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Part S5 - LT Properties of Solids 2: Electrons in 2D and weak localization

Low temperature subband 2D electron mobilities in heavy delta- and modulation doped GaAs/GaAlAs heterostructures

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We synthesised high-2D electron-density GaAs/GaAlAs heterostructures with different distance L_δ of Si delta-layer in GaAs from the heterojunction and uniform doped GaAlAs. The quantum Hall effect and Shubnikov-de Haas effect were measured for temperatures down to 0.4 K in magnetic fields up to 40 T. The enhanced 2D electron concentration achieved was $1.1*10^{13}$ cm^{-2} in six filled subbands. The Hall mobility depends on L_δ and has maximum for L_δ=600÷750Å. From the amplitudes of the SdH oscillations and Fourier transforms the subband mobilities and electron concentration in each subband have been extracted. According to calculations intersubband electron scattering appears to be important and reduces mobilities in subbands.

1. INTRODUCTION

Recently interest has appeared in high-carrier-density 2D electron gas structures in which more than one electron subband is populated. Interactions between the subbands appear to be important: intersubband scattering affects the scattering rates and reduces the electron subband mobility. We synthesised and investigated new high-carrier-density GaAs/GaAlAs heterostructures with combined doping, that is with delta-doping of GaAs and uniform doping of GaAlAs layers.

2 SAMPLES

All samples were grown by molecular beam epitaxy. On a GaAs(Cr) with help of MBE GaAs(δ-Si) structures were synthesised. In i-GaAs layer δ-Si layer was grown with different distance L_δ (200Å<L_δ<1200Å) from the heterojunction. Then structures were covered by two-layer spacer: $Ga_{1-x}Al_xAs$ (x=0.36, width L=40 Å) and $Ga_{1-x}Al_xAs$ (x=0.25, width L=50 Å). On the top the structures were covered by the 90 Å layer of $Ga_{1-x}Al_xAs$ with variable value of x from 0.25 to 0 and contacting layer of $Ga_{1-x}Al_xAs$. For transport measurements samples were prepared in the form of double Hall bridges.

3 RESULTS

The temperature dependence of conductivity for 4.2<T<300K, quantum Hall effect and Shubnikov-de Haas effect for 0.4<T<40K have been measured. Experiments were made in magnetic fields ranging up to 40 T. The temperatures down to 0.4K were obtained by pumping He^3.

For all samples the conductivity σ increases when temperature decreases down to 50-100 K and then σ decreases. For T<50 K the dependence σ(T) is a linear function in coordinates σ-lnT.

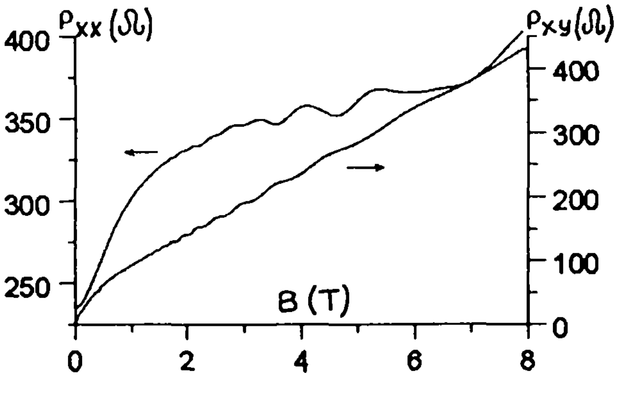

Fig. 1 ρ_{xx} and ρ_{xy} oscillations of sample with L_δ=600Å at T=0.4K.

The Hall effect measurements showed that for all samples the Hall coefficient does not depend on

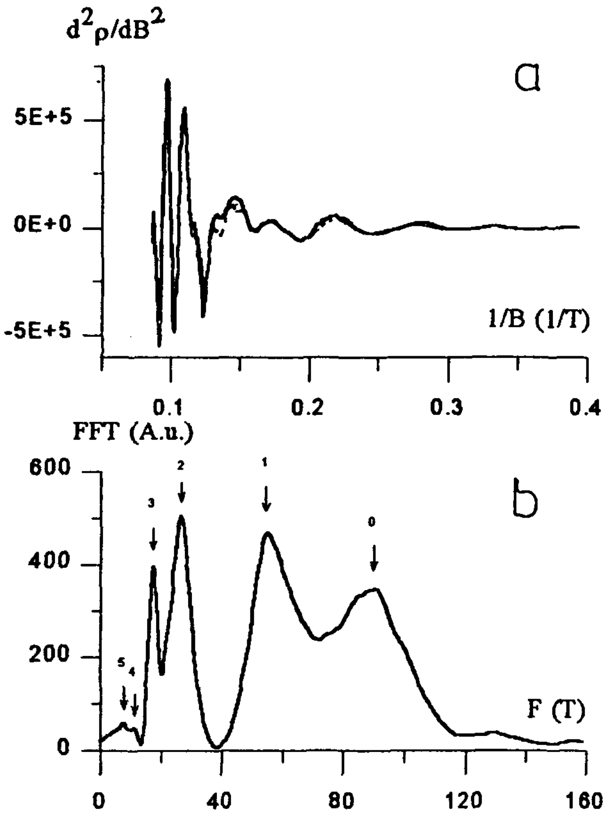

Fig. 2 Processing of the the measured $d^2\rho_{xx}/dB^2$ (a) to the Fourier transform (b) of the SdH oscillations for sample with L_δ=600Å. Arrows mark the theoretical positions of the peaks corresponding to six filled subbands (see text).

temperature in the temperature range 4.2<T<40K. At liquid helium temperature the transverse magnetoresistance exhibits oscillations (fig. 1). We make use of the Shubnikov-de Haas (SdH) effect at magnetic field up to 40 T to obtain the experimental electron concentration n_e in each subband with help of fast Fourier transform. The second derivative oscillations are shown in fig. 2a by solid line for sample with L_δ=600Å.

DISCUSSION

The amplitudes of the second derivative oscillations were fitted using transport μ_e^t and quantum μ_e^q mobility as parameters [1,2]. The best-fit calculation is shown by dash line in fig. 2a. In table we listed 2D subband theoretical n_t and experimental n_e concentrations (10^{12} cm^{-2}), quantum μ_e^q, μ_t^q and transport μ_e^t, μ_t^t mobilities (cm^2/Vs) for sample with L_δ=600Å. N is the subband number.

Table

N	n_t	n_e	μ_e^q	μ_t^q	μ_e^t	μ_t^t
0	4.54	4.50	490	460	1500	1600
1	2.83	2.82	610	750	1980	1860
2	1.45	1.32	1490	1230	2300	2440
3	0.63	0.82	1940	1050	3670	3100
4	0.48	0.58	--	850	--	10^5
5	0.20	0.24	--	370	--	3140

The energy spectrum, electron wave functions and the theoretical population n_t of each subband were determined by selfconsistent solution of Schrödinger and Poisson equations. The theoretical low temperature transport μ_t^t and quantum μ_t^q mobilities are calculated by using the Boltzmann equation and the relaxation-time approximation [3,4]. It is assumed that the electrons are scattered from ionized impurities. Screening of charged impurities by electrons occupying several subbands is described with help of the random-phase approximation. The mobility examined exhibits drops as a function of the electron concentration when the some subbands become occupied. The intersubband electron scattering appears to be important and reduces mobilities in subbands. According to calculations the main feature of the investigated structures is the localisation of the some subbands in delta-layer. The number of these subbands depends on L_δ and increases when L_δ increases. Electron mobility is very low in these subbands. Then some common for heterojunction and delta-layer subbands arise.

The dependence of conductivity σ, the total electron concentration n and Hall mobility on L_δ show maximum at L_δ=600-750Å. The enhanced 2D electron concentration achieved was $1.1 \cdot 10^{13}$ cm^{-2} in six filled subbands with Hall mobility ≈7000 cm^2/Vs.

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