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Electron spin relaxation during transport in GaAs

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1. Introduction

Recently, spin related phenomena in compound semiconductors have attracted much attention from the various points of view, not only in physics but also in application for new devices. Realizing active *spintronic*-devices depends on how efficiently spin polarized carriers are injected or created into semiconductors[1], how far and long the electrons are transported in semiconductors without losing their spin orientations [2, 3].

We report our direct observation of spin relaxation of electrons during the transport in 2-µm-long GaAs under the drift regime in the time-resolved photoluminescence measurements at 10 K. We have confirmed the enhancement of spin relaxation under the strong electric field.

2. Experimental results and discussion

Schematic layer structure of our sample is shown in Figure 1. The sample was grown on a p-type GaAs substrate by MBE. Spin polarized electrons are created in the GaAs layer (absorption layer) by sub-picosecond optical pulses with a circular polarization. The excitation wavelength (720 nm) was chosen so that the electrons were created only in the absorption layer, where more than 99 % of the pump light would be absorbed. The electrons drift downward by the applied bias voltage and the part of them are captured in the first quantum well (QW1 of 4 nm wide with PL at 871 nm). Since electrons recombine with unpolarized heavy holes to emit PL in the QW, the optical polarization directly shows the spin polarization of electrons. After transporting through the 2-µm-thick GaAs layer (drift layer), the electrons are captured in QW2 (8 nm wide with PL at 906 nm). The PL polarization from this well indicates the electron spin polarization after the transport through the GaAs layer under drift. By comparing the degree of polarizations from the two wells, we can estimate electron spin relaxation during transport in GaAs.

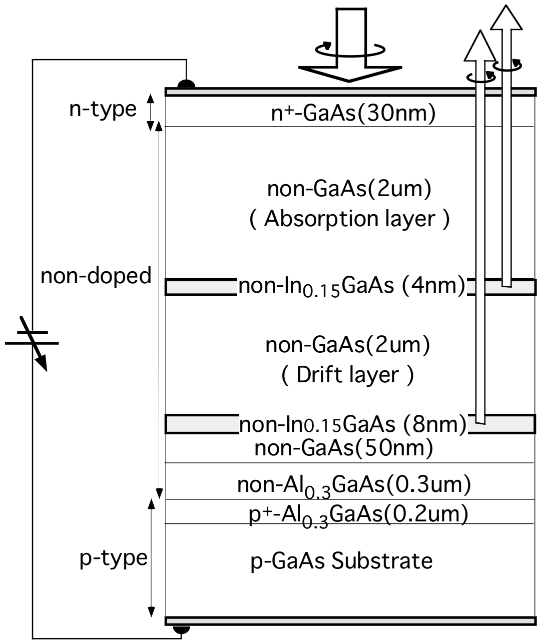

Figure 1. Schematic layer structure of our sample. The doping concentrations of *n*-, and *p*- are 1×10^{17}, 1×10^{18} [cm^{-3}], respectively.

Figure 2 shows the time evolutions of polarization-resolved photoluminescence and the optical polarization from QW1 and QW2 measured by a streak camera at 10 K when the bias voltage are 2.2 and 3.2 [V], respectively. The PL intensity from QW2 is very weak below the flat band condition (2.1[V]) and it gradually increases with the applied forward bias. Thus we confirm that the PL of QW2 originates from the electrons transported through the drift layer. The initial polarization of QW1 is about 20 % on the two different bias conditions. On the contrary, the initial polarization of QW2 is almost the same as QW1 in the low bias condition (2.2 [V]). But the polarization of QW2 decreases from 21 to 10 % with increasing bias voltage from 2.2 to 3.2 [V].

In Figure 3, we show the bias dependence of the initial polarization of QW1 and QW2. The polarization of QW1 is almost constant on the whole bias range. On the contrary, we can clearly observe that the polarization of QW2 decreases with the bias

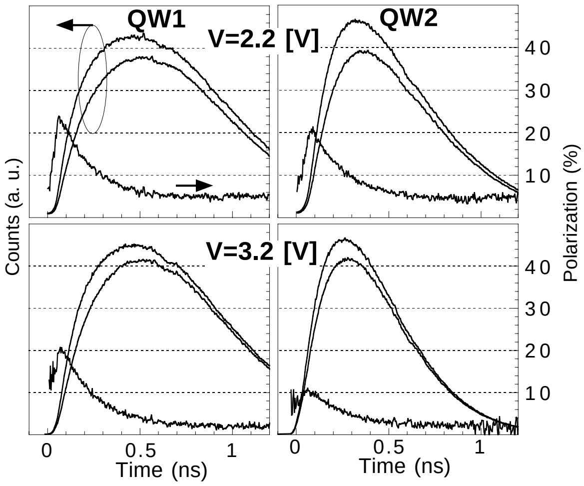

Figure 2. Time-resolved σ^+ and σ^- and electron spin polarizations when the bias voltage are 2.2 and 3.2 [V]. The excitation wavelength and power are 720 nm, 4 mW, respectively. Measurements were carried out at 10 K.

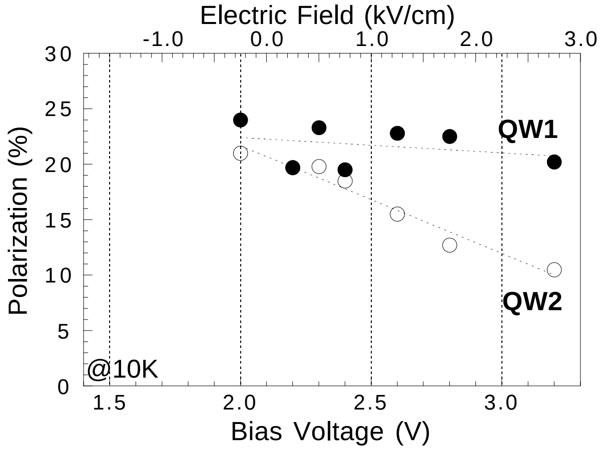

Figure 3. The bias voltage dependence of the electron spin polarizations in QW1 and QW2 at 10 K.

voltage. Since the photoelectrons are generated in the bulk region with circular polarization, the initial polarization should reach 50 %. However, the electrons may lose their spin orientations in the energy relaxation processes in the bulk region (from the photogeneration to the GaAs band edge) and in the well (from the GaAs band edge to the ground state of the well). The bias-independent initial polarization of QW1 corresponds to the electron spin polarization after the initial energy relaxation. On the other hand, the initial polarization of QW2 corresponds to the electron spin polarization after drifting through the 2-μm-GaAs layer. The spin relaxation rates during the energy relaxation in the well may differ in QW1 and QW2. We have confirmed that the spin relaxation rates are identical in the two wells within the accuracy of our measurements by observing the spin polarizations of electrons photogenerated close to the GaAs band edge. Thus we consider that the our measurement on the difference of the spin polarizations between the two wells gives a direct observation of the spin relaxation during the drift transport in the 2-μm-GaAs region.

Our result suggests that spin relaxation during drift transport strongly depends on electric field. The spin polarization reduces from 21 % in QW1 to 10% in QW2 in the highest field (2.75 [kV/cm]). We can understand the phenomena if the D'yakonov-Perel' mechanism dominates the spin relaxation in our sample. It is known that the spin relaxation of the D'yakonov-Perel' mechanism is accelerated when electrons are far above the band edge; the spin relaxation rate is proportional to the square of wavenumber *k*. During the transport in the strong electric field, electrons experience rapid spin relaxation because they have large kinetic energy between successive collisions.

3. Summary

We have investigated the electron spin relaxation during the drift transport in the bulk GaAs region by using two $In_{0.15}Ga_{0.85}As$ quantum wells as spin detectors. We have found a direct evidence that the electron spin relaxation during drift is strongly affected by the applied bias: The spin relaxation is accelerated with increasing electric field. We may ascribe the field-dependent spin relaxation to the k^2-dependence of the D'yakonov-Perel' mechanism.

References

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