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Spin depolarization via tunneling effects in asymmetric double quantum dot structure

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Exciton spin relaxation at low temperatures in InAlAs-InGaAs asymmetric double QD's embedded in AlGaAs layers has been measured as a function of the barrier thickness by the time-resolved photoluminescence (TR-PL) measurements. Decreasing the thickness of the AlGaAs layer between the QD's, the spin relaxation times change from 3 ns to less than 500 ps. The reduction of the spin relaxation time originates from the strong coupling effects between the excited state in InGaAs QD's and the ground state in InAlAs QD's and the resultant tunneling leads to the spin depolarization of the ground state in InAlAs QD's.

I. INTRODUCTION

The spin relaxation processes of excitons in semiconductor quantum dots (QD's) are of considerable interest in connection with the search for solid state implementations for qubit in quantum information technologies. One of the key points is obtaining long spin coherence times so that quantum information can be stored and manipulated without losses. Spin relaxation is quite fast in bulk (undoped) semiconductors, typically on the order of a few ps[1]. In quantum wells (QW's), the lifting of valence-band degeneracy due to quantum confinement leads to slow spin relaxation and actually the spin relaxation times are order of a few 10-100 ps.[2,3] Also, the effective spin relaxation mechanisms in QW's have been revealed by intensive experimental and theoretical studies[4–7] In QD's, several experimental results have been reported without magnetic field[8–10] and with magnetic field[11,12]. The experimental results suggest basically long spin relaxation times of the order a few ns. To date, however, it is important to know the dependences of the spin relaxation times on system and on parameters in order to refer to the spin relaxation mechanisms and give the guideline to the target system[13] both experimentally and theoretically. In the present work, the exciton spin relaxation at low temperatures in InAlAs-InGaAs double QD's embedded in AlGaAs has been observed by the time-resolved photoluminescence (TR-PL) measurements. We used five samples with different barrier thickness between the QD's and the spin relaxation times were measured as a function of the barrier thickness using circularly polarized excitation. As a result, the presented data indicates that the carrier tunneling effects from InAlAs QD's to InGaAs QD's lead to the spin relaxation of the ground state in InGaAs QD's.

II. EXPERIMENTS AND RESULTS

We have grown five double QD's that consist of $In_{0.75}Al_{0.25}As/Al_{0.3}Ga_{0.7}As$ QD and

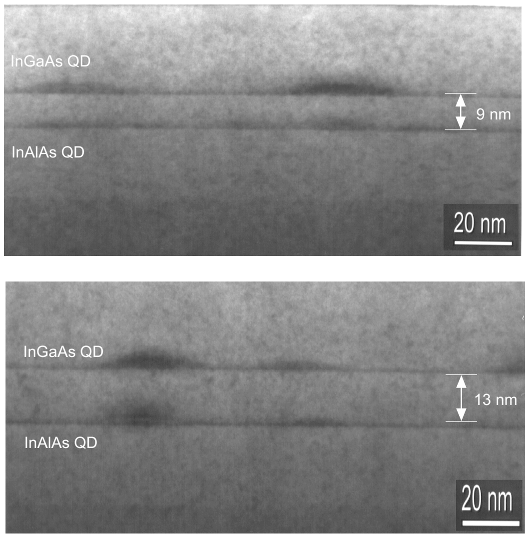

FIG. 1: Cross-sectional TEM images of InAlAs and InGaAs QDs with 9-nm and 13-nm AlGaAs barrier width. Both samples are aligned along growth direction.

$In_{0.7}Ga_{0.3}As/Al_{0.3}Ga_{0.7}As$ QD by conventional molecular beam epitaxy. The nominal distance between the wetting layers of each double QD's is different and their values are 9, 10, 11, 13, and 20 nm. Cross-sectional TEM were used to estimate the structure of the coupled QD's. Figure 1 shows the TEM images of the QD's with 9-nm and 13-nm AlGaAs barrier width. InGaAs QD is aligned vertically due to the strain generated by the lower InAlAs QD. In the QD's with 20-nm barrier width, QD's are not expected to be aligned.

Figure 2 shows time-integrated PL spectra of InAlAs QD's and InGaAs QD's at 10 K. A cw He-Ne laser was used as an excitation source and the PL was detected by a multichannel detector. The excitation power was 10 mW and the laser light was focused to the spot diameter of 200 μm on the sample surface. The central emission wavelength from ground state of InAlAs QD's and InGaAs QD's are found to be around 780 nm and 960

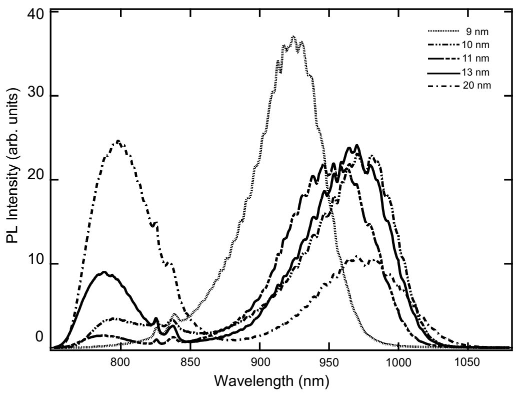

FIG. 2: PL spectra from InAlAs and InGaAs QD's having AlGaAs barrier width of 9, 10, 11, 13, 20 nm, respectively, at 10 K.

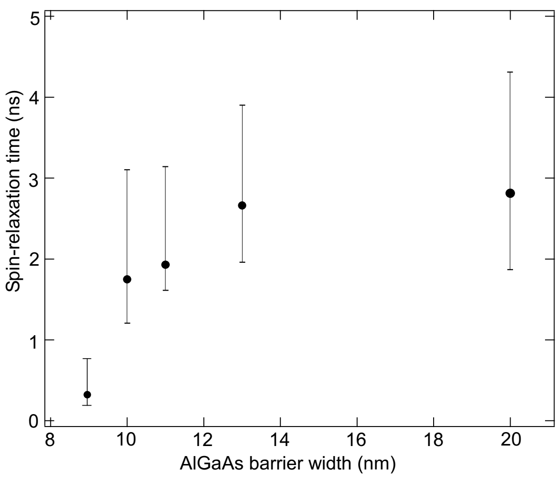

FIG. 3: Barrier width dependence of spin relaxation time in InGaAs QD's.

nm, respectively. Only for QDs with 9-nm barrier width, the PL from the InAlAs QD's is suppressed strongly and the PL peak from InGaAs QDs is blue shifted to ∼925 nm. This behavior can be explained by the structural and wave function coupling between InAlAs QD's and InGaAs QD's.

Figure 3 shows that spin relaxation time in the InGaAs QD's as a function of the barrier thickness at 10 K. The excitation wavelength is 780 nm that is resonant to the ground state of InAlAs QD's (see Fig. 2). A mode-locked Ti:sapphire laser with 100-fs pulse width was employed as an excitation source.

The population dynamics of spin-polarized carriers can be described by the simple rate equation, $\mathrm{d}N_\pm/\mathrm{d}t = -N_\pm/\tau_r \mp N_+/\tau_s \pm N_-/\tau_s$, where $N_\pm$, τ_r, and τ_s are the spin-up (+) and spin-down (−) exciton population, the recombination time, and the spin relaxation time, respectively. The spin relaxation time was estimated from the decay of the signal difference between right- and left-circularly polarized excitations. As seen in Fig. 3, the thinner AlGaAs barrier was, the faster the spin-relaxation time was. This behavior can be explained by the carrier tunneling from the ground state of InAlAs QD's to InGaAs QD's. In the samples of 10-, 11-, 13-, and 20-nm barrier width, the clear difference of signals were observed. For 9-nm barrier width sample, the signal difference between σ_+-PL and σ_--PL is small. This is regarded as due to the wave function coupling between the ground state of InAlAs QD's and the excited states of InGaAs QD's.

III. SUMMARY

We have performed the time-resolved photoluminescence (TR-PL) measurements of the exciton spin relaxation at low temperatures in InAlAs-InGaAs double QD's embedded in AlGaAs. The spin relaxation times were measured as a function of the barrier thickness and the experimental data indicates the effects of tunneling from the ground state of InAlAs QD's to InGaAs QD's. Also, the strong coupling between the excited state in InAlAs QD's and the ground state in InGaAs QD's is suggested to lead to the spin depolarization of the ground state in InAlAs QD's.

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