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Spin Relaxation in InAs Columnar Quantum Dots

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III-V-compound semiconductor quantum dots (QDs) are expected to be used in a circularly polarized light-emitting diode (LED) [1]. We have measured the spin relaxation time in InAs columnar QDs (CQDs), for the first time to the best of our knowledge. InAs CQDs exhibit a long nanosecond spin relaxation time, which is suitable for use in a circularly polarized LED. The obtained spin relaxation time of 35-period CQDs is about one order of magnitude longer than that of 3-period CQDs. In both CQDs, the spin relaxation time becomes longer as the excitation power increases. In the 35-period CQDs, the spatial overlap between electrons and holes is smaller than that in the 3-period CQDs, because the carrier wave functions spread more widely in the vertical direction. The observed strong carrier density dependence of the spin relaxation time indicates that the Bir-Aronov-Pikus (BAP) effect is dominant.

Experiment

The CQD samples were grown on a (001) GaAs substrate by molecular-beam epitaxy. The growth procedure includes a 500-nm-thick GaAs buffer layer grown at 600 °C, an array of CQDs formed by depositing a 1.8 monolayer (ML) InAs QD seed layer and a short-period GaAs (3 ML) / InAs (0.62 ML) superlattice (SL) grown at 500 °C, and a 100 nm GaAs capping layer [2]. The number of SL periods was 3 or 35.

The transient spin polarization was time-resolved by spin-dependent photoluminescence (PL) measurement. The optical source was a Ti:sapphire laser, which generated 100 fs pulses with an 80 MHz repetition rate. To generate and detect the spin polarization of the QDs, we used the optical transition selection rule between carrier spin and circularly polarized light [3, 4]. The excitation laser wavelength was tuned to 816 nm, which is near the band gap energy of GaAs at 10 K. The excitation light was right-circularly polarized using a quarter-wave plate. In bulk GaAs, the ideal initial spin polarization of electrons is 50%. Here, the spin polarization is defined by $(n_+ - n_-)/(n_+ + n_-)$, where n_+ and n_- are the up- and down-spin electron populations, respectively. The spin-aligned carriers generated in the GaAs barrier layer energetically relax into QDs with spin relaxation and subsequently recombine. The collected luminescence passes through an analyzer consisting of an achromatic quarter-wave plate and a linear polarizer arranged so that right- or left-circularly polarized emission can be selected. The transmitted light was dispersed in a spectrometer and detected using a streak camera.

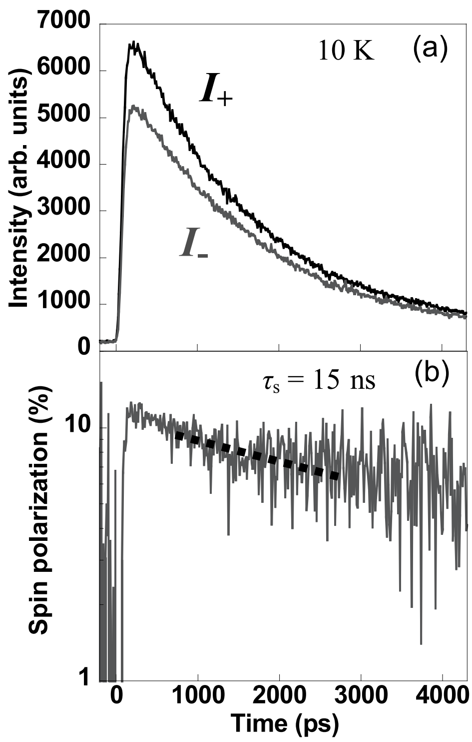

Fig. 1 Time evolution of (a) spin-dependent PL and (b) spin polarization of 35-period CQDs for the excitation power of 0.5 mW at 10 K.

Results and Discussion

Figure 1 (a) shows the time evolution of spin-dependent PL of the 35-period CQDs for the excitation power of 0.5 mW at 10 K. The black and gray curves indicate the PL intensity of the same (I_+) and opposite (I_-) circular polarizations from the pump laser, respectively. Figure 1 (b) shows the time evolution of the spin polarization of the 35-period CQDs for the excitation power of 0.5 mW at 10 K. The spin polarization P is calculated using

$$P = (I_+ - I_-)/(I_+ + I_-), \qquad (1)$$

and the spin relaxation time is derived from

$$\frac{dn_\pm}{dt} = -\frac{n_\pm}{\tau_R} - \frac{n_\pm}{\tau_S} + \frac{n_\mp}{\tau_S}, \qquad (2)$$

where n_+ (n_-) is the number of carriers with up- (down-) spin, τ_R is the recombination time, τ_S is the spin relaxation time, and τ_S is given by

$$\tau_s = \frac{2\tau_+\tau_-}{\tau_+ - \tau_-}. \qquad (3)$$

Here, τ_+ (τ_-) is the decay time of the sum (difference) of I_+ and I_-, and $\tau_+\tau_-/(\tau_+ - \tau_-)$ is equal to the decay time of the spin polarization, τ_p. Since τ_p is evaluated to be 7.3 ns by single exponential fitting in Fig. 1 (b), the spin relaxation time τ_S is 15 ns. Figure 2 shows the spin relaxation time as a function of the excitation power. The spin relaxation time of the 35-period CQDs is about one order of magnitude longer than that of the 3-period CQDs. In both CQDs, the spin relaxation time becomes longer as the excitation power increases. In the 35 periods-CQDs, the spatial overlap between electrons and holes is smaller than that in the 3 periods-CQDs, because the carrier wave functions spread more widely in the vertical direction. The observed strong carrier density dependence of the spin relaxation time indicates that the BAP effect is dominant.

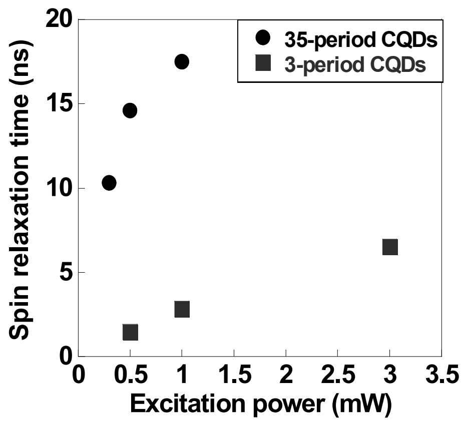

Fig. 2 Spin relaxation time as a function of excitation power.

Acknowledgements

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