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Resident electrons spin formation and spin dephasing in a single CdTe quantum well

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Abstract

We report on the dephasing time of resident electron spin polarization under pump and control excitation in a single CdTe quantum well (QW) by a time-resolved Kerr rotation (TRKR) method. The distribution and magnitude of the resident electron spin polarizations can be varied by control pulse. We found the spin dephasing time decreases largely with the increasing spin polarization magnitude under circularly pump pulse excitation. What is more, spin vector dispersions induced by control pulse can shorten the spin dephasing time.

1. Introduction

Electron spin polarization has a lot of possibilities which can be applied to store the quantum coherence [1] and be used as qubits for quantum information processing [2], as high-speed all-optical switches and light modulators in spin-based technologies [3]. Especially, resident electron spins have a long dephasing time even in a QW [4]. Highly sensitive techniques of ensemble electron spin manipulation and deep understanding of spin coherence play a significant role in the initiation of spintronics. Recent studies have revealed that spin dephasing time was influenced by magnetic field, temperature, and spin density [5]. Therefore, it is important to discuss the dependence of ensemble electron spin dephasing time on the controllable spin polarization. However, the comprehensive researches of spin dephasing time related to spin polarization have been a few so far [6]. In particular, there were no studies about spin dephasing time affected by the spin vector distribution. In the recent study, the control pulses combined to the standard TRKR method are able to repolarize and rephase the originally generated electron spin polarization [7]. Also, the spin dephasing time would be influenced by the electron spin polarization.

In this report, we managed to use double circularly pulses to form the resident electron spins with different magnitude and distribution under the situation of incomplete initial spin polarization, and investigated the spin dephasing time derived from Kerr rotation signal in a single QW. At last, this method demonstrated that the electron spin dephasing time can be changed by the polarization magnitude modification of spin vector in each independent subensemble of electrons and the dispersions of inhomogeneous spin vectors.

2. Experiments and results

The sample used here is a single CdTe/$Cd_{1-x}Mg_xTe$ (x=0.15) QW with the thickness of ~100 Å. The resident electrons in a QW are derived from the formation of the negative trions, consisting of spin-paired electrons and a hole [8]. Under the excitation of trion resonance, the photocreated electron-hole pair captures one of the resident electrons with a certain spin, leaving the polarizing residual electron ensemble with opposite spin polarization. The hole-in-trion spin relaxation time is rather smaller compared with the trion recombination lifetime (85 ps). Therefore, the depolarized excited electrons return to the system and never affect the ensemble resident electrons polarization.

The sample was excited by σ^+ circularly polarized picosecond pulses (duration~5 ps) with 769.6 nm wavelength near normal incidence and the generated spin signal was measured by the linearly polarized probe pulse with the controlled delay time. The external magnetic field ***B*** up to 205 mT was applied in Voigt configuration. The sample was mounted in a cryostat and was kept at 9 K through the measurements. Moreover, the control pulse with σ^+ circular polarization was injected at a given controlled timing in the different Larmor period stages. We focus on the transient properties of the *z* component of the precessing electron spin after the excitation of control pulse.

The blue (red) curve in Fig. 1 shows the TRKR signal in the case of σ^+ pump (control) pulse excitation, and represents that the ensemble residual spin polarization decays with ~2000 ps. In the figure, control pulse excites at just after two full Larmor periods (500 ps). The time evolution of the Kerr rotation signals observed in the combination of both σ^+ circularly polarized pulses (pump and control) with different control pulse excitation timings are also shown in the same figure: with the same phase (black curve) and with a quarter phase difference (yellow curve). There are almost equal Kerr signal amplitudes at the incident time of control pulse for the respective excitation of pump and control, when the pump (5 mW) and control (7 mW) intensities are fixed. From the detection and fitting of TRKR signals, the total spin polarization generated by the pump and control excitations in the same phase (black curve) shows a higher polarization (about 1.8 times) than that of pump excitation only (blue curve), both as a single spin vector. However, the total spin polarization in different phase (yellow curve) displays the nearly equal polarization magnitude as the spin of pump excitation (blue curve), just merely gives rise to a phase conversion.

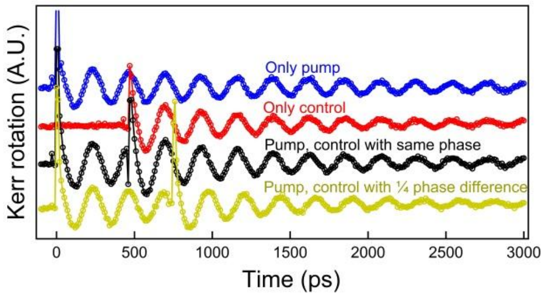

Fig. 1 Time evolution of the Kerr rotation in a CdTe QW sample observed with pump alone (blue curve), control alone (red curve), pump and control with the same phase (black curve), pump and control with a quarter phase difference (yellow curve) as σ^+ circularly polarized pulses.

The spin dephasing times were obtained from fitting the measured Kerr rotation signals on the control-probe delay Δt, and were plotted in Fig. 2. Figure shows the clear dependences of electron spin dephasing time on the spin polarization magnitude under different excitation powers: (a) σ^+ pump; (b) σ^+ control; (c) σ^+ pump fixed at 5 mW and σ^+ control from 1mW to 9 mW with same phase; (d) σ^+ pump fixed at 5 mW and σ^+ control from 1mW to 9 mW with a quarter phase difference. There is a directly inverse linear relationship between the transverse electron spin dephasing time and the spin polarization for an individual spin polarization under pump or control pulse excitation seen from Fig. 2(a) or Fig. 2(b). However, the spin dephasing is slowed down by the spin phase dispersion of electron spins formed in different phase in Fig. 2(d), in which the dispersity of spin vectors is considered to firstly increase in the region of control < pump, and then decrease with increasing the spins excited by control pulse. Also, the plot of Fig. 2(c) shows a little deviation from linear correlation, which can be explained by the potential spin heating and a little spin vectors diffusion due to experimental errors.

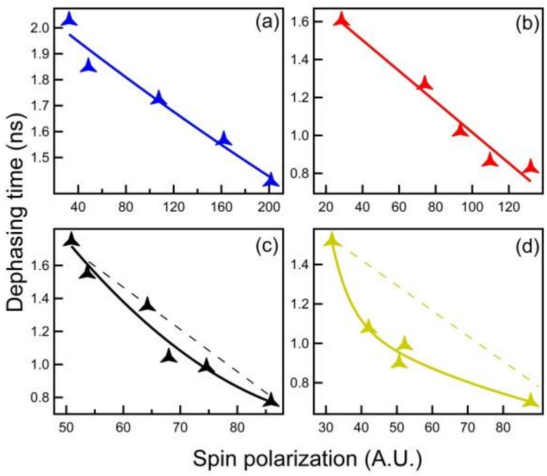

Fig. 2 Electron spin dephasing time versus spin polarization under different excitation intensities: (a) σ^+ pump; (b) σ^+ control; (c) σ^+ pump and σ^+ control with the same phase; (d) σ^+ pump and σ^+ control with a quarter phase difference.

Table I exhibits the main relationship of the spin vectors of pump-excited spins (green arrow), control-excited spins (black arrow) and the total spins (blue arrow). The measured electron spin polarization ratio derived from Kerr signal amplitudes and the fitted dephasing times (1550 ps: 2018 ps: 1519 ps ≈ 1: 1.3 :1) from Kerr rotation signals by pump and control with a quarter phase difference, pump alone, pump and control with the same phase, respectively, are summarized.

Table I Spin vector and dephasing time

Experiment excitation	Pump and control with same phase	Only pump	Pump and control with ¼ phase difference
Spin vector	↑↑↑	↑↑	S_{pump} S_{total} $S_{control}$
Polarization	1.8	1	1
Dephasing time	1550ps	2018ps	1519ps

From the spin polarization analysis above, it can be inferred that the electron spin dephasing is induced by two main aspects: the spin polarization magnitude of individual spin vector and the spin distribution of more than one spin vectors. According to Fig. 2(a) and Fig. 2(b) along with the left two columns of Table I, the spin dephasing time decreases with the increasing spins polarization. Also, as seen in Fig. 2(d) and the right two columns of Table I, the spin dephasing time is reduced by the diffused spin vectors compared to a concentrated spin for the equal spin polarization value. In addition, from the left and right columns of Table I for the pump and control with different phases, the following is concluded: the sum of spin vector modules seemingly mainly determines the dephasing time rather than the measurable total spin polarization.

3. Conclusions

In summary, the residual electron spin dephasing time in a QW goes down with the increasing spin polarization magnitude and dispersity of spin vectors respectively. Moreover, the magnitude and distribution of electron spins polarizations around the external magnetic field can be varied by control pulses with the same phase and different phase relative to pump. It demonstrates a novel mean of controlling spin polarization and dephasing time.

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