# Extremely Long Spin-Relaxation of Excitons Localized in GaAs/AlGaAs Coupled Quantum Well Structures

Adriana L. C. Triques*+, Anna Vinattieri+, Marcello Colocci+,
Robson Ferreira# and Philippe Roussignol#

+ *Dipartimento di Física, Università degli Studi di Firenze*
*Largo Enrico Fermi, 2, 50144 Firenze (Italy)*

* *Instituto de Física Gleb Wataghin, Universidade Estadual de Campinas*
*Cx.Postal 6165, 13081-970, Campinas-SP (Brazil)*

\# *LPMC, Ecole Normale Supérieure, 24 rue Lhomond 75005 Paris (France)*

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Strong spin polarization has been observed for localized excitons in GaAs/AlGaAs symmetrical double quantum-wells as a function of excitation energy and temperature. The spin relaxation time has been obtained from time-resolved luminescence spectroscopy and turns out to be surprisingly long at low temperatures. A localized nature of the exciton undergoing recombination is invoked in order to explain the observed polarization effects.

## I. Introduction

The spin dynamics in semiconductor heterostructures has been matter of interest in the last years as one of the basic processes involved in the complex relaxation and recombination dynamics of excitons and free carriers. Even though some important aspects of the spin-relaxation in quantum wells have been elucidated, in particular the role of the valence band mixing for the holes[1] and the exchange interaction for excitons[2], nevertheless the large spread in the experimental results still makes the spin-dynamics a topic deserving further investigation. In high quality samples it was shown[3] that the exciton spin-relaxation is mainly driven by the exchange interaction. Only recently[4] spin-relaxation started to be investigated when excitons are strongly localized, in samples where Stokes-shifts of the order of few meV are observed between photoluminescence (PL) and photoluminescence excitation spectra (PLE). In fact it seems that exciton localization could explain the large spread in the experimental results concerning the exciton spin dynamics.

In this paper we present results on the optical spin-polarization dynamics in GaAs/AlGaAs symmetrical double quantum-well structure as a function of the excitation energy and temperature. We observe strong spin-polarization both in continuous wave (CW) and time-resolved experiments even for excitation energies as high as 110 meV above the fundamental heavy-hole exciton transition and we deduce a long spin- relaxation time from fits to time-resolved data. Our results will be analyzed in the framework of a simple model, taking into account the localized nature of the exciton.

## II. Experimental results

Our sample consists of a coupled double quantum-well (CDQW) structure with two 40 Å-thick GaAs wells separated by a 20 Å-thick $Al_{.29}Ga_{.71}As$ barrier, grown on a vicinal GaAs surface. Because of such a thin barrier, there is a very strong coupling between the electronic states of the two wells, which produces a splitting of the electronic levels of the conduction and valence bands, originating symmetrical (S) and antisymmetrical (A) states. The energy separation between the S and A excitonic levels is 50 meV for the heavy-hole exciton and 90 meV for the light-hole exciton.

We performed continuous wave, picosecond time-resolved photoluminescence and photoluminescence excitation measurements at low excitation density ($\leq$1 W/cm$^{-2}$). A Ti:Saphire laser was used for the CW experiment, while a Styryl 9 dye laser synchronously pumped by the second harmonic of a Nd:YAG laser was used for the time- resolved experiment. The photoluminescence was time-resolved by a synchroscan streak camera with an overall time resolution of 20 ps. CW and time-resolved experiments were performed exciting the samples with circularly-polarized light ($\sigma^+$ or $\sigma^-$), detecting the circularly polarized component $\sigma^+$ of the luminescence. $I^+$ and $I^-$ are the PL intensities under $\sigma^+$ and $\sigma^-$ polarization excitations, respectively. The temperature of the sample was changed in the range 10-70 K. Hereafter we indicate with $S$ (sum) the total PL signal ($S = I^+ + I^-$) and with $D$ the difference ($D = I^+ - I^-$); therefore the polarization $P$ is given by the ratio $D/S$.

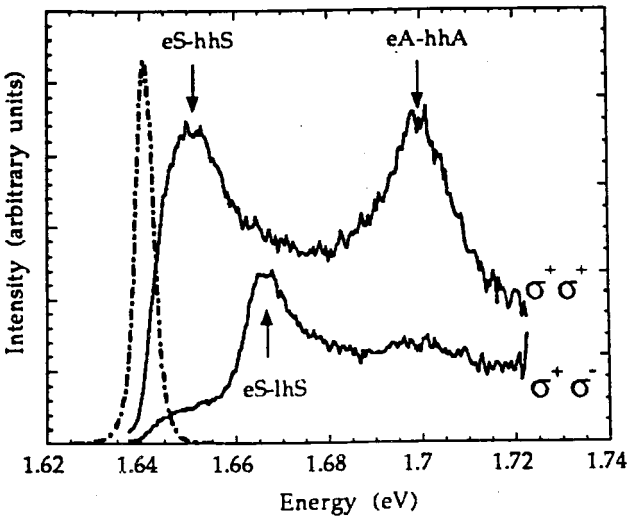


Figure 1. Comparison between PL (dashed line) and polarized PLE (solid lines) at 10 K.

Typical CW PL and PLE spectra are shown in Fig. 1; The PL linewidth is about 4 meV at 10 K and, at the same temperature, a Stokes-shift of 10 meV indicates the localized nature of the exciton. In the figure, ($\sigma^+$ $\sigma^+$) and ($\sigma^+$ $\sigma^-$) symbolize the detection of polarized luminescence $\sigma^+$ after excitation with $\sigma^+$ and $\sigma^-$ polarized light. Strong excitonic resonances are detected at the first symmetric heavy- and light-hole excitons (eS-hhS and eS-lhS, respectively) and the first antisymmetric heavy-hole exciton (eA- hhA); the first antisymmetric light-hole exciton resonance was also detected, although not shown in the figure.

The first remarkable feature is the high CW spin-polarization: strong polarization is found both at the symmetric (eS-hhS) and antisymmetric (eA-hhA) heavy-hole exciton transition energies while it goes to zero at the light-hole (eS-lhS) energy. At 10 K a 10% polarization is still detected when exciting at the eA-lhA exciton transition energy, 110 meV above the fundamental heavy-hole exciton transition. In Fig. 2 the polarization P is reported as a function of the excitation energy for different temperatures. It turns out that a significant polarization is still detectable at 50 K when the excitation energy is tuned at the eA-hhA transition energy.

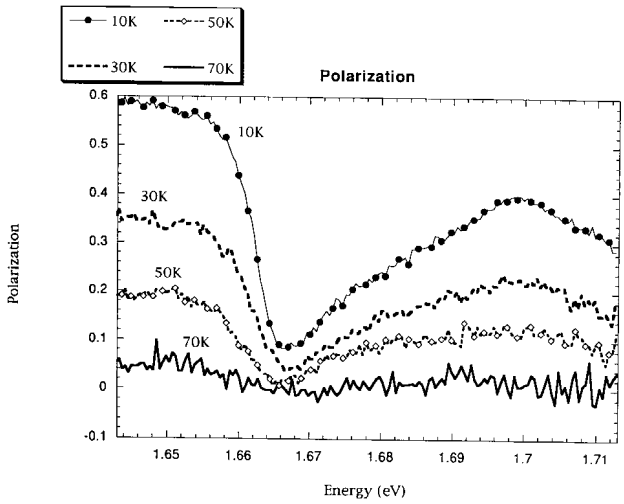


Figure 2. CW polarization as a function of the excitation energy for different temperatures.

Therefore it is clearly shown that the initial relaxation and the subsequent localization do not produce an important loss of polarization at least at low temperatures for the heavy-hole exciton states. These results are confirmed by the time-resolved experiments; initial polarization of the order of 90% is measured when the excitation energy is tuned at the eS-hhS exciton transition, dropping to 60% when exciting at the eA-hhA exciton energy (60 meV above the PL peak).

In Fig. 3 a typical PL decay at 10 K is shown for the sum S and the difference D for the excitation at the

energy of the symmetric heavy-hole exciton transition.

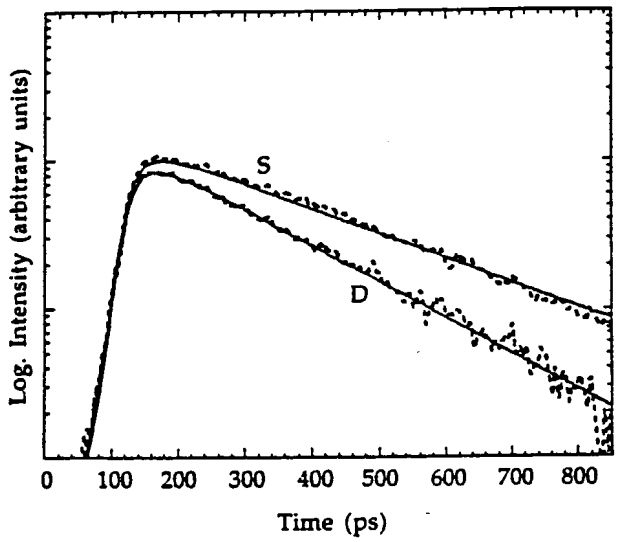


Figure 3. Typical PL decays for the sum S and the difference D at 10 K. Solid lines are fits to the experimental data.

Time resolved data were analyzed in the framework of a simple three-level model where the excitons, pumped into the optically active spin states $|+1>$, are quickly captured by the localized states $|\pm 1>_{\rm loc}$ where the spin-flip of the exciton (as a whole) takes place. This model allows for the independent extraction of the PL decay time $\tau_R$ from the temporal behavior of S and the spin-relaxation time $2\tau_X$ from the decay of D. A typical fit is shown, as a solid line, in Fig. 3. From fits to the experimental data we deduce a PL decay time $\tau_R$ of 270 ps at low temperatures which increases with temperature as commonly found in quantum-well structures[5]. A long spin-relaxation time of 600 ps is obtained at 10 K decreasing to 170 ps at 40 K.

As previously shown, it is quite surprising such a freezing of the spin-relaxation as demonstrated by time-resolved and CW data in a sample with a definitely localized exciton. We have therefore to conclude that, on one hand, the localization of the exciton does not produce an important loss of polarization as observed when exciting at the eS- hhS exciton transition energy. Nevertheless the exciton localization seems to strongly modify the spin-relaxation if we compare the spin-relaxation time of 600 ps obtained in this case with the value of few tens of picoseconds measured in quantum-well of similar thickness[6]. The observation of a polarization strongly dependent on the excitation energy, i.e. high correspondent to the heavy-hole exciton states and zero at the light-hole exciton energies, seems to suggest that the exciton mainly flips the spin as a whole and to indicate the exchange interaction as a possible spin-relaxation mechanism, even though modified by the localization.

On the other hand it is remarkable that also the energy relaxation does not modify the spin of the exciton whenever it is formed after resonant excitation at the fundamental heavy-hole transition energies. This result suggest that the interaction with phonons, both acoustic and optical, involved in the relaxation process is strictly spin-conserving.

It seems that a systematic study on samples with different degrees of localization would help in clarifying the role of localization in the spin-relaxation dynamics. Experiments are in progress.

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