Drift-induced Modulation of Spin Precession Frequency due to Spin-orbit Interaction Measured by Time-resolved Kerr Rotation Microscopy

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Backgrounds

In III-V semiconductor heterostructures, there exist two types of spin orbit interaction (SOI); the Rashba SOI induced by structural inversion asymmetry [1] and the Dresselhaus SOI induced by bulk inversion asymmetry [2]. These SOIs cause effective magnetic fields on moving electrons, which leads to the spin precession during the electron transport. Since the strength of SOI is controlled by an external gate voltage [3] or quantum well (QW) structures, for future spintronic applications [4-9], the evaluation of SOI becomes crucial. Under the drift electron motion, electron spins move in a direction given by an applied electric field and therefore precess about a drift-induced effective magnetic field. This effective magnetic field is proportional to the drift velocity of electron and depends on the crystal directions. Therefore, the induced spin precession frequency becomes a sensitive parameter to evaluate the strengths of Rashba and Dresselhaus SOIs.

Methods

The semiconductor heterostructure used in this study was a 20-nm-wide GaAs/AlGaAs QW, which was epitaxially grown by molecular beam epitaxy on a (001) GaAs substrate. The wafer was processed into Hall bar structures and the drift bias voltage was applied to the source and drain electrodes. Ti:Saphire pulse laser was used in order to excite/detect electron spins. For detecting the spin precession frequency, time-resolved Kerr rotation (TRKR) microscopy was employed. The spin polarized electrons are excited by circularly polarized pump beam and detected through the linearly polarized probe beam with time delay Δt. External magnetic field B_{ex} applied parallel to the QW plane induces the spin precession with precession frequency ω_{ex}. In addition to that, the drift-induced effective magnetic field further modulates spin precession frequency. As shown in Fig. 1, since Rashba- and Dresselhaus-induced effective magnetic fields (B_R and B_D) along [$1\bar{1}0$] and [110] directions become B_R+B_D and B_R-B_D, respectively, the different precession frequency in both directions enables the evaluation of Rashba and Dresselhaus SOI strengths.

Results

Figure 2 shows the spin polarization as a function of the delay time Δt in different drift bias voltages under B_{ex} = 0.65T parallel to [110] direction. It is noted that drifting electrons are moving to [$1\bar{1}0$] direction. When the drift bias voltage increases from −80V to 80V, the spin precession frequency gradually increases. By fitting the experimental data with exponentially decaying cosine function, we evaluate the SOI-induced spin precession frequency $\Delta\omega$ with various drift velocities. From the linear fit to the modulation of spin precession frequency, we can estimate the Rashba and Dresselhaus SOIs.

Conclusions

We demonstrated the modulation of spin precession frequency by drift-induced effective magnetic fields. In TRKR measurement, the frequency is linearly increased with the drift velocity, showing clear evidence of the drift-induced effective magnetic field. This result indicates that the SOI affects to the spin dynamics under the drift electron motion.

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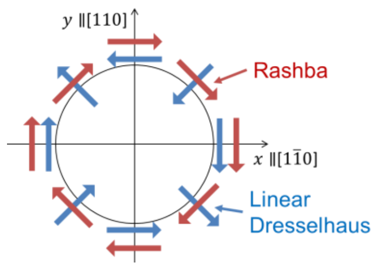

Fig. 1. Effective magnetic field directions induced by Rashba and Dresselhaus SOIs, B_R and B_D.

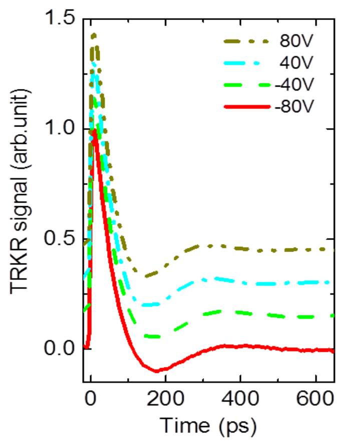

Fig. 2. Spin polarization as a function of the delay time in different drift bias voltages.