Magnetotransport studies of the single and bilayer two dimensional electron gas in the quantum Hall regime

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Summary

The work described in this thesis consists of two parts. The first and main part is dedicated to a magnetotransport study of the scaling of the integer quantum Hall effect, with an emphasis on probing the irrelevant critical behavior (*Chaps*. 3-5). The second part (*Chaps*. 6-7) is devoted to a magnetotransport study of quantum wells with a thin barrier and bi-layer quantum wells.

After an introduction of the quantum Hall effect (Chapter 1) and a summary of the theoretical aspects related to scaling (Chapter 2), we first describe the experimental technique used to measure the 2DEG in Hall bar samples in the high-ohmic regime (Chapter 3). Especially we describe a newly implemented dc-technique, which turned out to improve the measurement accuracy when compared to the traditional ac-technique. This is of particular importance for magnetotransport data taken in high magnetic fields, where the resistance of the samples rapidly increases in the regime of the plateau-insulator transition.

In Chapters 4 and 5 we report a scaling study carried out on a InGaAs/GaAs quantum well prepared with a relatively broad conduction channel as to reduce the total resistance of the Hall bar in high magnetic fields. The electron density of the 2DEG could be tuned by illumination and ranges from n_e= 1 to 2×10^{15} m^{-2}. Consequently, the plateau-insulator (PI) transition occurs in the magnetic field range 7.7-14.8 T. This work strongly builds on - and expands - the experimental scaling studies carried out previously at the Van der Waals-Zeeman Institute by De Lang and Ponomarenko on similar samples.

In Chapter 4 we focus on the characterization of the InGaAs/GaAs Hall bar by means of magnetotransport measurements. The gradient in the electron density along the bar is determined for four different electron densities by means of the method of "reflection symmetry" at the $2\rightarrow1$ plateau-plateau (PP) transition. The quality of the sample increases with increasing density. Next we investigate the relevant critical exponent κ extracted from the temperature variation of the longitudinal resistance at the PI transition. The deduced values $\kappa = 0.43\text{-}0.53$ are comparable to those obtained in previous studies. Numerical simulations are used to investigate the influence of density gradients on the value of κ. The

variation of κ is in part an experimental feature attributed to the remaining overlap of the Landau levels at the lower densities. On the other hand, the extracted κ values should be considered as "effective", because the scattering may exhibit long-ranged components with respect to the magnetic length.

In Chapter 5 we focus on the irrelevant critical exponent y_σ, which has been extracted from the deviations of the Hall resistance from the quantized value h/e^2. We have measured the Hall resistance using the dc-method for four different electron densities. A detailed analysis of the Hall data employing a new data collapse method results in y_σ ranging from 2.4 to 2.7 for the different electron densities. These values agree well with previously obtained values. However, in order to obtain a good data collapse it appeared necessary to apply a small temperature dependent shift of the data in the filling factor ν. The fact that the critical filling factor shows a small temperature variation underlines the high degree of macroscopic inhomogeneities in the sample. By using the universal scaling functions derived by Pruisken and the experimentally determined parameters for κ, y_σ and the characteristic temperatures T_0 and T_1 of the InGaAs/GaAs quantum well we construct the renormalization group flow diagram. This is the most important result obtained in this thesis. The flow diagram shows all the properties predicted for genuine scaling: relevant and irrelevant flow, the location of the critical point $(\sigma_H, \sigma_0) = (½e^2/h, ½e^2/h)$ and particle-hole symmetry. We stress that the determination of the flow diagram for the present sample is only possible through the determination of the conductivity tensor at the PI transition. Macroscopic sample inhomogeneities obstruct obtaining an accurate flow diagram from the conductivity tensor at the PP transition. Thus in order to unravel all facets of the arresting topic of scaling of the quantum Hall effect, progress can only be made after a complete understanding of the effect of macroscopic sample inhomogeneities.

In the remainder of the thesis quantum wells with a thin barrier and double layer quantum wells are investigated. In Chapter 6 we have investigated the energy spectrum of two sets of δ-doped GaAs/InGaAs/GaAs quantum wells, namely quantum wells with and without a thin central AlAs barrier. Our experimental probes are magnetotransport and photoluminescence. The experimental results were compared to numerical calculation of the energy levels and the wave function distributions. It turned out that the AlAs barrier can act as a phonon barrier and significantly changes the distance between the energy levels and the spatial distribution of the wave functions. In addition, we found that the δ-doping regions act as V-shaped quantum wells and undesirably distort the wave functions. In order to relocate (confine) the wave functions in the central quantum well, a second series of samples was grown in which the V-shaped quantum wells were partly compensated by surrounding them with AlAs barriers. Unfortunately the electron density in the 2DEGs was not high enough to fill more than one subband and the desired improvement was not obtained for this second series of samples.

In Chapter 7 we have studied the effect of a tilted magnetic field on an $In_xGa_{1-x}As/GaAs$ bilayer quantum well with a large Landé *g*-factor. The large Landé *g*-factor is chosen to enhance spin-splitting effects. By performing magnetotransport measurements for different angles of the magnetic field with respect to the plane of the 2DEG, we can add a parallel component, $B_{||}$, to the perpendicular magnetic field, while the effect of spin-splitting remains the same, i.e. one can study the effect of adding an in-plane magnetic field when the bilayer quantum well is tuned to a particular integer quantum Hall state. Magnetotransport data are taken on single (SQW) and double quantum wells (DQW) and compared with each other. The DQW data exhibit features that cannot be explained by the physics used to describe the SQW. These features are: (*i*) the $\nu = 2$ minimum disappears with increasing $B_{||}$, (*ii*) the $\nu = 3$ minimum widens and narrows as a function of $B_{||}$, (*iii*) the $\nu = 6$ minimum shows an irregular behavior with increasing $B_{||}$ and (*iv*) an unexpected and still unexplained dip in the even integer plateaus of the Hall resistance. The first three features could be understood by an analysis of the calculated Landau Level fans. The latter feature is attributed to the reentrant quantum Hall effect.