Current dependence of the Shubnikov-de Haas peaks in GaAs - Al_xGa_1-xAs heterostructures

Autor(en): **Svoboda, P. / Steda, P. / Nachtwei, G.**

Objekttyp: **Article**

Zeitschrift: **Helvetica Physica Acta**

Band (Jahr): **65 (1992)**

Heft 2-3

PDF erstellt am: **03.05.2024**

Persistenter Link: https://doi.org/10.5169/seals-116435

Current dependence of the Shubnikov-de Haas peaks in $GaAs - Al_xGa_{1-x}As$ heterostructures

P. Svoboda[(a)], P. Středa[(a)], G. Nachtwei[(b)] and M. Cukr[(a)]
[(a)]Institute of Physics, Czech. Acad. Sci., CS-162 00 Praha 6, Czechoslovakia
[(b)]Institute of Sol.St. Physics, Humboldt University, Invalidenstr.110,O-1040 Berlin, FRG

Abstract. Simple phenomenological model is suggested to describe the current dependence of the spin-splitted ShdH peaks observed in a high-mobility $GaAs - Al_xGa_{1-x}As$ heterostructure in terms of the Hall-voltage-induced coupling betweeen the edge conduction channels and the bulk.

Introduction

Anomalous behaviour of the Shubnikov-de Haas (ShdH) oscillations in $\rho_{xx}(B)$ has been observed in 2D electron system in $GaAs - Al_xGa_{1-x}As$ heterostructures with low-temperature mobilities above $1 \times 10^5 cm^2/V.s$. ShdH peaks corresponding to lowest Landau levels have been found to be strongly asymmetric in form and to depend on the measuring current density j. Apart from the asymmetry of individual spin-resolvent subpeaks dealt with by Zheng et al. [1] and Haug et al. [2], another type of asymmetry arises even in relatively wide samples from the different current dependence of the two spin-resolved subpeaks. In the limit of low measuring current, the latter effect results in a reduced resistivity on the high-magnetic-field side of the ShdH peaks [2].

Results and discussion

Both types of the above mentioned asymmetries can be seen in Fig. 1, where $\rho_{xx}(B)$ dependencies for three different measuring currents I are shown. The curves have been taken at $T = 1.3K$ by a standard d.c. four-point method on a $GaAs - Al_xGa_{1-x}As$ heterostructure grown by MBE. The sample had the form of a common Hall bar with the width of the conducting channel $w = 400\mu m$ and with the two voltage probes along the sample separated by $L = 1100\mu m$. The carrier density and mobility of the 2 DEG at liquid-He temperatures has been found to be $n_s = 5.5 \times 10^{11} cm^{-2}$ and $\mu = 3.0 \times 10^5 cm^2/V.s$, respectively.

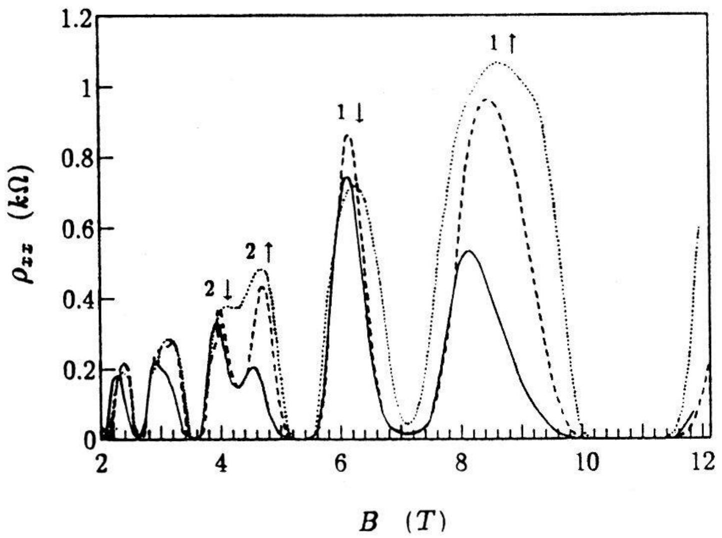

Fig.1: *Shubnikov-de Haas oscillations in $\rho_{xx}(B)$ at T=1.3K for the current I=0.7 μA (full line), I=7 μA (dashed line) and I=70 μA (dotted line), respectively*

To account for the current dependence of the ShdH peaks seen in Fig.1, edge-state picture of the quantum Hall effect has been invoked. Following the conclusions of Alphenaar et al. [4], we suppose that the topmost N-th channel (N being the number of spin-resolved Landau levels at or below the Fermi energy E_F) remains to be partially decoupled from the lower $(N-1)$ edge channels that are in mutual equilibrium.

When N-th Landau level in the bulk approaches E_F, N-th channel accounts for a finite conductivity in the bulk and a peak in $\rho_{xx}(B)$ arises. In contrast to ref.[4], we assume that equilibration between the edge channels and the bulk one takes place not only within voltage probes, but everywhere along the sample. Characterizing the rate of the equilibration by an average electron mean free path λ for the electrons in the edge channels, we get [3]

$$\rho_{xx} = \frac{\rho_{xx}^{(0)}}{1 + N\,\frac{2\lambda}{w}\,\frac{e^2}{h}\,(N-1)\,\rho_{xx}^{(0)}} \tag{1}$$

where $\rho_{xx}^{(0)}$ corresponds to the limiting case $\lambda \to 0$, i.e. to the conditions of very strong coupling between edge and bulk states. Fitting the current (i.e. the Hall voltage U_H) dependence of the peak values ρ_{xx}^{max} for the upper four spin-resolved subpeaks in Fig. 1 to (1), we have found that the mean free path λ of the edge electrons can be expressed in the form

$$\lambda = \lambda_0 \exp[-\frac{U_H}{w\beta}\,(N-1)\,] \tag{2}$$

Peak	Bulk channel	$\rho_{xx}^{(0)}$ $[\Omega]$	λ_0 $[\mu m]$	β $[V/cm]$
1 ↑	$N=3$	1170	1170	2.1
1 ↓	$N=4$	890	110	2.0
2 ↑	$N=5$	510	1000	1.9
2 ↓	$N=6$	390	110	2.0

Tab.1: *Values of the model parameters obtained by fitting the expressions (1) and (2) to the experimental peak values ρ_{xx}^{max} for the spin-resolved ShdH peaks indicated in Fig.1*

The values of the three fitting parameters $\rho_{xx}^{(0)}$, λ_0 and β are summarized in Table 1. It is worth noting that while parameter β (a critical electrical field) is virtually independent on N, the mean free path $\lambda_0 = \lambda(I \to 0)$ has been found to be an order of magnitude higher for the spin-up peaks than for the spin-down ones. We believe, that this parameter reflects the fact that in the former case the spatial separation between the uppermost edge channel and the adjacent part of the bulk scales with Landau level separation $\hbar\omega_c$, while in the latter one the much smaller Zeeman splitting $g\mu_B B$ is relevant.

The observed different current dependence of the spin-resolved ShdH subpeaks is thus a manifestation of an easier equilibration between the bulk and the edge channels in the case when E_F coincides in the bulk with a spin-down level (N even). The crucial role of the equilibration processes taking place far from voltage probes seems to be confirmed by recent experiments by Komiyama et al. [5].

References

[1] H.Z. Zheng, K.K. Choi, D.C.Tsui and G.Weimann , *Phys. Rev. Letters* **55**, 1144 (1985)

[2] R.J. Haug, K.v. Klitzing and K. Ploog , *Phys. Rev.* **B 35**, 5933 (1987)

[3] P. Svoboda, P. Středa, G. Nachtwei, A. Jaeger, M. Cukr and M. Láznička , *submitted to Phys. Rev.* **B**

[4] B.W. Alphenaar, P.L. McEuen, R.G. Wheeler and R.N. Sacks , *Phys. Rev. Letters* **64**, 677 (1990)

[5] S. Komiyama, H. Nii, M. Ohsawa, S. Fukatsu, Y. Shiraki, R. Itoh and R. Toyoshima , *submitted to Solid St. Commun.*