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Rashba effect in Spin Field Effect Transistors

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1. Introduction

Spin transport device is located at the center of a new paradigm in the field of electronic devices. Controlling not only the charges but also the spins of electrons, a spintronic device is expected to overcome the physical limitation of present electronics which are based on electronic charges only. Among spin transport devices, the spin field effect transistor (spin FET) has attracted much interest in the field of spin electronics because of their potential uses in devices requiring high-speed switching such as logic devices. Fully electrical spin transport is the primary necessity for realizing a spin field-effect transistor (spin-FET), for which a seminal model device structure was proposed by Datta and Das in 1990 [1]. Recent experiments have shown that the spin-polarized electrons are transferred into metal and semiconductor channels. However, the electrical spin detection efficiency is still very low, and the spin transport with a gate modulation has yet to be realized. The main concept underlying the functions of spin FET is that the amount of spin precession of the traveling electron depends on a spin-orbit interaction in a semiconductor quantum well. In the spin FET, an electric field applied by a gate electrode modulates the spin-orbit interaction and hence controls the amount of spin precession. Moving electrons (k_x) in a perpendicular electric field (E_z) experience an effective magnetic field (H_R) in the y direction due to a mechanism known as the Rashba effect. This induced magnetic field, in turn, interacts with the magnetic moment of the electrons, resulting in spin orientation control. The Rashba Hamiltonian can be expressed as $H_{SO} = \alpha(\sigma \times k)\hat{z}$ where α is the spin-orbit interaction parameter and σ is the Pauli matrix. Generally, an electric field applied by the gate electrode induces a spin-orbit interaction in the relativistic frame, but a structural asymmetry of a quantum well has the same effect. In this work, we study the channel width effect on α and the gate control of the spin precession in InAs based spin field effect transistors.

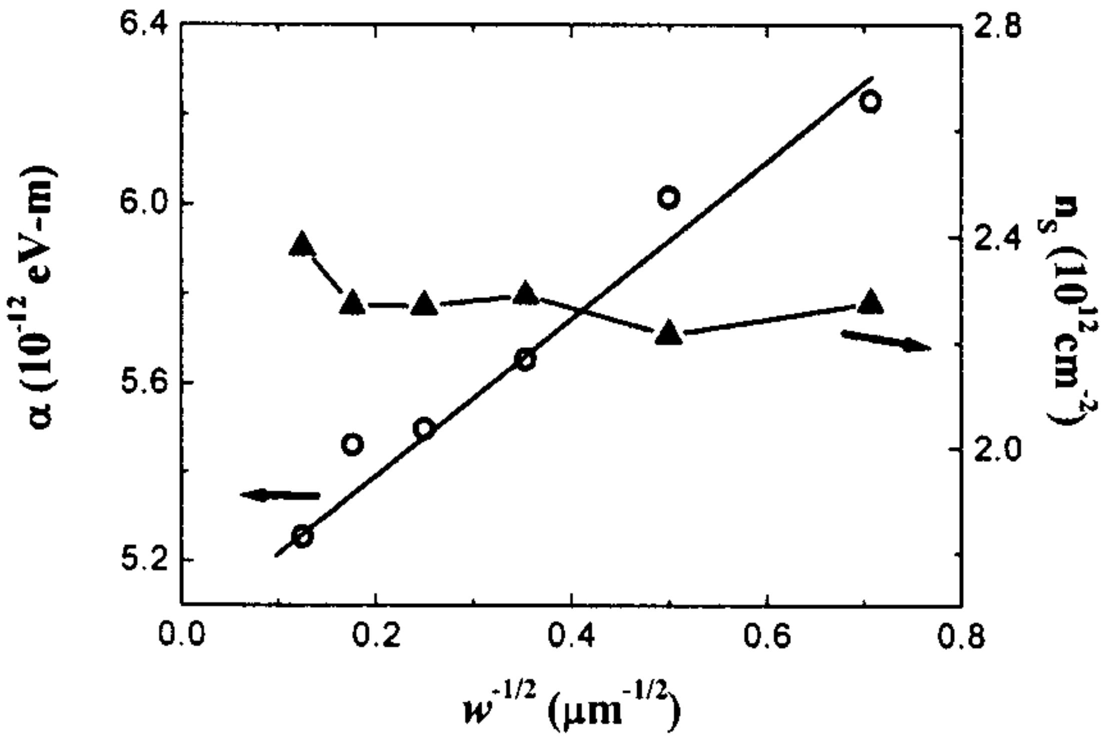
2. Experiments and Results

Two-dimensional electron gas (2DEG) structure with InAs channel is used for spin transport channel and NiFe is used for spin injector and detector. The carrier density and mobility of 2DEG are $n = 4.6\times10^{12}$ cm^{-2} and $\mu = 34{,}700$ cm^{2}V^{-1}s^{-1}. In the first experiment, the Rashba effect in the 2DEG has been studied by investigating the Shubnikov de Haas oscillations (SdH oscillations). The spin splitting energy obtained from the Shubnikov de Haas oscillation increases with decreasing channel width (w) of the InAs-based heterostructure. Since the surface charge concentration (n_s) depends only weakly on w, the channel width dependence of the spin splitting energy is attributed to variations in the spin-orbit interaction strength. The spin-orbit interaction parameter was found to be inversely proportional to $\sqrt{w}$ in the range of w = 2 - 64 μm (See Fig. 1). Our findings indicate that a strong spin-orbit interaction is induced in a narrow channel due to suppression of the spin precession length for a thin quantum well layer system.

In the second experiment, the gate control of the spin precession has been studied in a spin FET with top gate structure. The spin injector and detector are made of CoFe/Pd multilayer with perpendicular magnetization. After the magnetizations of the CoFe/Pd electrodes are aligned in the perpendicular to the device plane, non-local spin valve signal is measured as a function of top gate voltage (See Fig. 2). The non-local spin signal oscillates as the top gate electrode modulates the spin-orbit interaction parameter of the InAs quantum well.

3. Conclusions

In the first experiment, we have determined the channel width dependence of the spin-orbit interaction parameter and the spin splitting energy from direct observations of SdH oscillations. We found that the spin-orbit interaction parameter is inversely proportional to the square root of the width, whereas the total carrier concentration is independent of the channel width. In narrower channels the spin precession length is suppressed by the sidewall of the channel and the spin-orbit interaction becomes stronger. In the second experiment, the spin-orbit interaction parameter is modulated by using a top gate. The spin signal oscillates as the amount of the spin precession changes with applied gate voltage. This demonstrates the basic operation of the spin FET.



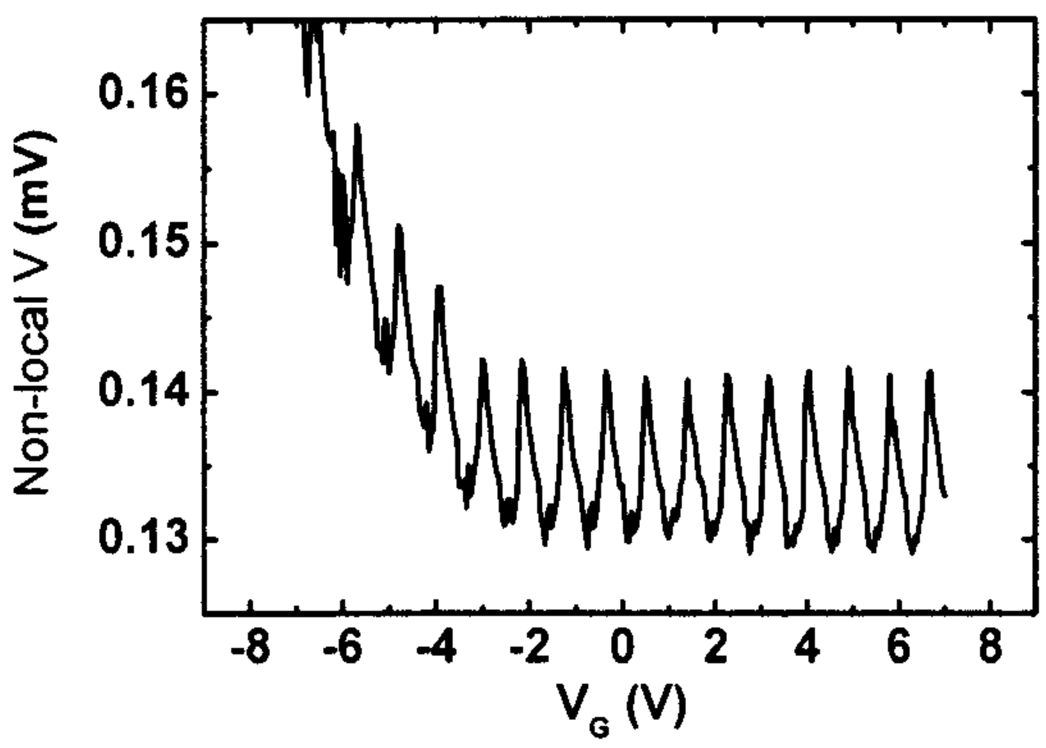


Fig. 1. Channel width dependence of the spin-orbit interaction parameter and the carrier concentration.

Fig. 2. Non-local spin signal as a function of top gate voltage in a spin FET (T= 1.8 K).

4. References

[1] S. Datta and B. Das, Appl. Phys. Lett. **56**, 665 (1990).