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Spin Orbit Interaction in an $In_{0.53}Ga_{0.47}As$ / $In_{0.7}Ga_{0.3}As$ Shallow Two Dimensional Electron Gas for Electrical Spin Injection and Detection

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1. Introduction

Spin orbit interaction (SOI) plays an important role for realizing new functional devices based on spins such as a spin field effect transistor (spin FET) [1]. Since the SOI induces the momentum-dependent effective magnetic field, it gives the potential controllability for electron spins without any external magnetic fields. In a semiconductor heterostructure, Rashba SOI is induced by a structural inversion asymmetry and can be controlled by the gate bias voltages [2]. Recently, electrical manipulation of electron spin has been realized by measuring the Al'tshuler -Aronov-Spivak oscillations in the mesoscopic ring structures [3]. To realize spin functional devices, *i.e.* spin FET, electrical spin injection and detection for a semiconductor two dimensional electron gas (2DEG) are indispensable for taking advantage of the Rashba SOI. Consequently, ferromagnetic metal / tunnel barrier / 2DEG structures are employed. Since the thin surface layer brings about carrier depletion in a 2DEG resulting in a modulation of the Rashba SOI, optimization of the surface layer thickness as well as the strength of Rashba SOI in a shallow 2DEG structure is of great interest. In this point of view, we have investigated the Rashba SOI in an $In_{0.53}Ga_{0.47}As$ / $In_{0.7}Ga_{0.3}As$ 2DEG with different surface layer thickness. Magneto-conductance is measured to evaluate the Rashba SOI parameter α by using weak antilocalization (WAL) analysis. Since selective etching between InP and $In_{0.52}Al_{0.48}As$ layers are well established, we can reduce the surface layer by a wet-etching technique for optimizing surface layer thickness.

2. Sample preparation and measurement setup

The sample was epitaxially grown on (100) InP substrate by metal organic chemical vapour deposition. It consists of, from the substrate, 200 nm $In_{0.52}Al_{0.48}As$ for buffer layer/6 nm n-$In_{0.52}Al_{0.48}As$ for carrier supply (Si doping with $N_s = 4 \times 10^{18}$ cm^{-3})/15 nm $In_{0.52}Al_{0.48}As$ spacer layer/ 2.5 nm $In_{0.53}Ga_{0.47}As$ / 10 nm $In_{0.7}Ga_{0.3}As$/7.5 nm $In_{0.53}Ga_{0.47}As$/5 nm InP for barrier/20 nm $In_{0.52}Al_{0.48}As$/1.5 nm AlAs/5 nm $In_{0.52}Al_{0.48}As$. The layer structure and the energy band profile are shown in Figs. 1(a) and 1(b). The epitaxial wafers were processed into 20μm×80μm Hall bar structures by using wet chemical etching and lift off techniques. The surface $In_{0.52}Al_{0.48}As$ and AlAs layers of the channel region were systematically etched in 0 (no etching), 9.6, 13.8, 18.4, 20.6, 24.8, and 26.5 nm. We measured magneto-conductance for WAL analysis with various etched samples at T = 1.7 K. Carrier density N_s is determined by the fast Fourier transform of the Shubnikov-de-Haas oscillations. The external magnetic field is applied perpendicular to the 2DEG plane.

3. Experimental result

Figure 2 shows the etching depth dependence of the car-

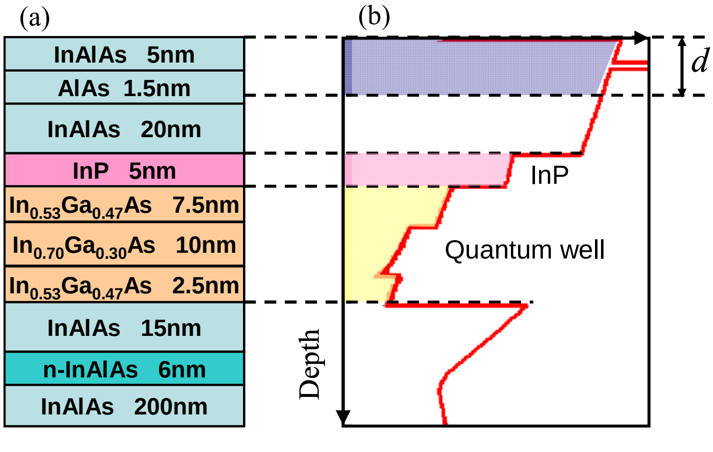

Fig. 1 (a) Layer structure of the $In_{0.7}Ga_{0.3}As$ based two dimensional electron gas and (b) Energy potential of conduction band.

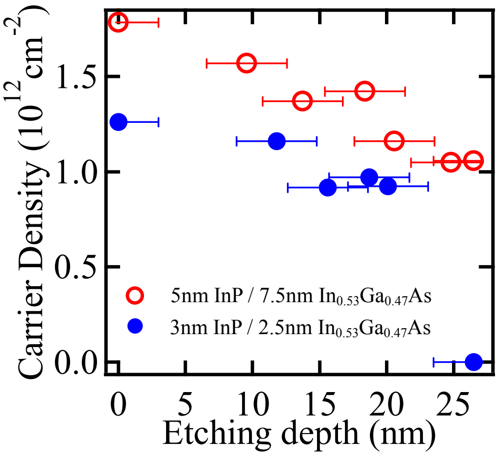

Fig. 2 Etching depth dependence of the carrier density. Open circles show the experimental results investigate here and closed circles show the results in Ref [4]

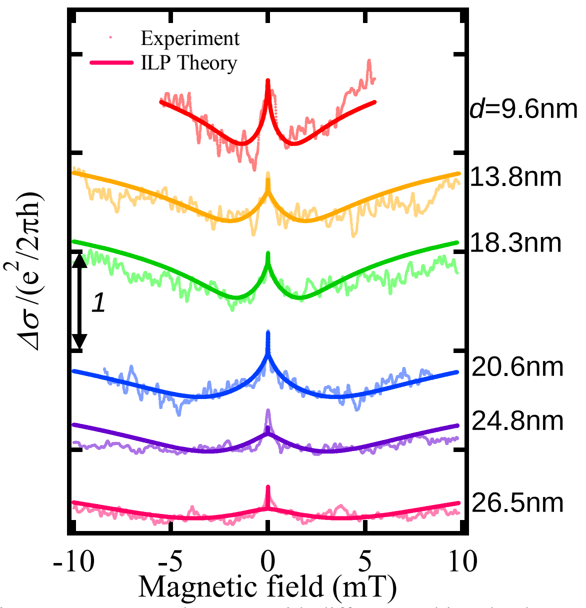

Fig. 3 Magneto-conductance with different etching depth from 9.6 to 26.5 nm. Solid lines show the fitting result by the ILP theory.

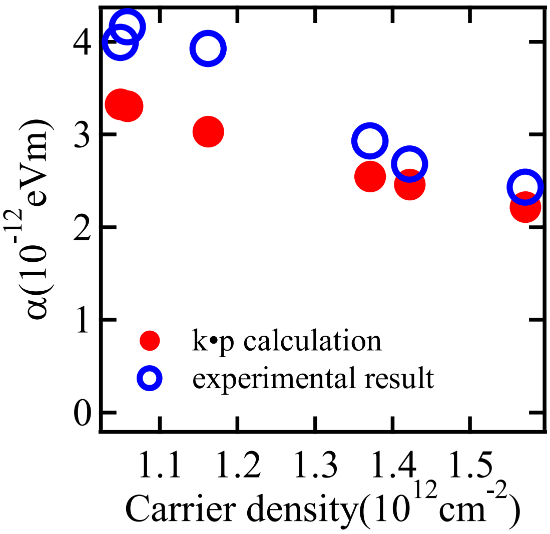

Fig. 4 Carrier density dependence of the Rashba parameter α. Open circles show the experimental results and closed circles shows the calculated results based on *k·p* formalism.

rier density. Closed circle corresponds to the results of Ref [4], which reports on an $In_{0.53}Ga_{0.47}As$ / $In_{0.7}Ga_{0.3}As$ 2DEG with 3 nm InP / 2.5 nm $In_{0.53}Ga_{0.47}As$ thinner top layer structure. When the etching depth changes from 0 to 26.5 nm, N_s decreases from 1.86×10^{12} to 1.05×10^{12} cm^{-2}. In contrast to the result of Ref. [4], which shows the entire carrier depletion when the surface etching reaches to the InP barrier layer, the 2DEG with 26.5 nm etching depth investigated here still exhibits the carrier density of 1.05×10^{12} cm^{-2}. It indicates that the 2DEG is remained in an $In_{0.53}Ga_{0.47}As/In_{0.8}Ga_{0.2}As$ channel region located 5 nm below the InP surface barrier. Thus, we measured magneto-conductance with different etching samples to investigate the strength of the Rashba SOI. Figure 3 shows the results with etching depth from 9.6 to 26.5 nm. Clear WAL is observed even in the sample with 26.5 nm etching depth, which is the shallowest 2DEG investigated here. As decreasing the etching depth, negative magneto-conductance is enhanced near zero magnetic fields indicating that the Rashba SOI is systematically modulated. To evaluate the Rashba SOI parameter α, we fitted the experimental data with Iordanskii, Lyanda-Geller, Pikus (ILP) theory as indicated solid lines in Fig. 3 [5]. The extracted Rashba SOI parameter α is shown in Fig. 4. As decreasing the carrier density which corresponds to the decrease of the surface thickness, the Rashba SOI parameter α systematically increases from 2.4×10^{-12} to 4.1×10^{-12} eVm. We also plotted the calculated Rashba parameter α derived from the *k·p* formalism [6] and it shows good agreement with the experimental data. Consequently, the shallow 2DEG with thin InP surface barrier enables us to make the electrical spin injection and detection device since InP top layer acts as the tunnel barrier for efficient electrical spin injection. For the electrical spin manipulation, we evaluated the spin rotation angle $\theta = 2\alpha m^* L/\hbar^2$, where m^* is an electron effective mass and L is mean free path. $\theta = 2.49\pi$ is obtained with $\alpha = 4.1\times10^{-12}$ eVm, where the more than π spin rotation is achieved in shallowest 2DEG structure.

3. Conclusions

In conclusion, we have investigated the Rashba SOI in an $In_{0.53}Ga_{0.47}As$ / $In_{0.7}Ga_{0.3}As$ 2DEG with different surface layer thickness. By the selective etching technique, the 2DEG located 5 nm below the InP surface barrier shows $N_s = 1.05\times10^{12}$ cm^{-2} and clear WAL is observed. The Rashba SOI parameter α increases from 2.4×10^{-12} to 4.1×10^{-12} eVm with decreasing the carrier density. Spin rotation angle with 5 nm InP barrier structure shows 2.49π indicating that such a 2DEG structure is a good candidate for the electrical spin injection and detection device.

Acknowledgements

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