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# QUANTUM CORRECTIONS TO CONDUCTIVITY AND QUANTUM HALL EFFECT IN GaAs-GaAlAs MULTIPLE QUANTUM WELL STRUCTURES

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We report on an investigation of the galvanomagnetic properties of GaAs-GaAlAs superlattices. The results can be explained in terms of interface roughness scattering of electrons in quantum wells.

GaAs-$Ga_{1-x}Al_xAs$ superlattices and multiple quantum well (MQW) structures attract much attention because of their high sensitivity in the infrared spectral range 8-14 $\mu$m. The interesting physical properties of these semiconducting artificial superlattices are primarily determined by electron scattering processes. In order to investigate the relevant scattering mechanisms we have studied the galvanomagnetic properties by means of conductivity ($\sigma$) and magnetoresistivity ($\rho_{xx}$) (B< 6 T) measurements in the temperature range 4.2 K < T < 100 K. Furthermore, the quantum Hall effect was investigated in very high magnetic fields up to 38 T at T= 4.2 K.

Samples with multiple quantum wells were grown by molecular beam epitaxy. Fifty periodic layers of GaAs (width $L_w$= 33-66 Å) and $Ga_{1-x}Al_xAs$ (x= 0.03, width 254 Å) were prepared. The quantum wells were doped with Si up to a concentration of $2\times10^{18}$ $cm^{-3}$. The structure was separated from a GaAs(Cr) substrate by an i-$Ga_{1-x}Al_xAs$ buffer (width 1 $\mu$m). All structures were covered by a contact layer of n-GaAs (width 200 Å). Double Hall bridges (channel width 150 $\mu$m) were prepared for measurements in a magnetic field.

Samples with different well widths ($L_w$) were investigated. In Table 1 we have listed some typical parameters of the investigated samples (labeled N1, N2 and N3). Note that the electron concentration (n) is given per quantum well. The conductivity of all samples decreases with decreasing temperature. For T< 20 K $\sigma(T) \propto \ln T$. The electron mobility ($\mu$) increases when $L_w$ increases. The transverse magnetoresistance ($\rho_{xx}$) is negative at low temperatures (B< 6 T). It has the following characteristics: i) $\rho_{xx} \propto B^2$ up to ~1 T, ii) the field range of the $B^2$ dependence is reduced by decreasing the temperature, and iii) for B≥ 2 T $\rho_{xx} \propto \ln B$. For all samples the Hall effect measurements showed that the electron concentration is independent of temperature. This implies that $\sigma(T)$ is dominated by $\mu(T)$. In spite of the low mobilities of our samples we observed the QHE, albeit in very high magnetic

Table 1. Well width ($L_w$), Fermi energy ($E_F$), electron concentration per well (n), coefficient of diffusion (D), mobility ($\mu$), semiwidth of the fotoluminiscence peak ($\delta E$) and fluctuation energy of the groundstate in the quantum well ($\delta E_o$) for samples N1, N2 and N3 at T= 4.2 K.

| N | $L_w$ (Å) | $E_F$ (meV) | n ($10^{11}cm^{-2}$) | $\mu$ ($cm^2/Vs$) | D ($cm^2/s$) | $\delta E$ (meV) | $\delta E_o$ (meV) |
|---|---|---|---|---|---|---|---|
| 1 | 33 | 23 | 6.5 | 260 | 7.2 | 21 | 30 |
| 2 | 44 | 15 | 4.3 | 480 | 8.8 | 13 | 16 |
| 3 | 66 | 92 | 25.7 | 860 | 47 | 15 | 7 |


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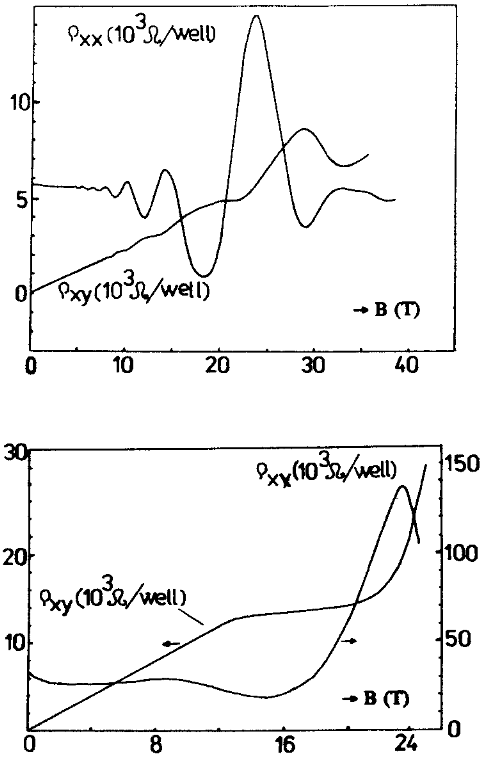


Fig.1 Shubnikov - de Haas oscillations and quantum Hall effect at T= 4.2 K of sample N1 (lower frame) and N3 (upper frame).

fields. Pulsed magnetic fields up to 38 T were produced in the High Magnetic Field Facility of the University of Amsterdam. In fig.1 we show $\rho_{xx}(B)$ and $\rho_{xy}(B)$ at T= 4.2 K for two samples. From this figure it can be concluded that approximately all the parallel connected quantum wells exhibit almost the same electron density in the populated ground subband, which results in one observable period of Shubnikov-de Haas (SdH) oscillations. The electron concentration evaluated from the SdH signal is almost the same as the one calculated from the Hall effect.

In fig.2 we show the dependence of $\mu$ on $L_w$ in a double logarithmic plot. Our results are in good agreement with the results obtained in Ref.[1]. In Ref.[2] it was proposed that in thin quantum wells ($L_w$< 60 Å) interface roughness scattering is the dominant scattering mechanism. In that case $\mu= (L_w^6/A^2C^2)g$, where A is the lateral width and C

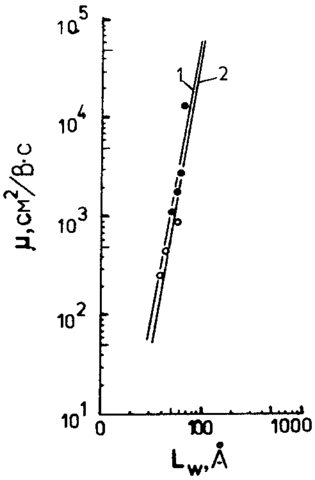


Fig.2 Mobility ($\mu$) as function of the well width $L_w$. Open circles - this work. Closed circles - Ref.[1]. The solid lines correspond to calculations with an interface roughness size A= 50 Å (1) and A= 70 Å (2).

the height of the roughness and g=g(A,n,T). Using A and C as fitting parameters we obtained with this relation a good agreement between the theoretical curves and the experimental data points (see fig.2).

The observed $\sigma(T)$ and the negative $\rho_{xx}$ allows us to calculate some electron parameters of the samples, e.g. the relaxation time of the electron wave function phase $\tau_\varphi$. The decrease of $\sigma(T)$ with increasing T and the observed magnetoresistance may be fully described by the theory of quantum corrections to the conductivity in the 2D-case [3,4], which is valid for $k_BT << E_F$. Calculated values for the diffusion coefficient D are shown in Table 1. Using $\tau_\varphi$ as a parameter we fit the theoretical curve to the exerimental negative magnetoresistance. From this fit we were able to evaluate $\tau_\varphi$ as function of temperature. A more complete account of this work will be published elsewhere [5].

## REFERENCES

[1] K. Hirakava et al., Surf. Sci. 196 (1988) 365.
[2] H. Sakaki et al., Appl. Phys. Lett. 51 (1987) 1934.
[3] B.L. Alshuler et al., JETP 81 (1981) 758.
[4] Abrahams et al., Phys. Rev. Lett. 42 (1979) 673.
[5] V.A. Kulbachinskii et al., to be published.