Magnetotransport of low dimensional semiconductor and graphite based systems

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Summary

The subject of this thesis is magnetoresistance of low-dimensional carrier systems. Magnetoresistance experiments at low temperatures are very suitable to obtain information about the electronic structure of low-dimensional systems. 'Low-dimensional' in the materials investigated means lower than three dimensions (3D). In these systems the charge carriers are confined and the materials have dimensionalities between 3D and 2D, 2D or between 2D and 1D. Four different materials were investigated, notably semiconductor and graphite based systems. After a general introduction, in chapter 2 an overview is given of magnetotransport properties of low dimensional electron gases in a perpendicular magnetic field.

In chapter 3 we present the energy spectrum of $PdAl_2Cl_8$ graphite intercalation compounds (GIC) stage 1, 2 and 3. Shubnikov-de Haas oscillations, measured up to 38T, were used to characterise the Fermi surface and the data were compared to a 2D band structure model. This 2D model is a good description of the band structure, when the interlayer interaction between the carbon atoms in neighbouring layers separated by the intercalant layer is small. The stage 1 compound has a 2D bandstructure, which is confirmed by the high anisotropy between the c-axis and the in-plane conductivity. The energy spectrum for the stage 2 GIC is also in agreement with the 2D band structure model. However, the Fourier spectrum shows more frequency components than expected. Some of these could be attributed to sum and difference frequencies of two fundamental frequencies and by higher harmonics of a fundamental frequency. For the stage 3 compound a clear undulation of the Fermi surface, due to interlayer interaction, is observed by the angular variation of the Shubnikov-de Haas frequencies. Because of the interlayer interaction in the stage 3 compound, the applicability of the 2D model is limited.

In the next chapter another graphite-based material is investigated, namely carbon foils fabricated from exfoliated graphite. All samples show the main features of weak localisation: a logarithmic dependence of the resistance on temperature ($T<2.5K$) and a negative magnetoresistance in low magnetic fields ($B<0.5T$). The negative magnetoresistance can be explained by the theory of quantum corrections to the conductivity for the 2D case. The data were analysed within a model for weak localisation beyond the diffusion limit, where the phase relaxation time of the carrier wave is the only fit parameter. The weak localisation in the carbon foils is attributed to disorder in the stacking sequence of the graphene layers. The effect of structural differences in the foils on the negative magnetoresistance was investigated by varying the density and the temperature at which the samples were heat treated. The negative magnetoresistance did not change significantly with the density, indicating that intergrain scattering processes play a minor role. Annealing decreases the negative magnetoresistance significantly due to lower disorder in the stacking sequence.

The subject of chapter 5 is scaling in the quantum Hall regime. The scaling theory predicts a power-law behaviour for the temperature dependence of the transport coefficients, which is a universal feature of delocalisation in the integral quantum Hall effect. Experiments

on low-mobility InGaAs/InP heterostructures form a remarkable demonstration of a quantum phase transition indicating that the plateau-plateau (PP) transitions become infinitely sharp as the temperature approaches absolute zero. Due to the short-range random-alloy potential scattering, the low-mobility InGaAs/InP structure has proven to be exceptionally important for studying scaling phenomena. We investigated for the first time on an InGaAs/InP heterostructure the scaling of the transition from the $\nu=1$ quantum Hall plateau to the insulating phase (PI). This critical behaviour was compared with PP transitions investigated on the same InGaAs/InP heterostructure. We find that the PI transition shows the same scaling behaviour as the plateau transitions, with the same critical exponent. This is in complete agreement with the prediction of the scaling theory. The exponent of the plateau-to-insulator transition can be affected by the (weak) macroscopic inhomogeneities of the sample. This weak inhomogeneity results in a temperature dependence of the critical conductivity σ^*_{xx}. The temperature dependence of σ^*_{xx} can be used to correct for inhomogeneity effects and the critical exponent can be determined. By combining the results for the PP transitions and PI transition we conclude that the critical exponent $\kappa=0.42$ stands for the universal critical exponent of the quantum phase transition.

In the last chapter magnetotransport in GaAs δ-doped with tin is discussed. For the first time tin is used as dopant in a δ-layer, which has some pros and cons in comparison with the more commonly used dopants silicon and beryllium. An advantage of tin is the possibility to achieve very high electron densities. In our structures the maximum electron density obtained equals 8.4×10^{13} cm^{-2}, as determined by Hall measurements. A disadvantage of tin is the high segregation and diffusion velocity, which results in wide δ-doping profiles. However, this turns into an advantage for the growth on vicinal substrates. Vicinal substrates are formed by misorientation of the substrate at a small angle, which results in step edges and terraces on the surface. The high segregation velocity of tin may lead to ordering of the dopant atoms at the step edges. Besides the reduced dimensionality in the form of an array of quasi-1D conducting wires, lateral ordering of dopant atoms will lead to an improved carrier mobility. Indeed a clear anisotropy in the electronic properties is observed for a current $\parallel$ and $\perp$ to the step edges, especially $R_\perp/R_\parallel$ amounts to 1.5 (at T=4.2K) for a sample with an electron density $n=8\times10^{12}$ cm^{-2}. The last part of this chapter deals with the persistent photoconductivity effect in both the structures grown on singular and vicinal substrates. In the heavily doped samples ($n>2\times10^{13}$ cm^{-2}) two different illumination effects depending on the wavelength are observed. For illumination by light with wavelengths smaller than 850nm positive persistent photoconductivity is observed, which means that the resistance is decreased after illumination. For illumination by light with wavelengths greater than 850nm negative persistent photoconductivity is observed. For the lightly doped samples only the positive effect for all wavelengths is observed. The difference in photoconductivity between heavily and lightly doped samples is due to the occupation of deep donor states, the so-called DX centres in the heavily doped samples. The ionisation of the filled DX centres gives rise to the negative persistent photoconductivity effect.