Effect of momentum distribution on cubic Dresselhaus spin-orbit interaction in two-dimensional electron gas

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The comprehensive understanding of spin dynamics of drifting electrons is significantly important for future spintronics. In this report, we discuss the in-plane electric field dependence of the spin-orbit interaction (SOI) for laterally drifting spins in a GaAs quantum well. The strengths of spin-orbit effective magnetic fields were quantitatively estimated from spin precession periods measured using spatially resolved Kerr rotation microscopy. The in-plane electric field dependence of the spin precession frequency for steadily drifting spins reveals that the strength of the cubic Dresselhaus SOI is directly varied by the momentum distribution of the electron system in a single device.

The sample that we studied was a 15-nm-thick modulation-doped $Al_{0.3}Ga_{0.7}As/GaAs/Al_{0.3}Ga_{0.7}As$ single quantum well grown by molecular-beam epitaxy on a (001) semi-insulating GaAs substrate. The epitaxial wafer was fabricated into a cross-shaped channel with a semi-transparent Au gate electrode. The spatial distribution of drifting spins was detected with Kerr rotation microscopy based on the pump-probe technique at $T = 8$ K.

The drift transport of optically injected electron spins was detected as spatially oscillating Kerr rotation signals θ_K with finite decay. The spatial frequency of the spin precession was extracted by employing a fitting analysis of the experimental data with a model function $\theta_K = A\exp(-d/l_{SO})\cos(k_{SO}d)$, where d is the distance from the pump position, l_{SO} is the spin decay length and k_{SO} is the wavenumber that represents spatial precession frequency. The drift velocity dependence of k_{SO} for the spins drifting in the [1-10], [100], and [110] directions is shown in Fig. 1(a). The anisotropy of k_{SO} for the three directions is caused by the interplay between the Rashba and Dresselhaus SOIs. k_{SO} decreases monotonically with increases in drift velocity v_d for all crystallographic directions, indicating that the effective magnetic fields are weakened by applying in-plane electric fields. Since the spin precession frequency Ω is proportional to v_d for the k-linear SOI, the spin wavenumber $k_{SO} = \Omega/v_d$ is constant for the drift velocity [1]. Therefore, k_{SO} variation in the experiment results from the cubic Dresselhaus SOI. This spin precession due to the cubic Dresselhaus SOI is qualitatively explained by the theoretical model including electron momentum distribution characterized by electron temperature T_e in electrically-warmed two-dimensional electron gas as shown in Fig. 1(b). Our achievement enables us to manipulate spin precession electrically via cubic Dresselhaus SOI, and will provide a new way to control spins in future spintronics devices.

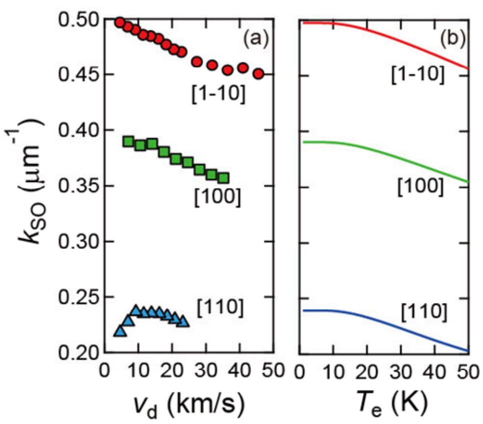

Fig. 1 (a) Drift velocity dependence of spin wavenumbers k_{SO} for the three drift directions. (b) Theoretically calculated k_{SO} as a function of electron temperature T_e.

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