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Magnetoresistance Oscillations in the $Si/Si_{1-x}Ge_x/Si$ 2DHG

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From a detailed analysis of the Shubnikov de Haas oscillations we determine an effective mass of $(0.23\pm0.02)m_0$ in the $Si/Si_{0.87}Ge_{0.13}/Si$ 2DHG in agreement with theoretical predictions and with that obtained from cyclotron resonance measurements. In contrast to previous work, we consider the effect of weak localisation, hole-hole interactions and a temperature dependent screening term. We demonstrate that the value of m^* obtained is independent of magnetic field and temperature and that the dominant scattering mechanism is short range.

Although there have been a few reports of the experimental determination of effective masses (m^*) in the $Si/Si_{1-x}Ge_x/Si$ 2DHG, there remains some disagreement about the values obtained (1,2,3), particularly those determined from the Shubnikov de Haas (SdH) oscillations. In early work on the Si inversion layer it was noted that the apparent value of m^* deduced from SdH measurements was strongly dependent on magnetic field and temperature (4,5). More recently similar effects were observed in the $GaAs/Al_xGa_{1-x}As$ system (6) with the apparent value of m^* decreasing with magnetic field to values much lower than that obtained from measurements of cyclotron resonance.

Therefore, in the present work we have carried out a detailed analysis of the temperature and magnetic field dependences of the magnetoresistance coefficients ρ_{xx} and ρ_{xy} at temperatures down to 0.3K and in fields of up to 15T. Our recent achievement of record mobilities of up to 18,000 $cm^2V^{-1}s^{-1}$ at 4K in this system (7) has permitted a more comprehensive investigation than hitherto.

Figure 1. shows the temperature dependence of ρ_{xx} for a sample with Ge concentration, $x=0.13$ and 4K mobility ~11000 $cm^2V^{-1}s^{-1}$. Examination of the Fourier transform of the dependence of ρ_{xx} on 1/B identifies a single frequency component confirming the occupation of a single subband, as anticipated. From the period in 1/B we deduce a sheet density of $2\times10^{11}cm^{-2}$. The onset of spin-splitting is clearly observed at ~2.5T where the resolution of the $\nu=4$ level increases as the thermal broadening of the Fermi surface decreases with temperature. According to theory the amplitude of the oscillations is described by,

$$\frac{\Delta\rho_{xx}}{\rho_0} = R_s V \frac{\xi}{\sinh\xi} e^{-\pi/\omega_c\tau_s} \cos\left(\frac{2\pi E_F}{\hbar\omega_c} + \phi\right) \quad (1)$$

with $\xi = \dfrac{2\pi^2 kT}{\hbar\omega_c}$ and $\omega_c = \dfrac{eB}{m^*}$. The spin reduction factor $R_s=\cos(\pi g m^*/2m_0)$ and V depends on the ratio of the single particle and transport scattering times (τ_s and τ_t)(8), a value of 4 being commonly used under the assumption that $\tau_s=\tau_t$. However, τ_s/τ_t may differ significantly from unity depending on the dominant scattering mechanism (9).

A further complication arises since Equation 1. does not account for the effects of weak localisation and hole-hole interactions which have been observed in similar samples, albeit of lower mobility (10). These effects may be removed by bandpass filtering the Fourier transformed data to remove any DC and low frequency components (8). However, in addition to weak localisation and interaction terms, a temperature dependent screening term of form $\tau_t(\mathrm{T}) = \tau_{t0}\left[1 - \mathrm{C}\frac{\mathrm{T}}{\mathrm{T_F}}\right]$ was introduced to explain the temperature dependence of the conductivity(9,10). It may be shown that the single particle scattering time has a similar form ie

$\tau_s(\mathrm{T}) = \tau_{s0}\left[1 - \mathrm{C}'\frac{\mathrm{T}}{\mathrm{T_F}}\right]$ .In the present case $\mathrm{T_F} \cong 35\mathrm{K}$ and we expect $\mathrm{C} \sim \mathrm{C}' \sim 1$. Thus, over the temperature range considered τ_s varies by less than 5%.

If we assume R_s,V and the exponential term in Equation 1. are temperature independent, a plot of $\ln(\Delta\rho_{xx}/\rho_0)$ versus $\ln(\xi/\sinh\xi)$ should yield a straight line of gradient 1 and intercept $\ln(R_sV)-(\pi/\omega_c\tau_s)$. A gradient of 1.00 is obtained for $m^*=(0.23\pm0.02)m_0$, independent of magnetic field, as shown in Figure 2. To confirm that m* is independent of temperature, Figure 3. shows a

Dingle plot, ie $\ln\left(\frac{\Delta\rho_{xx}}{\rho_0}\frac{\sinh\xi}{\xi}\right)$versus$\frac{1}{\mathrm{B}}$, for three

temperatures. The gradient is $\frac{-\pi}{\alpha\mu}$ where $\alpha = \frac{\tau_s}{\tau_t}$ from which we deduce $\alpha=1.42$. A value of $\alpha=1.5$ is predicted for short range scattering (9). This is consistent with our recent work (11,12) which demonstrated that scattering from interface charge was the mobility limiting mechanism.

In conclusion, we obtain $m^*=(0.23\pm0.02)m_0$ for Ge concentration, $x=0.13$ independent of temperature and magnetic field. This result is in reasonable agreement with theoretical predictions (13,14) and with the value of $0.26m_0$ obtained from cyclotron resonance measurements on similar material (14). Finally, we note that the discrepancies in the reported effective masses in this system may be explicable as follows: the high carrier densities of some of the samples used in previous work (up to an order of magnitude than that considered here) result in the effective mass being affected by the non-parabolicity of the SiGe valence band; alternatively the weak localisation and hole-hole interaction terms, which are more significant in the samples of lower mobility previously measured, may not have been accounted for.

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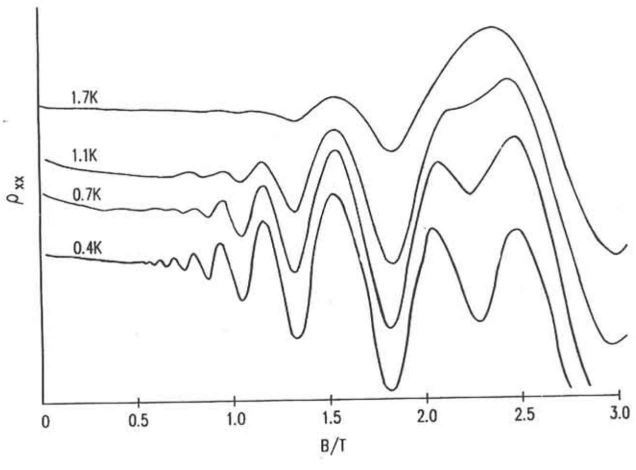

Figure 1.
Temperature dependence of the Shubnikov de Haas oscillations.

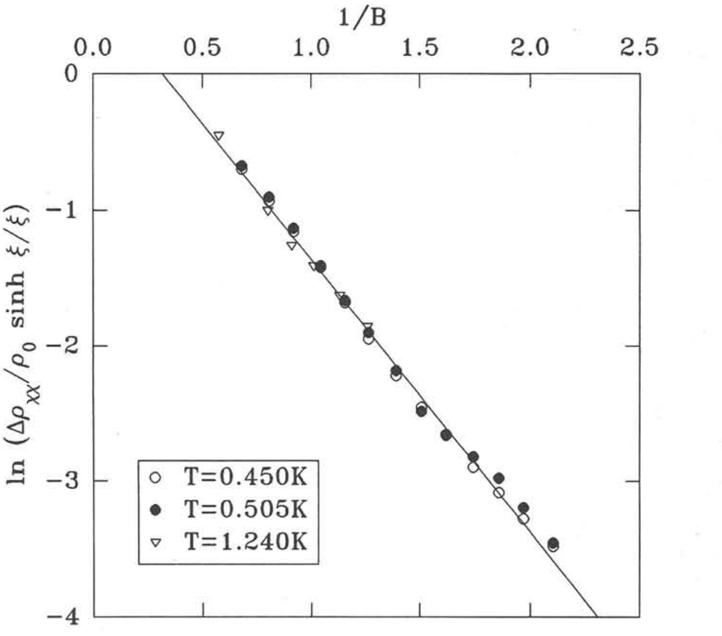

Figure 3.
Dingle plot for various temperatures.

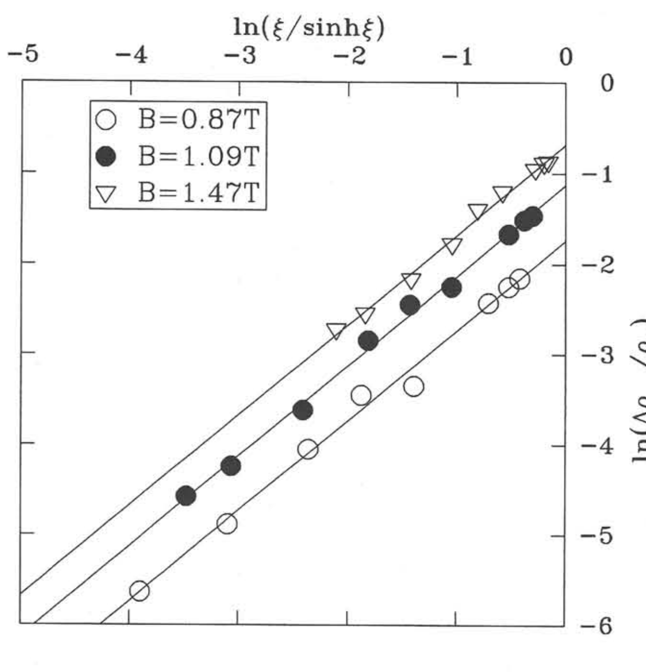

Figure 2.
$\ln(\Delta\rho_{xx}/\rho_0)$ versus $\ln(\xi/\sinh\xi)$ for various magnetic fields.