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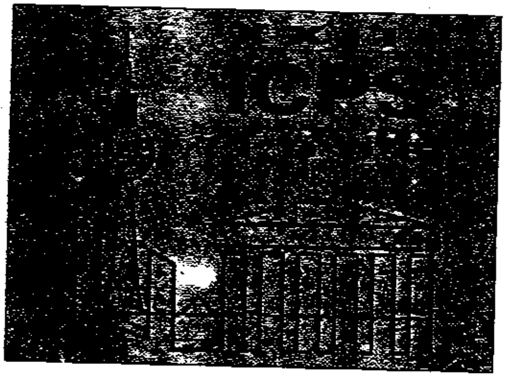

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SPIN-DEPENDENT PROPERTIES IN THE CONDUCTION BAND OF P-DOPED GaAs QUANTUM WELLS

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Photoluminescence experiments using polarized light and in transverse magnetic field (Hanle experiments) on p-type modulation GaAs quantum well structures are reported. Combined with time resolved measurements, they allow us to estimate the effective electron g-factor, and to determine the electron spin relaxation rates. The respective efficiency of the different spin relaxation mechanisms is discussed with respect to the temperature range considered and structure quality.

Although the electron spin relaxation mechanisms are well understood in bulk semiconductors through numerous studies both theoretical and experimental[1], many open questions remain concerning two-dimensional structures. We report here conventional c.w. Hanle experiments combined with time resolved measurements performed on a series of p-type GaAs/GaAlAs modulation doped quantum well structures. In these structures, the large reservoir of non-polarized holes allow to investigate the spin properties of the electronic states in optical pumping experiments with circular polarization of the excited and emitted light. The measurement of the electron lifetime in the conduction band enable us to determine independently the electron effective g-factor and the electron spin relaxation time for each system investigated. We use the temperature evolution of this last quantity to determine the spin relaxation processes of electrons in quantum wells.

The well known Hanle effect leads to a decay of the luminescence polarization $\rho = (I_+ - I_-)/(I_+ + I_-)$ with the application of a magnetic field in the Voigt configuration. This decay is given by the Lorentzian function

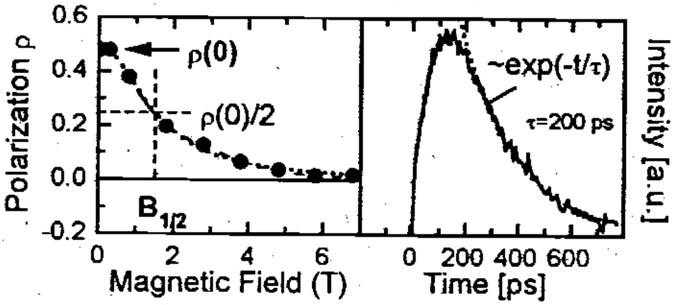

Figure 1: (a) Degree of spin polarization as a function of the transverse magnetic field. The Lorentzian fit is shown in dotted line. (b) Time resolved luminescence spectra. The dotted line present the exponential decay fit.

$\rho(B) = \rho(0)\left[1 + (B/B_{1/2})^2\right]^{-1}$, where $\rho(0)$ is the polarization degree at zero field, and $B_{1/2}$ corresponds to the half maximum of the depolarization field. These parameters are related to τ_s the spin relaxation time, τ the electron lifetime in the conduction band and g^* the effective electron g-factor by the relation : $\rho(0) = \frac{\rho_0}{1+\tau/\tau_s}$ (1) and $B_{1/2} = \left[g^* \frac{\mu_B}{\hbar}(\frac{1}{\tau} + \frac{1}{\tau_s})\right]^{-1}$ (2). We have assumed that the initial degree of spin polarization $\rho_0 = 1$ due to exclusive excitation of heavy hole states. From equations (1) and (2), it can be easily deduced that τ_s and g^* are functions of the following set of parameters $\rho(0)$,$B_{1/2}$,τ. The first two parameters can be experimentaly deduced from optical pumping experiments, and the last one from time resolved measurements.

The samples investigated are GaAs/$Ga_{0.7}Al_{0.3}As$ p-type modulation-doped single quantum well structures with similar doping concentration ($p=3\times10^{11}$ cm^{-2}). The structures with well widths of 30, 40, 65 and 85 Å have been studied. The 30Å- and 65Å-thick quantum wells have been grown on (100) oriented substrate and modulation-doped with Be acceptors, whereas two other wells have been grown in (311) direction and modulation-doped with Si dopants. In spite of different growth directions we think that the essential difference between investigated structures (with respect to our experiments) is the sample quality. The mobility of carriers confined in (311) structures have been found to be approximately two times higher with respect to (100) structures.

The temperature range between 2 and 50 K has been probed in our experiments. The Hanle experiments have been performed with a conventional c.w. magneto-optical set-up. Typical experimental results are presented in Fig.1.a. The fit of a the Lorentzian dependence to the observed decay of the degree of polarization measured as a function of the transverse magnetic field allows to determine the parameters $\rho(0)$ and $B_{1/2}$. Time resolved luminescence spec-

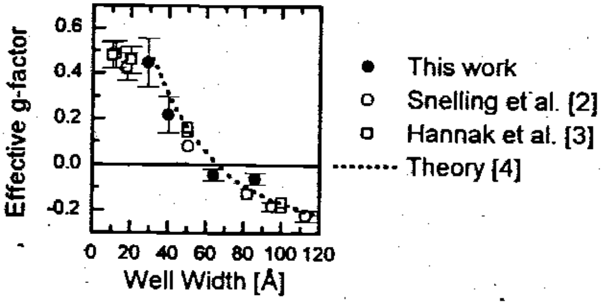

Figure 2: Experimental values of the effective electron g-factor for the investigated systems.

tra performed with an 'up-conversion set-up', described in Ref.[8], is presented Fig.1.b. The electron lifetime τ is given by fitting the exponential decay of luminescence for $t > 200$ ps.

Values of the effective electron g-factor g^* obtained for the investigated samples are shown in Fig.2 as a function of the well width. Previously reported data obtained using similar methods [2] and those deduced from time resolved Hanle experiments [3] are also plot in this figure. The well-width dependence of the effective electron g-factor is well reproduced in calculations [3] (dashed line in Fig.2) based on a three band Kane model [4].

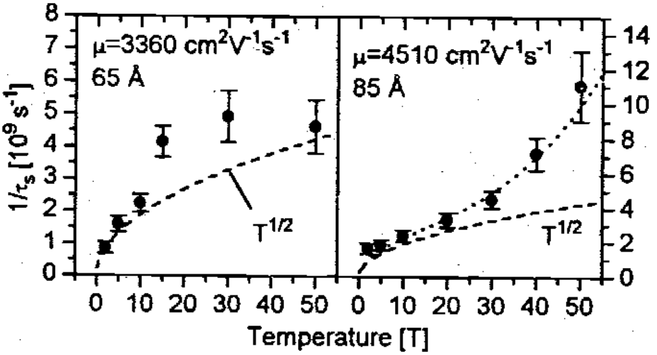

Figure 3: Temperature dependence of the electron spin relaxation time for two samples of similar well width and different mobilities.

The analysis of temperature dependences of the measured spin relaxation rates $1/\tau_s$ allow us to deduce the relevant mechanisms of spin relaxation in the investigated samples. It has been found that sample quality has a remarkable influence on the character of the $1/\tau_s$ versus T dependence. This fact is illustrated in Fig.3 where data for two samples with quite similar well widths but rather different mobilities are presented. It can be seen in this figure that $1/\tau_s$

vary as $\sqrt{T}$ for the low mobility sample. Such temperature evolution of $1/\tau_s$ is characteristic for the spin flip processees caused by the electron-hole exchange interaction. This mechanism , is known to be a dominant spin-flip process at low temperature in highly p-type bulk materials[7]. The temperature evolution of $1/\tau_s$ is essentially different for the higher mobility structure (Fig.3.b.) . In particular the high mobility structure shows a remarkable deviation from $\sqrt{T}$ - dependence in the high temperature range. We believe the observed behaviour indicates an essential contribution of the D'yakonov and Perel (DP) mechanism[7] to the spin relaxation processes in case of higher quality structures. The spin relaxation rate related to DP mechanism is known to be more effficient at higher temperatures and for higher electron mobility samples. Although we have not been able to determine the mobility of minority carriers (electrons) in our structures we believe that the measured hole mobilitities reflect the quality of our samples and are proportional to electron mobilities. Under this assumption our data indicate an important role of DP mechanism in the electron spin relaxation even in p–doped samples of relatively high quality.

In conclusion we have determined the effective g-factor and spin relaxation rate for several p-type GaAs quantum wells. The observed changes in the g-factor are in agreement with previous reports[2,3] and relatively well reproduced by theory[4]. Two mechanisms of spin-flip trantitions determine the spin relaxation rates in the investigated samples. The exchange interaction induced processes are favored for low quality structures and in the low temperature range. The DP mechanism remains important for higher quality structures and higher temperature. These conclusions are in qualitative agreement with previous theoretical and experimental studies of single-electron spin relaxation processes in bulk[1] and two-dimensional structures[5,6,7,8,9].

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