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DYNAMICS OF SPIN POLARIZATION IN A TWO-DIMENSIONAL ELECTRON GAS

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Time-resolved optical-pumping experiments on p-type GaAs quantum wells are applied to study the spin polarization of a two dimensional electron gas (2DEG) in the density range up to ~$5x10^{11}cm^{-2}$.We have found that the two spin components of an optically pumped 2DEG are well described by Fermi-Dirac distributions with common temperature but different chemical potentials. The rate of spin depolarization of the 2DEG is found to be independent on the electron kinetic energy but strikingly fastened by thermal spreading of carriers. Our findings are in contrast with the situation expected under equilibrium conditions, i.e., a common chemical potential but differently renormalized band edges for the two spin-unbalanced components of a 2DEG.

A circularly polarized, near-band edge, excitation of a semiconductor structure permits to create a gas of photoexcited electrons with appreciable different populations of spin-up and spin-down components[1]. These populations can be analyzed in polarization resolved emission. A variety of optical pumping experiments[2], including time-resolved spectroscopy, have been employed to determine the mechanisms of spin relaxation and its dependence on doping, temperature, dimensionality, etc. Only recent studies on excitons raised the problem of interactions within a gas of spin polarized carriers[3]. In this paper, we investigate the time evolution of the two spin components of a photocreated 2DEG as a function of the density of carriers excited with a picosecond laser pulse. Exciting a p-type GaAs quantum well below the light-hole resonance, electrons with almost purely one spin component are photocreated. An appreciable shift between σ^- and σ emission is observed due to different filling of the conduction band for both electron-spin components. The two spin components of the 2DEG are characterized by Fermi distributions with very similar T's, but different Fermi levels. The energy

distribution of carriers (electrons and holes) is found to be a dominant factor determining the rate of relaxation of spin polarization of the optically aligned 2DEG. This rate is accelerated by high carrier T's (high lattice T and/or short times after the pulse excitation) but in the case of a cold system it does not change as a function of the electron kinetic energy (driven by the electron density).

We have studied several p-type modulation doped GaAs/GaAlAs QWs with hole sheet concentrations of ~$3\cdot10^{11}$ cm^{-2} , mobilities of ~ 4000 $cm^2V^{-1}s^{-1}$ and well widths from 30 to 80 Å. The structures were initially extensively tested with conventional, low power, cw experiments[4]. Polarization-resolved measurements in Voigt configuration allowed us to estimate the spin relaxation time at very low excitation powers. Furthermore, the samples were investigated with time resolved PL experiments (resolution of 5 ps) using a standard up-conversion system equipped with a tunable excitation laser and double monochromator to disperse the up-converted signal. The σ^+ and σ^--circularly polarized PL was measured, for different excitation powers and lattice T's, as a function of the emission energy and the time delay after the σ^+-polarized excitation pulse. We present here the results on the 30Å-thick QW grown on [100]-GaAs substrate, but our conclusions are also confirmed by the experiments performed on the other structures.

Representative experimental data obtained at relatively low excitation powers are shown in Fig.1. The variation of the energy of the σ^+-excitation leads to changes of the luminescence intensity which are clearly different for the two σ^- and σ^+ PLE components (a). They are particularly distinct when the excitation energy is below the energy gap associated with the light hole valence band subband (lh). The observed high intensity of σ^+ luminescence, as compared to the σ^-, indicates a long electron spin relaxation time $\tau_{\uparrow\downarrow}$, which can be readily measured in time resolved experiments (see Fig.1b&c). Here the energy of the σ^+-excitation is fixed below the lh transition, the detection energy is fixed at the maximum of the luminescence peak and the lattice T is 10K. The measured time evolution of the I^{++} and I^{+-} intensities of the σ^+- and σ^--emission components, as well as the calculated decay of the polarization degree $\rho = (I^{++} - I^{+-})/(I^{++} + I^{+-})$, are shown in Fig.1b and c, respectively. With the exception of very short times after the excitation pulse, the time evolution of ρ is well described with a single exponential with a decay time of $\tau_{\uparrow\downarrow}$=550ps, identified with the electron-spin relaxation time.

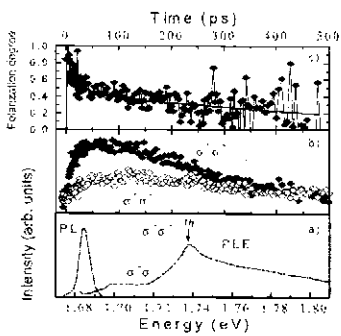

Fig.1 a) PLE spectra under σ^+ excitation: σ^+ (solid) and σ^- (dash-dotted) emission. b) Time evolution of PL exciting at 1.717eV c) Polarization degree from b).

Electron spin relaxation in semiconductors is usually attributed to either the existence of odd terms in the dispersion relation of the conduction band (DP mechanism[5]) or to the exchange interactions between electrons and holes (BAP mechanism[6]). We believe that our results obtained under high intensity excitation conditions give a new insight into the physics of optically spin-aligned electronic states. An intriguing experimental observation is already seen in Fig.1c: a considerable drop of the polarization degree takes place at very short times (≤ 150ps) and is followed by a slow decay with a typical time of 550ps.

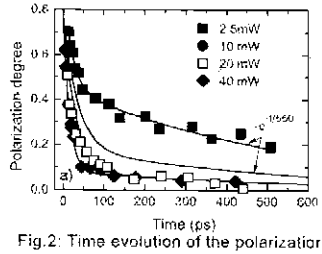

Fig.2: Time evolution of the polarization from the integrated spectra for different powers of excitation. Lines are the best fits with the sum of 2 exponential decays.

In the following, the polarization degree is defined with respect to the integrated intensities of the σ^+ and σ^--PL spectra. The time evolution of ρ is shown in Fig.2. Once more, appreciable losses of the polarization, enhanced by the excitation power, are observed at short times, whereas a characteristic 550ps-exponential decay is found for times ≥150ps. Figure 3 shows spectra at different times after the laser pulse for σ^+ and σ^- emission. In order to be more quantitative and to obtain more detailed information about the energy distribution of both spin components of the 2DEG, we have simulated the measured spectra, $I^{\sigma^\pm}(\hbar\omega)$, by the broadened convolution of Fermi-Dirac statistics for non-polarized gas of holes and two spin components of the 2DEG, assuming the conservation of **k**-selection rules. Our simulation (lines in Fig.3) satisfactorily reproduces the spectra. The splitting in the PL maxima, which amounts to 2.5 meV at 17 ps, is linked to the differences in the Fermi energies of spin-up and spin-down electrons. This difference increases to 6 meV at 17 ps when the power of the exciting pulse is increased by a factor of 5. An analysis of pairs σ^+ and σ^--PL spectra leads us first to conclude that each component is well described assuming a common T for the two electron spin components (and for holes), but different values of the chemical potential. This means that, under our experimental conditions, the exchange interaction between electrons is unable to stabilize a common chemical

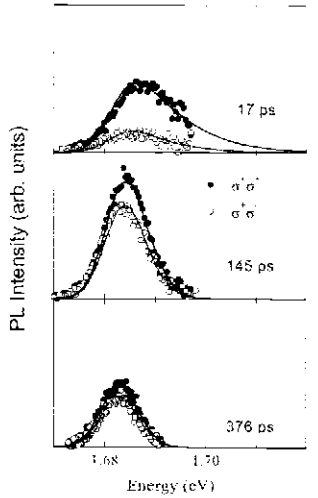

Fig.3:PL spectra for different time delays exciting with σ^+ light. The lines depict the results of the modelling.

potential of the 2DEG for the two spin components. This latter situation might be expected under equilibrium conditions and would imply a difference in the renormalization of the conduction band edges for the two spin components. The renormalization effects are very weak in our experiments and all the spectra are fairly well simulated assuming the same value for the energy gap E_g=1.6815eV. The carrier T rises up to ~100K just after the laser pulse. This fact accounts for the fast depolarization of electronic spins, induced by the laser power. Our results confirm the high efficiency of carrier-carrier interaction in establishing a common T for electrons and holes. Cold before excitation, the gas of holes becomes nondegenerate almost immediately after the laser pulse. Nondegenerate carrier distributions favor the efficiency of spin-flip electron scattering via the exchange interaction with holes, in contrast, the available number of scattering configurations is appreciable reduced for the degenerate systems.

Summarizing, we have shown that strong effects, nonlinear in the excitation power, observed in the polarization of a photocreated 2DEG originate from nondegenerate carrier distribution at short times after the laser excitation. An optically aligned, spin-polarized electron gas can be well described by two separate Fermi-Dirac distribution functions, one for each spin component, with common temperature but different chemical potentials.

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