Observation of spin relaxation in self-assembled InAlAs quantum dots by using four-wave mixing technique

T. Watanuki, S. Adachi, H. Sasakura, and S. Muto

Department of Applied Physics, Hokkaido University, and CREST, Japan Science and Technology Agency, N13 W8, Kitaku, Sapporo 060-8628, Japan

adachi-s@eng.hokudai.ac.jp, phone/fax: +81-11-706-6669

It is obvious that knowledge of spin dynamical processes in quantum structures is important for development of the spin-based devices. Although the leading spin-flip mechanism may be different depending on dimensionality of the quantum confinement, it is little known about its unified understanding. For example, exciton spin relaxation time changes drastically from quantum wells (QW's) to quantum dots (QD's) which have similar band-gap energy, and therefore the different effective spin relaxation mechanisms are supposed to work. In this work, we have investigated the exciton spin relaxation in QD structures at low temperatures and resonant excitation condition by using spin-diffracted four-wave mixing (FWM) [1-3] combined with heterodyne detection technique. Although the FWM is known to be a powerful tool for the research of carrier dynamics since it can extract the intrinsic information regardless of the large inhomogeneous broadening, it was difficult to apply to QD's because of its low areal coverage [4].

The used sample has the 15-layers of $In_{0.75}Al_{0.25}As$ QD's embedded in $Al_{0.3}Ga_{0.7}As$, which has been fabricated using Stransky-Krastanow growth mode. Three-pulse FWM experiments were carried out with this sample at 10 K in closed-cycle He cryostat. From a Ti:sapphire laser oscillator with the pulse width of 130 fs, the synchronized four pulses were produced by a phase mask. The FWM signals that generated by two simultaneous excitation pulses and a delayed third pulse were mixed with the fourth (reference) pulse that is collinear with the diffracted signal, and as a consequence were detected heterodyningly and time-integrated by a avalanche photodiode and a lock-in amplifier.

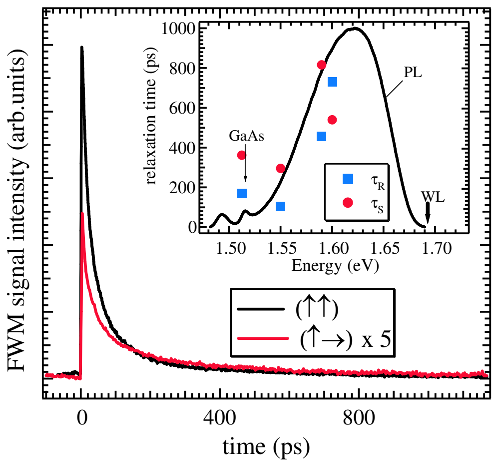

Figure shows the observed FWM traces at the central excitation energy of 1.5896 eV (780 nm). In the figure, (↑ ↑) and (↑ →) indicate the light polarizations of two excitation pulses. Corresponding to the results in QW's [2, 3], the signals for (↑ ↑) and (↑ →) should indicate the decay of exciton population grating via recombination and the decay of exciton spin grating via spin relaxation, respectively. In the case of QD's, exciton diffusion in real space is not important and does't contribute to the decay of the exciton (population or spin) grating . The signals for both polarizations were found to consist of three components in the observed excitation energy range. The fastest component (decay time 5-15 ps for both polarizations) appears around time origin and becomes significantly stronger near GaAs bandgap energy. The decay time of the second component is 30-60 ps and its magnitude also becomes stronger near GaAs bandgap. The decay times and amplitude of the third components for both polarizations depend on the excitation energy, which correspond to exciton recombination time τ_R for (↑ ↑) signal and half of exciton spin relaxation time $\tau_S/2$ for (↑ →) signal, respectively. In the inset, the values of τ_R and τ_S are plotted for some excitation energies.

[1] A. R. Cameron, P. Riblet, and A. Miller, Phys. Rev. Lett. **76**, 4793 (1996).

[2] S. Adachi,Y. Takagi, J. Takeda, and K. A. Nelson, Opt. Commun. **174**, 291 (2000).

[3] O. Ikeuchi, S. Adachi,H. Sasakura, and S. Muto, J. Appl. Phys. **93**, 9634 (2003).

[4] D. Birkedal, K. Leosson, and J. M. Hvam, Phys. Rev. Lett. **87**, 227401 (2001).