Spin-induced time reversal symmetry breaking in an InGaAs mesoscopic ring with Rashba spin-orbit interaction

Fumiya Nagasawa[1], **Makoto Kohda**[1,2], **and Junsaku Nitta**[1]

[1] *Graduate School of Engineering, Tohoku University, Sendai 980-8579, Japan*
[2] *PRESTO, Japan Science and Technology Agency, Saitama 331-0012, Japan*

Elucidating the dynamics of spins in solid state systems is a key concept in modern spintronics. In previous studies [1, 2], spin-dependent decoherence has been investigated in an InGaAs-based two-dimensional electron gas (2DEG) subject to competition between Rashba spin-orbit (SO) and Zeeman couplings, the latter induced by a parallel magnetic field $B_\parallel$ to the 2DEG plane. It has been revealed that the decoherence is *a universal function* of the ratio of the Rashba SO coupling and the Zeeman energies ($E_{\rm SO}$ and $E_{\rm Z}$, respectively). In this study, we investigate the spin-dependent decoherence in InGaAs mesoscopic rings, namely, in artificially defined interference paths.

An array of rings has been fabricated lithographically from an InGaAs quantum well. The radius of each ring is 0.61 μm. The perpendicular magnetic field dependence of the electrical resistance of the ring array has been measured as functions of gate voltage $V_{\rm g}$ and $B_\parallel$ at a temperature of 1.5 K. Due to ensemble averaging in the ring array, the time-reversal Altshuler-Aronov-Spivak (AAS) oscillations have been observed. We utilize the amplitude of the AAS oscillations, ΔR, to estimate the spin-dependent decoherence.

Suppression of ΔR in the in-plane $B_\parallel$-field has been observed (Fig. 1a). As shown in Fig. 1b, the suppression is a universal function of $(E_{\rm Z}/E_{\rm SO})^2$ for two dips of the ΔR oscillations (see the Inset of Fig. 1b), as observed in two-dimensional systems [2]. Not only that, the relative amplitudes $\Delta R_{1,2,3}$ (see Fig. 1a) can also be represented by a universal relation (Fig. 1c). The results suggest that the ratio $\tau_\phi(0)/\tau_{\rm SO}(0)$, with $\tau_\phi(0)$ being the phase-coherence time at $B_\parallel = 0$ and $\tau_{\rm SO}(0)$ the spin-relaxation time at $B_\parallel = 0$, is constant in our device. Thus, the universal relations studied in refs [1] and [2] are still valid for the ring array structure.

[1] F. Meijer, A. Morpurgo, T. Klapwijk, T. Koga, J. Nitta, Phys. Rev. B **70**, 201307 (2004).
[2] F. Meijer, A. Morpurgo, T. Klapwijk, J. Nitta, Phys. Rev. Lett. **94**, 186805 (2005).

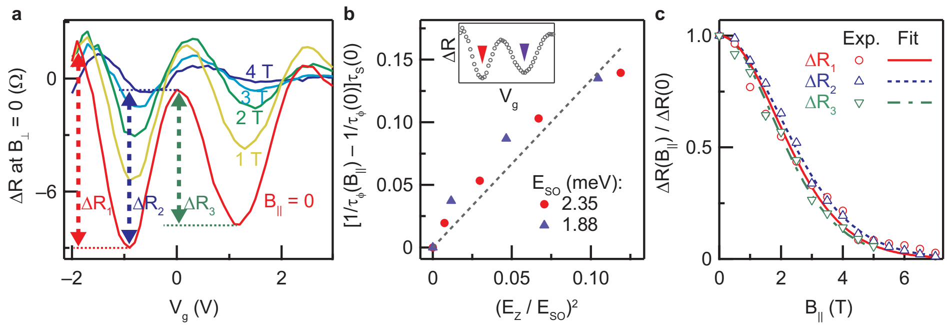

Figure 1: a, Amplitude of the AAS effect ΔR as a function of gate voltage $V_{\rm g}$ for varying in-plane $B_\parallel$-fields. b, Spin-induced dephasing rate $1/\tau_\phi(B_\parallel) - 1/\tau_\phi(0)$ multiplied by $\tau_{\rm S}(0)$, i.e., the spin-relaxation time at $B_\parallel = 0$, as a function of $(E_{\rm Z}/E_{\rm SO})^2$. Here, τ_ϕ is the phase-coherence time, $E_{\rm Z}$ is the in-plane Zeeman energy, and $E_{\rm SO}$ is the SO coupling energy. c, $B_\parallel$-field dependence of ΔR at different Rashba SO coupling strengths.