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Presentation Title

Electrically tuned spin-orbit interaction and g-factor for implementing electron spin qubits with high performance

Abstract

We aim at applying spin-orbit interaction (SOI) to realize an electron spin qubit, which is the most robust and fast-operating ever reported so far. SOI converts the electric field to the effective magnetic field, providing a way of all electrical manipulation of electron spin. A strong SOI allows fast operation as recently reported in InAs nanowires. By raising the SOI strength and conversion efficiency further, high performance spin qubit with low power consumption can be realized. Therefore, the electrical control of SOI is indispensable but has not yet been realized in genuine quantum dots (QDs). In this presentation we show the electrical tuning of SOI and g-tensor in InAs QDs with strong SOI. We also examine the microwave spectroscopy of the QD from photon-assisted tunneling to realize the electric-field induced spin resonance in the QDs.

The devices are uncapped self-assembled InAs quantum dots with a back-gate and side-gate electrode (Fig. 1). We identified that for a relatively large InAs QD the side-gate nearby the QD can effectively tune the lateral potential profile and affect the parameters of the device such as the tunnel coupling with the leads while the back-gate mainly tunes the charge state in the QD. Used in combination with the back-gate the charge state of the device can be maintained while other properties are tuned.

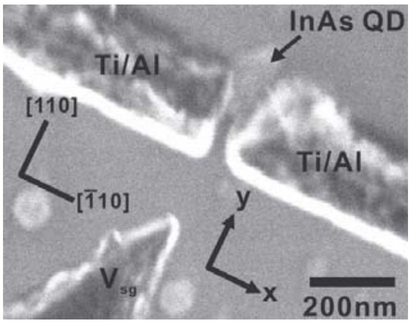

Fig. 1: Scanning Electron Microscope image of an InAs QD device

In InAs QDs, SOI hybridizes the two states with different orbital and opposite spin when these states are nearly in degeneracy. In our previous work, we have quantitatively evaluated the anisotropic SOI energy Δ_{SOI} by measuring the avoid crossing from excited state spectroscopy. Here, we observe directly the avoided crossing of the levels and Δ_{SOI} as a splitting of the high magnetic field Kondo effect. When the side-gate voltage is applied, the size of the splitting is changed and reaches to almost zero as shown in Fig. 2. This successfully indicates the electrical control of Δ_{SOI}. We observed that the tunability of the SOI energy varies depending on the charge state of the QD and is therefore strongly linked to the orbit state. We propose a mechanism for the tunability based on the angular anisotropy of Δ_{SOI} in which the electrical gating causes relative shifts the relative position of the wavefunctions of the two near degenerate orbital states.

We have also demonstrated that the Landé g-factor in the InAs QD can be regarded as a tenor and the g-factor anisotropy can be altered by the side-gate. The in-plane g-factor and its anisotropy are evaluated by measuring the magnetic evolution of the Coulomb peak separations at various in-plane magnetic field angles. We observed that the absolute g-factor is significantly modified by more than 50 % and the anisotropy is also altered when the side-gate voltage is changed. The detail analysis shows that g-tensor modulation resonance (g-TMR) with a Rabi frequency of 2 MHz is feasible in the QDs.

Finally we have measured the photon-assisted tunneling to examine the microwave (MW) efficiency on the InAs QDs. From the dependence of the pumped current on the power and frequency of MW applied on the side-gate, we evaluated the MW efficiency and found that the MW efficiency is high enough to realize fast single spin manipulation via SOI in our system.

In summary, we have demonstrated the electrically tunable SOI in single InAs QDs. This enables us to optimize the strength and anisotropy of SOI for realizing high performance electron spin qubits. We have shown the feasibility of g-TMR in QDs offers an alternative electron spin manipulation scheme without using magnetic field.

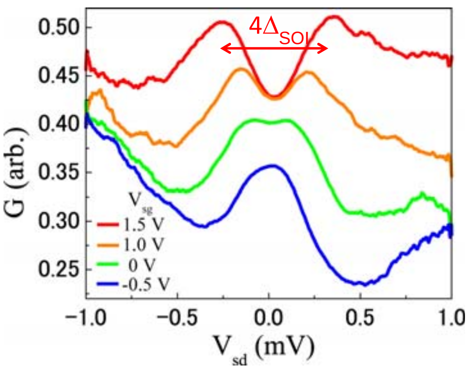

Fig. 2: Splitting of Kondo zero-bias anomaly at various sidegate voltages, indicating the electrical tuning of the SOI energy Δ_{SOI}