Spin relaxation in CdTe/ZnTe quantum dots

Ye Chen, Tsuyoshi Okuno, Yasuaki Masumoto

Institute of Physics and Venture Business Laboratory, University of Tsukuba, Tsukuba, Ibaraki 305-8571, Japan

Yoshikazu Terai, Shinji Kuroda, Koki Takita

Institute of Material Science, University of Tsukuba, Tsukuba, Ibaraki 305-8573, Japan

Abstract. We have measured photoluminescence (PL) spectra and time-resolved PL in CdTe quantum dots (QDs) under the longitudinal magnetic field up to 10T. Circular polarization of PL increases with increasing magnetic field, while its linear polarization is absent under linearly polarized excitation. Time-resolved PL measurements clarified that this behavior is caused by the suppression of spin relaxation induced by the longitudinal magnetic field. We believe that this behavior is related to the hyperfine interaction of electron spin with magnetic momenta of lattice nuclei.

INTRODUCTION

The spin state of electron in QDs is considered as one of the most promising candidates of spintronic and quantum information techologies. Contrary to bulk and quantum well, the main spin relaxation mechanisms connected with the spin-orbit interaction of carriers and inelastic processes are strongly suppressed due to the absence of the carrier's space motion in QDs. Recently Merkulov et al.[1] pointed out that the hyperfine interacting with nuclei may become the dominant mechanism of electron spin relaxation in QDs. However, no direct experimental evidence proved the importance of hyperfine interaction with nuclei responsible for spin relaxation in QDs till now. Here we investigated the spin relaxation mechanisms of carriers in self-assembled CdTe QDs. Our results indicate that the spin relaxation in QDs is mainly caused by the nuclear hyperfine field.

EXPERIMENTS AND DISCUSSIONS

The CdTe QD was grown by MBE on a thick (0.6-1.0μm) ZnTe buffer layer formed on a GaAs (100) substrate. The sample was undoped intentionally. The average size of CdTe QDs are ~20nm in diameter and ~2.7nm in height. Optical measurements were performed in magnetic fields up to 10T and at 10K in Faraday configuration. An optical parametric amplifier of a Ti:sapphire laser was used as an excitation source with a photon energy of 2.217eV corresponding to a quasi-excitation condition.

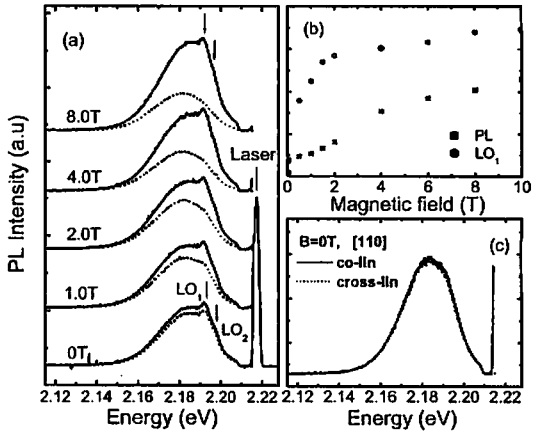

FIGURE 1. (a) Circularly polarized PL spectra in co- and cross-circular geometries at various magnetic fields. (b) Magnetic field dependence of circular polarization of QDs PL peak and LO_1 phonon. (c) Linearly polarized PL spectra in co- and cross-linear geometries along [110] direction.

CP772, *Physics of Semiconductors: 27th International Conference on the Physics of Semiconductors*, edited by José Menéndez and Chris G. Van de Walle

The circularly polarized PL spectra are shown in Fig. 1(a). Two sharp features, LO_1 and LO_2, are related to LO phonons of ZnTe and CdTe. At zero field, the PL band shows very weak circular polarization (7%). With increasing magnetic field the circular polarization of PL band increases. The phonon replica is not polarized at zero field, while it becomes strongly polarized in co-circular geometry with applying magnetic field. The magnetic field dependence of circular polarization of the emission peak and LO_1 phonon replica are shown in Fig. 1(b).

This behavior is quite similar to the conversion from optical orientation to alignment induced by the anisotropic exchange interaction of excitons,[2] which has been observed in elongated QDs. However, we did not observe any linear polarization at zero field under linearly polarized excitation along [110]and $[1\bar{1}0]$ directions as shown in Fig.1(c). These experimental results indicate that anisotropic exciton fine structure is not responsible for our results.

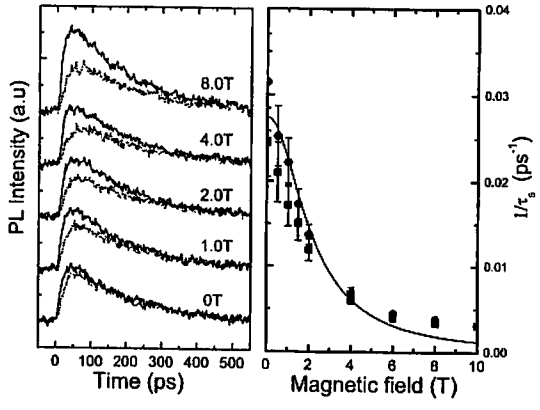

FIGURE 2. (a) Time dependence of circularly polarized PL for co-circular (solid lines) and cross-circular (dotted lines) geometries at various magnetic fields. (b) Magnetic field dependence of the spin relaxation rate. The experimental values from time-resolved PL (squares) and the estimated values from PL spectra (circles) are shown together. The solid line is the fitting according to Eq. (1).

The temporal profiles of circularly polarized PL under two geometries are shown in Fig. 2(a). We can see that the spin relaxation time becomes longer with increasing magnetic field. The time-resolved PL measurements proved that the spin relaxation in QDs was suppressed by the external magnetic field. We can obtain the spin relaxation time by fitting the decay curves of the polarization $P(t)=(I^+-I^-)/(I^++I^-)$. The obtained spin relaxation rates, $1/\tau_s$, are shown with the estimated one from PL spectra together in Fig. 2(b). We can see that they are in agreement very well. Correspondingly the polarization of phonon structures can be explained by the assumption that spin flip time becomes longer than the time for the relaxation mediated by the LO phonon plus acoustic phonons with the increase of the magnetic field.

Such suppression of spin relaxation by external longitudinal magnetic field has been reported for the case of spin relaxation of electrons localized at donors in bulk crystal.[3,4] The spin relaxation of electrons localized in potential wells is mainly caused by hyperfine interaction of electron spins with nuclei. In strong magnetic field, the nuclear hyperfine fields only perturb the precession frequency of the electron spin about the external magnetic field. As a result, the spin component parallel to B is conserved, while the transverse spin component precesses with Larmor frequency. This mechanism should also work for localized electrons in QDs. Following this model we can fit the dependence of the electron spin relaxation time τ_s on magnetic field well by the expression:

$$\frac{1}{\tau_S}=\frac{1}{\tau_S(0)\left(1+\Omega^2\tau_C^2\right)}. \qquad (1)$$

Here $\tau_S(0)$ is the spin relaxation time under the zero magnetic field, Ω is the precession frequency of the electron spin in the field B, and τ_C is a characteristic time of the order of correlation time of the fluctuating magnetic field responsible for the spin relaxation.

Merkulov et al. studied theoretically electron spin relaxation in InAs and CdSe QDs via interaction with nuclear spins.[1] In CdTe QDs only a fraction of the nuclei (25% of the Cd ions) have magnetic moment (I=1/2). As a result, the electron spin interaction with the nuclei in these QDs is weak. The hyperfine interaction constants in CdTe are not experimentally determined. Reliable quantitative calculation is difficult to be obtained. Further theoretical and experimental works are needed to understand the effect of hyperfine field on spin relaxation in QDs.

REFERENCES

1. Merkulov, I. A., Efros, A. L. and Rosen, M., Phys. Rev. B 65, 205309 (2002).
2. Paillard, M., Marie, X., Renucci, P., Amand, T., Jbeli, A. and Gérard, J.M., Phys. Rev. Lett. 86, 1634 (2001).
3. Berkovits, V. L., Ekimov, A. I. and Safarov, V. I., Sov. Phys. JETP 38, 169 (1974) [Zh. Eksp. Teor. Fiz. 65, 346 (1973)].
4. Parsons, R. R., Can. J. Phys. 49, 1850 (1971).