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MAGNETOCONDUCTIVITY OF METALLIC InSb IN THE EXTREME QUANTUM LIMIT

S.S. Murzin*, A.G.M. Jansen and U. Zeitler.

Max-Planck-Institut für Festkörperforschung, Hochfeld-Magnetlabor, 166X, F-38042 Grenoble Cedex, France.

In the extreme quantum limit of the applied magnetic field, the resistivity tensor of n-type InSb has been measured in magnetic fields up to 20 T and temperatures down to 50 mK. For decreasing temperatures below 1 K, the transverse resistivity shows an anomalous decrease with a logarithmic temperature dependence, but the Hall effect is temperature independent. Because of the constant number of electrons, the observed phenomenon is totally different from the usually observed metal-insulator transition induced by a magnetic field.

For metallically doped semiconductors in strong magnetic fields, the extension of the electronic wavefunction at the impurity shrinks and a metal-insulator transition can be induced by the magnetic field (1). Experimentally this magnetic freeze-out of the electrons is observed in an applied magnetic field with a strong increase in all the elements of the resistivity tensor. This increase is more pronounced at lower temperatures. Ignoring the disorder which is inherently present in a doped semiconductor, correlated phenomena for the interacting electron system in a magnetic field (spin-density-wave, charge-density-wave, Wigner crystal) have been predicted (2) with similar effects on the transport properties. Well below the metal-insulator transition, we investigated the magnetoconductivity of doped InSb in magnetic fields in the extreme quantum limit with only one spin-splitted Landau level occupied by the electrons, and observed an anomalous behaviour in the magnetotransport data.

The studied InSb samples were single crystalline with electron concentrations n above 10^{16} cm^{-3} (InSb 1: 1.4 10^{16}; InSb 2: 5.6 10^{16}; InSb 3: 5.4 10^{16}). The dimensions of the bulk samples were of the order of 1 mm^2 in cross section and 10 mm in length. The various components of the resistivity tensor were measured in a $^3He/^4He$ dilution refrigerator in fields up to 20 T using phase-sensitive detection techniques.

In Figure 1 we have plotted the transverse (ρ_{xx}) and Hall (ρ_{xy}) resistivities for InSb 3 as a function of the magnetic field (parallel to the z-axis) at ≃ 1 K and 100 mK. The Shubnikov-de Haas oscillations in ρ_{xx} end up in a strong increase of the resistivity above 8 T as a manifestation of the extreme quantum limit. In the extreme quantum limit the measured transverse resistivity decreases with decreasing temperature. The amount of

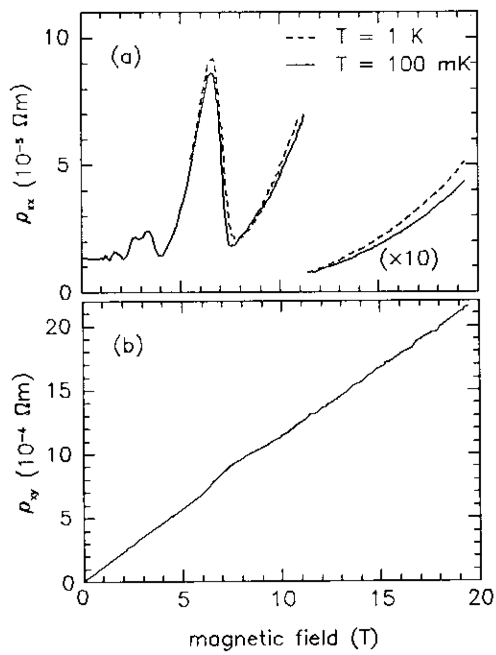

FIGURE 1
Magnetic field dependence of the transverse resistivity ρ_{xx} (a) and Hall resistivity ρ_{xy} (b) for the n-InSb 3 sample at ≃ 1 K and ≃ 100 mK. The Hall resistivity was independent of temperature.

* permanent address: Institute of Solid State Physics, Chernogolovka, 142432 USSR.

temperature dependence in ρ_{xx} increases with increasing magnetic field. The Hall resistivity ρ_{xy} varies approximately linearly with the magnetic field. The structure in ρ_{xy} around 8 T can be ascribed to magnetic quantum oscillations in the Hall effect. The Hall coefficient $R = \rho_{xy}/H$ reveals an oscillatory behaviour similar to the Shubnikov-de Haas effect in the transverse resistivity.

The observed temperature dependence of ρ_{xx} and ρ_{xy} in the extreme quantum limit differs from related work on the metal-insulator transition, where both ρ_{xx} and ρ_{xy} increase for decreasing temperatures (3). The constant Hall coefficient can be interpreted as a constant number of electrons without any influence of magnetic freeze-out. The field for magnetic freeze-out to occur can be found from the Mott criterion by comparing the size of the electron wavefunction with the electron density, $na_{//}a_{\perp}^2 = \delta^3$ with $\delta = 0.3$, $a_{//} = a_B/\ln(a_B/\Lambda)^2$ and $a_{\perp} = 2\Lambda$ (a_B is the effective Bohr radius and $\Lambda = (\hbar/eB)^{1/2}$ the magnetic length in a magnetic field B) (4). The applied magnetic fields are not sufficiently high to reach the Mott criterion for the investigeted samples. In the presented experiments holds $\rho_{xy} > \rho_{xx}$, pointing to a good metallic system where $\rho_{xy}/\rho_{xx} = \omega_c\tau$ ($\omega_c = eB/m^*$ is the cyclotron frequency with m^* the effective mass). However, this condition is not observed in experimental data near the known metal-insulator transition induced by a magnetic-field.

In Figure 2 we have plotted the temperature dependence of the transverse resistivities for the investigated samples at constant magnetic fields in the extreme quantum limit. The resistivity decreases with a logarithmic temperature dependence for temperatures below 2 K. At the magnetic fields indicated in Figure 2, the variation in the Hall resistivity ρ_{xy} was much smaller (≤ 1 %). Because $\rho_{xy} >> \rho_{xx} \geq \rho_{zz}$ in the applied magnetic fields, the conductivity components can be written as $\sigma_{xx} \simeq \rho_{xx}/\rho_{xy}^2$, $\sigma_{xy} \simeq 1/\rho_{xy}$ and $\sigma_{zz} = 1/\rho_{zz}$ with $\sigma_{zz} >> \sigma_{xy} >> \sigma_{xx}$. Hence, the conductivity σ_{xx} decreases also with a logarithmic temperature dependence upon cooling down. In a measurement of σ_{zz}, a similar decrease with logarithmic temperature dependence has been observed.

The observed log-T dependence is difficult to explain with the dimensionality of our bulk samples. In disordered systems a log-T dependence is expected for two-dimensional systems in view of diffusion related quantum phenomena in the transport properties (electron-electron interaction and weak localization). In a three-dimensional system, diffusional transport yields rather a $T^{1/2}$-dependence.

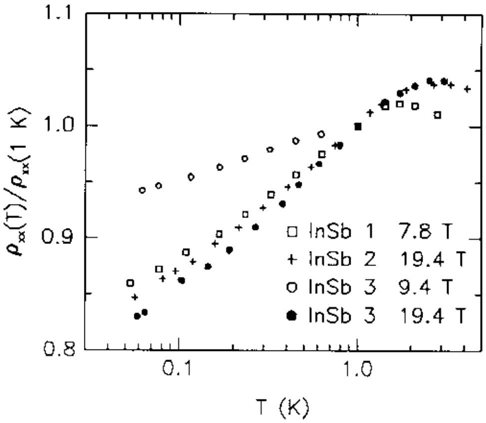

FIGURE 2
The transverse resistivity $\rho_{xx}(T)$ normalized at T = 1 K as a function of the temperature on a logarithmic scale for the different samples in the indicated magnetic fields.

The observed log-T dependence in ρ_{xx} yields $\sigma_{xx} \to 0$ in the limit $T \to 0$. This situation describes a Hall insulator in three dimensions, with a conductivity tensor analogously to that of the quantum Hall effect (zeros on the diagonal and constant σ_{xy}). For the possible occurence of such a novel state, the importance of the electron-electron interaction in a disordered system (5) in the extreme quantum limit of the magnetic field has been put forward (6). Especially in the extreme quantum limit, electron-electron interaction effects could give a large correction to the conductivity.

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