Drifting spin precession modified by cubic Dresselhaus spin-orbit interaction in GaAs quantum wells

NTT BRL [1], Tohoku Univ. [2], °Yoji Kunihashi[1], Haruki Sanada[1], Hideki Gotoh [1], Koji Onomitsu [1], Makoto Kohda[2], Junsaku Nitta[2], Tetsuomi Sogawa[1]
E-mail: kunihashi.y@lab.ntt.co.jp

We investigated theoretically the spin dynamics of drifting electrons in a GaAs quantum well using a semiclassical Monte Carlo (MC) approach. Our theoretical procedure enabled us to estimate the strengths of Rashba, linear Dresselhaus and cubic Dresselhaus spin-orbit interactions (SOI) from the crystal orientation dependence of the precession frequency of drifting spins without applying any external magnetic field. Our results will provide a useful tool for the accurate detection of SOI parameters.

In a quantum well based on a zinc-blende crystal structure, spin splitting due to the Rashba and Dresselhaus SOIs are characterized by Hamiltonians with the coordinates $x \parallel [1\text{-}10]$ and $y \parallel [110]$, $H_R = \alpha(\sigma_x k_y - \sigma_y k_x)$, $H_D = -\gamma\langle k_z^2\rangle(\sigma_x k_y + \sigma_y k_x) + \gamma/2\,(-\sigma_x k_y (k_x^2 - k_y^2) + \sigma_y k_x (k_x^2 - k_y^2))$ [1], where σ_x and σ_y are Pauli spin matrices and α is a Rashba parameter that depends on the materials constituting the quasi 2D system whereas γ is a material constant. The interplay between the Rashba and Dresselhaus SOIs is reflected in the anisotropic precession frequency k_{so} of spins drifting with wavenumber k_d. Thus, we obtained,

$$k_{so} = 2m^*/\hbar^2\,[\alpha^2 + \beta'^2_1 + \alpha(2\beta'_1 - \beta'_3)\cos(2\varphi) - (\beta'_1\beta'_3 - \beta'^2_3/4)\cos^2(2\varphi)]^{1/2}, \quad (1)$$

where $\beta'_1 = \gamma\langle k_z^2\rangle - \gamma k_F^2/2$ and $\beta'_3 = \gamma k_d^2$. φ is defined as an angle from the x axis. Once we obtain the φ dependence of k_{so}, we can determine α, β'_1, and β'_3 from Eq. (1). To check the validity of our theoretical approach, we performed an MC simulation and compared it with Eq. (1). Electron spins of 10^3 are initially polarized in the z direction, and experience isotropic impurity scattering on the Fermi circle shifted by drift wavenumber k_d in every elastic scattering event. In the simulation, we used SOI parameters $\alpha = 0.5$, $\gamma\langle k_z^2\rangle = 1.0$ meVÅ, and $\gamma = 9$ eVÅ^3.

The crystal orientation dependence of k_{so} for each applied in-plane electric field is shown in Fig. 1. We found that k_{so} values simulated by the MC method agree well with the theoretical results expressed by Eq. (1). We also observed the fourfold symmetry of k_{so} in the high in-plane electric field region, which was due to β'_3 enhanced by in-plane electric fields. According to Fig. 1, the SOI parameters (α, β'_1, and β'_3) will be determined from the experimentally observed k_{so} of drifting spins. At the conference, we will discuss the experimental estimation of the SOI parameters of GaAs quantum wells.

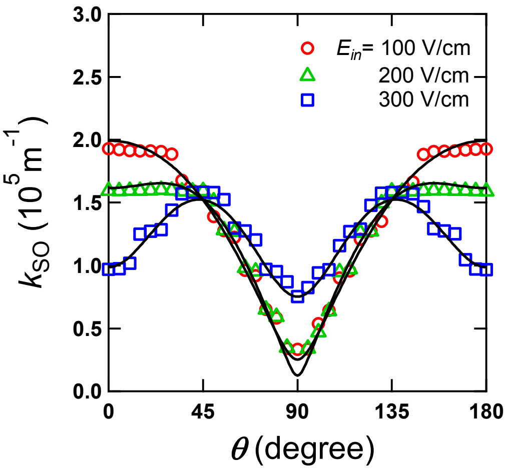

Fig. 1 Anisotropy of k_{SO} for various in-plane electric fields. Symbols and solid lines indicate k_{SO} obtained from the MC simulation and Eq. (1), respectively.

[1] R. Winkler, PRB **69**, 045317 (2003).