2$, as has in fact been observed experimentally in p-Si inversion channels[5] and at GaAs/GaAlAs heterojunctions.[6]

In this letter we are reporting the first results of a study of the anomalies in the galvanomagnetic coefficients of quasi-two-dimensional electrons in p-InSb/i-GaAs heteroepitaxial structures produced by vacuum epitaxy on substrates of semi-insulating GaAs. The samples were prepared in the standard geometry for dc Hall measurements: with two pairs of potential contacts, formed by fusing pure indium, with a length-to-width ratio of four.

Over the temperature range 12 K $< T <$ 300 K the samples exhibited $R_H(T)$ and $\sigma(T)$ dependences typical of ordinary, bulk p-InSb with an impurity hole concentration of 2×10^{15} cm^{-3}. At $T < 10$ K, however, the Hall coefficient becomes negative, a highly anisotropic magnetoresistance arises, and the effective Hall mobility of the electrons, $\mu_H = \sigma R_H$, does not exceed 500 cm^2/(V·s) at $T = 1$ K.

The measurements were taken in a cryostat-in-cryostat apparatus, in which a temperature $T \simeq 0.99$ K was reached through high-vacuum removal of the He^4 vapor from the inner helium Dewar by an adsorption pump. A magnetic field was produced by a superconducting solenoid and monitored by a thin-film n-InSb Hall pickup positioned beside the sample. All the measurements were carried out under conditions linear in the electric field (the current through the sample did not exceed 10^{-6} A) in magnetic fields below 200 Oe (Fig. 1).

Figure 2 shows the temperature dependence of the relative change in the Hall coefficient, $\Delta R_H/R_H$ (line 1), and the surface resistivity, $\Delta \rho/\rho$ (line 2), in semilogarithmic scale. We see that these quantities have a logarithmic temperature dependence

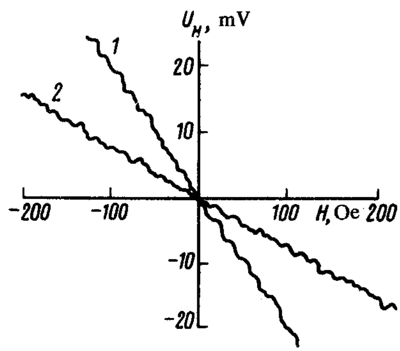

FIG. 1. Dependence of the Hall voltage on the magnetic field at 1.5 K (1) and 4.2 K (2). The current through the sample is 10^{-6} A.

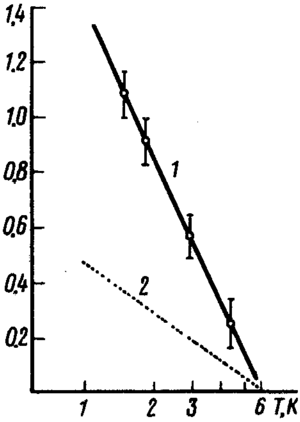

FIG. 2. Temperature dependence of the relative change in the Hall coefficient, $\Delta R_H/R_H$ (1), and the surface resistivity, $\Delta\rho/\rho$ (2).

over the range $1\ \mathrm{K} < T < 6\ \mathrm{K}$, and we find $\gamma = 3.2 \pm 0.5$.

A value $\gamma > 2$ agrees with the positive anomalous transverse magnetoresistance observed in fields below 10 kOe at $T = 4.2$ K, and it proves that spin-orbit effects are predominant in the kinetic phenomena of quasi-two-dimensional invesion layers at the boundary of an InSb/GaAs heterostructure (on the InSb side, since the resistivity for GaAs is $\rho > 10^9 \Omega$ cm).

The observed results can thus be explained by taking into account the spin-orbit splitting of the band states in a consideration of ordinary scattering, as must be done in cubic $A^{\mathrm{III}}B^{\mathrm{V}}$ semiconductors (such as InSb), which lack an inversion center.[4]

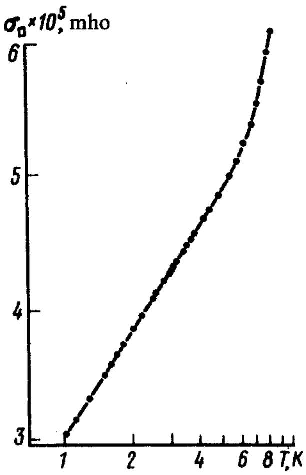

FIG. 3. Temperature dependence of the surface conductivity $\sigma_\square$ for a quasi-two-dimensional inversion layer at a p-InSb/i-GaAs heterojunction.

Working from the measured temperature dependence of the surface resistivity (Fig. 3), the expression for the resultant quantum correction, $\Delta\sigma = (A + B)(e^2/2\pi^2\hbar)\ln T\tau$, and (5), we can separately calculate the coefficients characterizing the contributions from localization and interaction effects:

$$A = \frac{b\gamma}{2} \qquad B = b\left(1 - \frac{\gamma}{2}\right), \tag{6}$$

where $b = A + B = 0.85 \pm 0.005$, $A = 1.36 \pm 0.2$, and $B = -0.5 \pm 0.2$.

This value of B agrees well with the value $p = 1$ found from the temperature dependence of the transverse magnetoresistance according to Ref. 4, and it indicates that electron-electron collisions are important, serving as an inelastic scattering mechanism.

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[1]B. L. Altshuler, A. G. Aronov, and P. A. Lee, Phys. Rev. Lett. **44**, 1288 (1980).
[2]B. L. Altshuler, D. E. Khmelnitzkii, A. I. Larkin, and P. A. Lee, Phys. Rev. **B 22**, 5142 (1980).
[3]H. Fukuyama, J. Phys. Soc. Jpn. **48**, 2169 (1980).
[4]B. L. Al'tshuler, A. G. Aronov, P. I. Larkin, and D. E. Khmel'nitskiĭ, Zh. Eksp. Teor. Fiz. **81**, 768 (1981) [Sov. Phys. JETP **54**, 411 (1981)].
[5]M. J. Uren, R. A. Davis, and M. Pepper, J. Phys. C **13**, L995 (1980).
[6]D. A. Poole, M. Pepper, and R. W. Glew, J. Phys. C **14**, L995 (1981).

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