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Rashba spin-orbit interaction due to wavefunction penetration in $In_{0.05}Ga_{0.95}As/GaAs$ quantum dots

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1. Introduction

A concept of spin-polarized field effect transistor (SPFET) has been proposed [1]. The key idea of the device is that spin-orbit interaction in a semiconductor quantum well causes the spins of the carriers to presses. The spin-polarized carriers are injected and collected by the ferromagnetic electrodes. The SPFET has been performed in a semiconductor heterostructure. The spin-orbit interaction is controlled by the carrier density, which is modulated by electric voltage [2]. Recently, we observed a wave function dependent spin-orbit interaction in a low potential barrier quantum dot. By applying electric voltage, electron wave function penetration through interface of quantum wells. Due to the different distribution of wave function at different electron states, the spin-orbit intensity increases significantly in this type of low barrier potential system.

2. Experiment, Results and Discussion

The heterostructure is grown by molecular beam epitaxy. The heterostructure consists of two 12-nm-thick $In_{0.05}Ga_{0.95}As$, which are interspersed between three GaAs layer, which are 6.5 and 9-nm-thick outer barrier and center barrier layers, respectively. Quantum dots are formed in a submicron scale pillar. The quantum dots and barriers are surrounded by Ti/Au Schottky bates. The geometric diameter of the quantum dot is 0.5 μm

The sample is mounted on a standard dilution refrigerator with base temperature of 6 mK. The effective electron temperature is about 0.1 K, which is estimated via the full width at half height of the resonance tunneling peak at low bias.

Figure 1 (a) and 1 (b) show the differential conductivity of electron tunneling spectrum as a function of source-drain voltage, V_{SD}, and side-gate voltage, V_g, at 9 T and 12 T, respectively. The differential conductance strength is indicated in color scale, blue and red meaning negative and positive slope, respectively. All of the corresponding energy states of tunneling peak are labeled by Fock-Darwin states. The notation of $|n,l,s>$ means the principal, orbital-angular-momentum, and spin quantum number. As shown in Fig. 1 (c), the spin splitting energies of ground and first excited orbital states from 9 T to 12 T. Both energies of ground and first orbital excited states increase with the increase of magnetic field increases. It also shows that the spin splitting of $|0,0>$ state is always larger than that of $|0,-1>$ state. This orbital dependent spin splittings can be explained by the influence of Rashba spin-orbital interaction.

Theoretically, we include the Rashba and Dresselhaus spin-orbit coupling into the standard parabolic potential model and assuming that the Rashba and Dresselhaus spin-orbit energies are smaller than the confined potential energy. As shown in fig. 2, this theoretical calculation of energy splitting energies, black lines, can well explain our experimental results. This numerical calculation shows that the Rashba spin-orbit interaction is 92 meVA, which is roughly four times larger than those in AlGaAs/GaAs heterostructure system.

It is well know that the Rashba spin-orbit coupling mainly originates in the effective electric field, resulting from the wave function penetration into interface. According to the KP pertubation theory, the counter-intuitive face is that the effective electric field stem from the valence-band structures, not from conduction-band profile [3]. The contribution of this effect is given by the band-edge offset weighted by the density of probability of the conduction electron at the interface. In case of symmetric or infinite potential barriers, the amplitudes of the envelope function both interfaces of the quantum well are the same; both contributions compensate and the effect of the wave function penetration is not obvious. A wave function in a quantum well can be pull toward one of the interface and change the density of probability at two interfaces by tuning the shape of the potential profile. This asymmetric wave

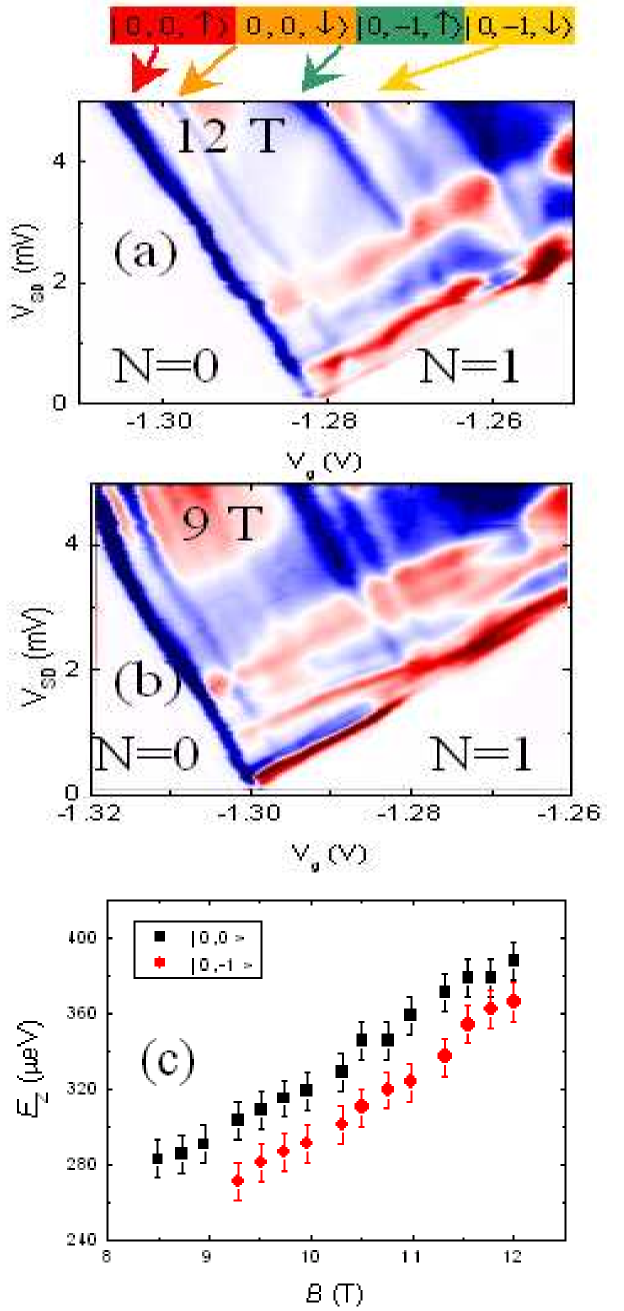

Fig. 1 (a)-(b) Defferential conductance peak lines from *N=0* to *N=1* as a function of side-gate voltage, V_g, and source-drain voltage, V_{SD}, at 9 T and 12 T, respectively. Following the Fock-Darwin states, the peak lines indicate ground and first excited orbital states. (c)Spin splitting energies of |0,0> and |0,-1> orbital states as a function of magnetic fields.

function penetration effect can explain the observation of the strong enhancement of Rashba spin-orbit interaction in a low barrier confined quantum well, $In_{0.95}Ga_{0.05}As/GaAs$ [4]. The enhancement magnitude of the penetration effect is also theoretical estimated and it shows a reasonable agreement with our experimental results.

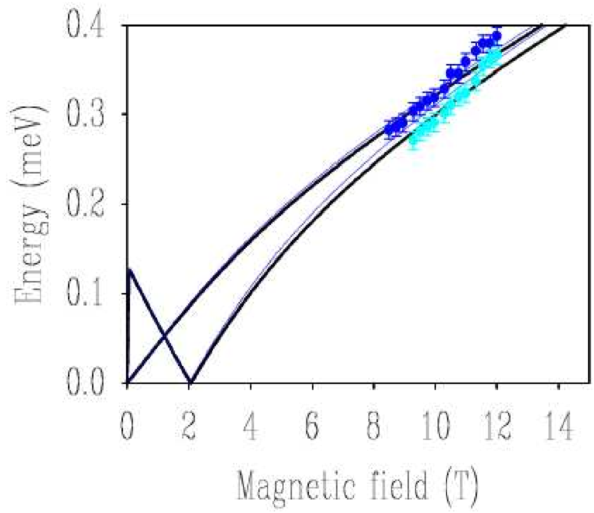

Fig. 2 Energy splittings of the first and second levels as a function of magnetic field. Thick lines are the theoretical results obtained from the numerical diagonaliztion.

3. Conclusions

We measured the spin splitting energies of the ground and first orbital excited states in an $In_{0.95}Ga_{0.05}As/GaAs$ quantum dot. Spin-orbit interaction causes the splitting energy of the ground state to be larger than that of the first orbital excited state. The numerical fitting of the results indicate that a strong Rashba spin-orbit interaction. The enhancement of the Rashba spin-orbit interaction can be understood from the high penetration of the electron wave function into the quantum well with low potential barrier structure.

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