Sharp current suppression at the triplet resonant tunneling in a two-electron double quantum dot

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A two-electron system in a double quantum dot (DQD) provides the simplest and richest spin-dependent transport characteristics. The Pauli spin blockade (PSB) effect prohibits spin triplet (1,1)T states (one electron in each dot) to transfer to the doubly occupied singlet (0,2)S state. This effect disappears when doubly occupied triplets (0,2)T are energetically accessible. Here we focus on the triplet resonant tunneling from (1,1)T and (0,2)T, where a couple of sharp current dips on the top of the broad resonant tunneling peak are resolved. The experiment implies the importance of dynamic nuclear spin polarization (DNP), while the detailed mechanism of the sharp suppression remains veiled.

The system we focus upon involves four-fold (1,1) as well as three-fold (0,2)T and (0,2)S states in the transport window (Fig. 1(a)). Experimentally, current through a DQD fabricated in an AlGaAs/GaAs heterostructure is measured as a function of a gate voltage, which is converted into the energy detuning ε between (1,1) and (0,2)T. Current spectrum measured at magnetic field B = 100 mT exhibits clear PSB with a small leakage current (-400 μeV < ε << 0) and a triplet resonant tunneling peak (ε ~ 0), as shown in Fig. 1(b). Surprisingly, a sharp current dip appears around the top of the broad triplet resonant peak (marked by an arrow). This dip develops with increasing B up to a critical field B_C (~ 300 mT depending on the tunneling coupling t_P), above which the dip disappears and other multiple dips start to appear at slightly off-resonant conditions (ε < 0), as shown in Fig. 1(c).

In the absence of nuclear Overhauser effect, (1,1)S partially blocks the transport when the relaxation rate to the ground state (0,2)S is smaller than the triplet transport rate. The spectrum at B = 0 could be the case under the singlet spin blockade (SSB). At finite B (< B_C), net nuclear polarization arises from flip-flop transitions from (0,2)S, and actually the current enhancement (marked by a circle) suggests lifting SSB with an inhomogeneous Overhauser field ΔA. However, one of the eigenstates at ε = 0 remains close to the singlet □ $|(1,1)S\rangle - \frac{\Delta A}{t_P}|(0,2)T_0\rangle$ for small $\Delta A << t_P$. This explains the suppression of current (SSB) at ε = 0, but not the sharp ε dependence. Although detailed analysis with Overhauser field is required, an intriguing three-level resonance with different spin states is anticipated at ε = 0. Electron-nuclear dynamics plays a role even when the current is not completely suppressed.

[1] K. Ono et al., Science 297, 1313 (2002). [2] Y. C. Sun et al., Appl. Phys. Lett. 101, 263108 (2012).

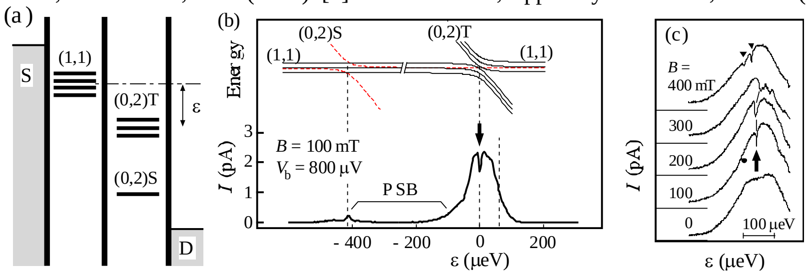

Fig. 1 (a) Energy diagram of a DQD. (b) Current spectrum. The inset shows a schematic energy diagram of singlet (dashed) and triplet states (solid lines). (c) Magnetic field dependence of the dip structure.