Nonmagnetic Control of Spin Transport in InGaAs quantum wells

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Abstract

We have studied the Rashba constant values α in the $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ quantum wells (QW), as a function of the degree of the structural inversion asymmetry (SIA), using the weak antilocalization analysis. We control the SIA of the QWs both by the specific sample design and by the applied gate voltage. The deduced α values are in a quantitative agreement with the theoretical values obtained in the $\mathbf{k}\cdot\mathbf{p}$-type calculation. We, then, propose a novel spin-filter device solely based on the Rashba effect as an example of the devices that utilize the Rashba spin-orbit coupling effect.

Key words: spintronics; Rashba spin-orbit coupling; spin filter;InGaAs/InAlAs

1. Introduction

There has been growing interest in the field of "spintronics", which involves exploration of the extra degrees of freedom provided by electron spin, in addition to those due to electron charges, with a view to realizing new functionalities in the future electronics devices. In the present paper, we introduce our recent achievement in non-magnetic controls of electron spin in the InGaAs/InAlAs material system using the Rashba spin-orbit interaction.

2. Weak antiloclization study of the Rashba constant α

It is believed that the value of the Rashba spin-orbit coupling constant α has a strong correlation with the degree of structural inversion asymmetry (SIA) of the quantum well (QW). In this regard, we prepared four

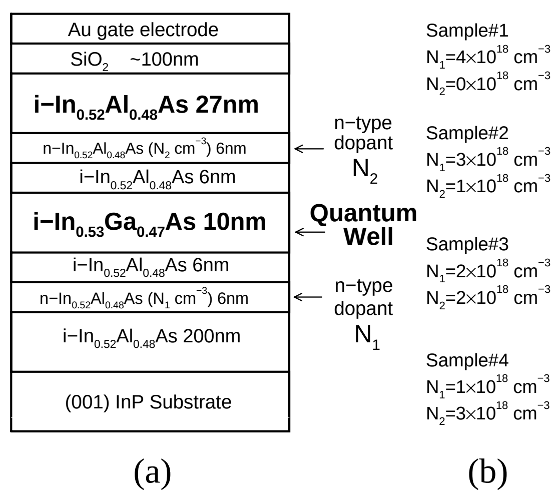

Fig. 1. (a) Schematic layer structures for the four samples we used in the present study. (b) Doping conditions for these four samples.

QW samples with different degrees of SIA as shown in Fig. 1, and studied the α values of these samples using the weak antilocalization analysis (WAL) (See Fig. 2) [1,2]. We found that the α values deduced from the

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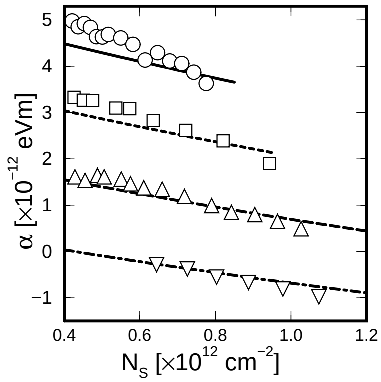

Fig. 2. The α values deduced from the weak antilocalization analysis for samples 1(open circles), 2 (open squares), 3 (open triangles) and 4 (open inverted-triangles) together with theoretical results using $\mathbf{k} \cdot \mathbf{p}$ formalism (the solid, short-dashed, long-dashed and dash-dotted curves denotes the results for samples 1-4, respectively).

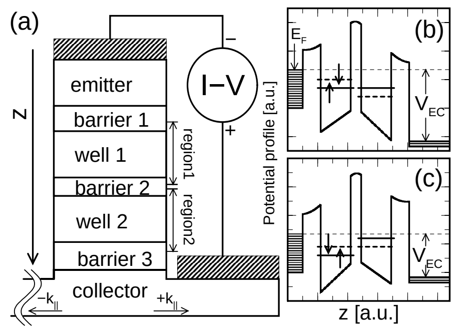

Fig. 3. (a) A schematic illustration of the proposed spin-filter device, where wells and barriers are made of $In_{0.53}Ga_{0.47}As$ and $In_{0.52}Al_{0.48}As$, respectively. The z axis is set vertically, pointing downward. The shaded areas denote the metal electrodes for the I-V measurement. (b)(c) Conduction band potential profiles for the proposed device to show how the matching of spin-dependent resonant tunneling levels is performed by controlling the emitter-collector bias voltage V_{EC}. The down- and upward arrows in region 1 denote the clockwise and counter-clockwise spin states, respectively.

WAL analysis agree with those predicted by the $\mathbf{k} \cdot \mathbf{p}$ calculation and that the spin relazxation of these samples are governed by the D'yakonov-Perel' mechanism [3,4].

3. Non-magnetic spin filter using a resonant tunnel structure

As a specific example for the devices that use the Rashba spin-orbit coupling, we have proposed a non-magnetic spin filter using a resonant tunnel structure. A sketch of the proposed device structure and illustrations of the operational principle of this device are given in Fig. 3. It is noted that we need to introduce n-type impurities in barriers 1 and 2 and

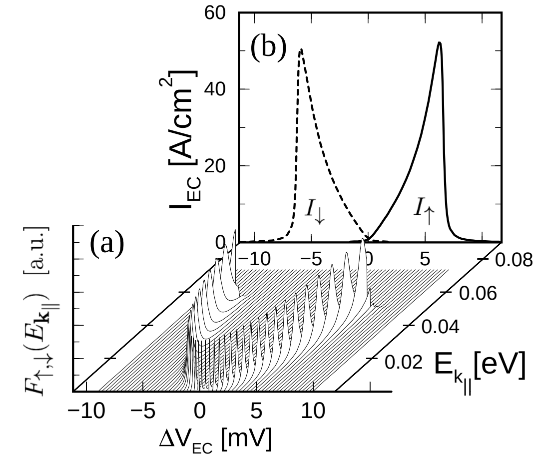

Fig. 4. (a) The calculated electron transmission, for the majority spin state, as a function the in-plane mode $E_{\mathbf{k}_{\|}}$ and the emitter-collector bias voltage V_{EC}. (b) The spin-dependent tunnel currents across the proposed device [$I_{\uparrow}$ for counter-clockwose spin (solid curve) and $I_{\downarrow}$ for clockwise spin (long-dashed curve)] as a function of the emitter-collector bias voltage ($\Delta V_{EC} = V_{EC} - V_{EC}$).

p-type impurities in barrier 2, respectively, to establish the "mountain-like" potential shape as illustrated in Fig. 3(b)(c).

The actual tunnelling current across this device is calculated using the transfer matrix method as a function of the emitter-collector bias voltage (See Fig. 4) [5–7]. We find that the separation between the two spin-dependent current peaks is sufficiently large (12 meV) for this effect to be observed in a real experiment and that spin filtering efficiencies exceed 99.9 % at the peak positions in the I-V curve.

Acknowledgements

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