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Mapping of photoexcited local spins in a modulation-doped GaAs/AlGaAs wires

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Abstract

We directly measured the evolution of photoexcited local spins in wires made from a modulation-doped GaAs/AlGaAs quantum well by using a time- and spatially resolved Kerr microscopy measurement. We observed the spatial precession of spins in [$\bar{1}$10] wires and the retention of a spin up state in [110] wires which was designed that the Dresselhaus and Rashba spin orbit interaction are nearly equal to each other in magnitude.

1. Introduction

The spin-orbit interaction (SOI) has attracted considerable attention in the field of semiconductor spintronics because the effective magnetic field arising from SOI enables for the accumulation and manipulation of the spin states by electrical means without using magnetic fields [1,2]. On the other hand, the SOI field causes electron spin relaxation, for example via the D'yakonov-Perel' (DP) mechanism, in which the dephasing of electron spin precession in an ensemble results in the spin relaxation [3]. However, when the two types of SOI (Rashba SOI and Dresselhaus SOI) are nearly equal to each other in magnitude, the resultant effective magnetic fields are aligned along the same direction, leading to a persistent spin helix (PSH) state [4,5]. In this state, the spin rotation depends only on the displacement, which is independent of the electron path. Thus, the spin information can propagate over a long distance without relaxation. Recent experimental studies have shown the emergence of the PSH state where this suppression of relaxation was examined using spin-grating spectroscopy [6] and spatiotemporally-resolved Kerr-rotation microscopy on properly designed 2DEG in quantum wells (QWs) [7]. When the 2DEG motion is restricted along one direction, a strong anisotropy in the spin relaxation is observed as a result of the large difference in orientation-dependent effective SOI field [8,9]. In this work, we directly measured the evolution of local spins in wires made from a modulation-doped GaAs/AlGaAs quantum well by using a time- and spatially resolved Kerr microscopy measurement.

2. Experimental setup

The structure we studied here was a modulation-doped 20-nm-thick GaAs QW grown on a semi-insulating (001) GaAs substrate by using molecular beam epitaxy. From the substrate side it consists of a 200-nm GaAs buffer layer/ [18-nm $Al_{0.3}Ga_{0.7}As$ and 2-nm GaAs]×60 superlattice/ 100-nm $Al_{0.3}Ga_{0.7}As$/ 20 nm GaAs QW/ 35-nm $Al_{0.3}Ga_{0.7}As$ spacer layer/ 20-nm Si-doped $Al_{0.3}Ga_{0.7}As$ doping layer (6×10^{18} cm^{-3})/ 5-nm GaAs capping layer. The structure was designed such that the Dresselhaus and the Rashba SOI fields nearly cancelled each other out for the [110] wires. In general, the Rashba SOI in a GaAs/AlGaAs nanostructure is smaller than that in a narrow gap semiconductor such as InGaAs, while the Dresselhaus SOI is comparable. To enhance the Rashba SOI in the QW by increasing the electric field in it, we used a high Si doping concentration. Figure 1(a) shows the calculated energy band profiles and probability densities for electrons in the present QW sample by self-consistently solving the Schrödinger-Poisson equations. We fabricated arrays of 4, -μm-wide wires and 1-μm-wide spaces aligned along the [110] and [$\bar{1}$10] orientations using electron beam lithography and wet etching (etching depth ~80 nm), as shown in Fig. 1(b). In order to probe the local spin polarizations, we performed time- and spatially resolved Kerr microscopy measurement. We used a mode-locked Ti:sapphire laser at a pulse duration of ~3 ps and a repetition rate of 76 MHz. A pump beam was circularly polarized and modulated between the left and right circular polarizations at f = 50 kHz by using a photoelastic modulator. A probe beam was linearly polarized and modulated by acousto-optical modulator at f_a = 50.6 kHz. The position of the probe beam was scanned in the QW plane for spatially resolved KR meas-

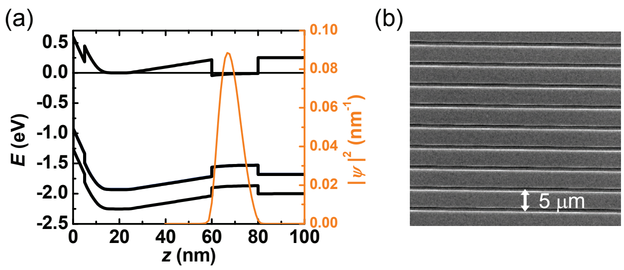

Fig. 1 (a) Energy band profiles and probability densities for electron (conduction band, heavy hole band, and spin split off band). (b) Scanning electron microscopy image of GaAs/AlGaAs wire structures.

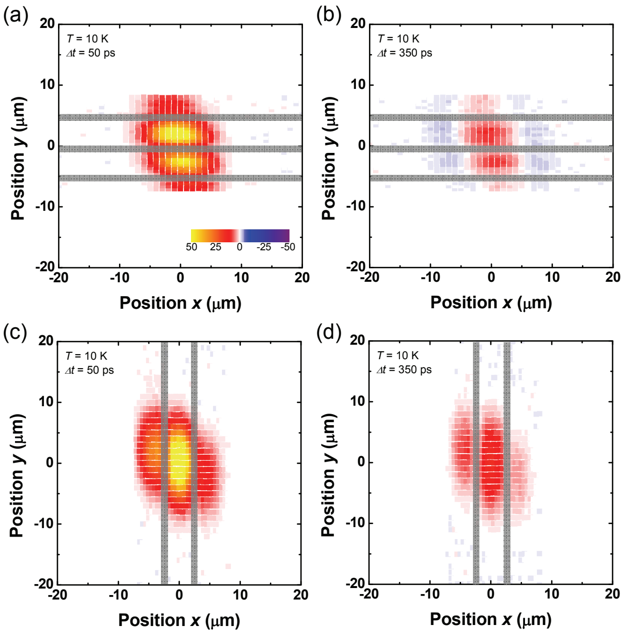

Fig. 2 2D mapping of spins $S_z(x, y)$ in 4-μm-wide wires. (a)(b) KR signals in [$\bar{1}$10] oriented wire at Δt =50 and 350 ps, respectively. (c)(d) KR signals in [110] oriented wire at Δt =50 and 350 ps, respectively. Gray areas in figures show positions of trenches.

urements. The Kerr rotation angle is detected by a balanced photo receiver and a lock-in amplifier tuned at $f_a - f$. The full width at half maximum spot size of the linearly polarized probe beam and the circularly polarized pump beam were approximately 1.5 μm and 10 μm, respectively.

3. Results and discussion

Figure 2 shows the results of time- and spatially resolved Kerr rotation measurement in wires at T = 10 K. In this experiment, electron spins are excited over 3 wires because the spot size of the pump beam was 10 μm. As shown in Figs 2(a) and 2(b), a striped pattern of the spin up and down electrons was evolved with time in [$\bar{1}$10] oriented wires. This indicates that spins rotate along [$\bar{1}$10] direction due to the effective magnetic field given by the addition of the Dresselhaus and the Rashba SOI fields. On the other hand, in [110] oriented wires, while the KR signals decrease with time, spins hold spin up states because the SOI field for electrons moving along [110] direction is almost cancelled. (Figs 2(c) and 2(d)). Another finding is that the precession of spins is not observed in any [110] oriented wires because the motion of electrons is restricted much less than spin precession length λ_{so} which is the length the electron spins rotate for an angle 2π. These results show that the SOI field in present sample has strong anisotropy.

4. Conclusions

We directly measured the evolution of local spins in wires made from a modulation-doped GaAs/AlGaAs quantum well by using a time- and spatially resolved Kerr microscopy measurement. We found that the spin stripes are formed not only in the situation of 2DEG, but also in the situation of wire structure due to the addition of two types of SOI.

Acknowledgements

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