Complete lifting of spin blockade under unstable electron-nuclear dynamics

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Current suppression in the Pauli spin-blockade regime of a double quantum dot (DQD) is associated with triplet states orthogonal to the singlet state allowed for transport [1]. Here we report that such spin-blockade effect is completely lifted even in a conventional measurement, where dynamic nuclear spin polarization (DNP) gives rise to vanishing orthogonal spin states to the singlet. Unstable dynamics causing this unusual situation is studied by evaluating current levels and noise characteristics consistent with model calculations [2].

A two-electron DQD fabricated in AlGaAs/GaAs heterostructure shows typical spin-blockade characteristics with high non-blockaded current I_H (~ 800 fA in our device) in the reverse bias and lowest spin-blockaded current I_L (~ 30 fA) in the forward bias. Figure 1(c) shows a current trace at a forward bias (usually spin-blockade) during a slow sweep of energy detuning ε between (1,1)S and (0,2)S from negative ε, where (1,1) charge configuration is the ground state, to positive ε, where (0,2)S state is the ground state. The current increases stepwise at ε ~ -25 μeV and more dramatically at ε ~ -5 μeV reaching to the non-blockaded current level of I_H, which indicates the complete lifting of spin blockade. This behavior can be understood with highly non-linear DNP with nuclear spin polarization vectors $\vec{p}_L$ and $\vec{p}_R$ in the left and right dot, respectively. When significantly different Overhauser fields in both magnitude and direction are accumulated as shown in Fig. 1(a), the total fields $\vec{F} = g\mu_B\vec{B} + A_{HF}\vec{p}$ (thick arrows) of the two dots are no longer parallel. This is the case where all four eigenstates of the (1,1) charge states involve spin-singlet components, and thus spin blockade is lifted as illustrated in Fig. 1(b). Stability of the electron-nuclear feedback against its own statistical fluctuation plays an essential role in reaching this situation. In the case of negative ε, balanced polarization ($\vec{p}_L = \vec{p}_R$) is unstable, and DNP takes place dominantly only in one dot (assumed to be the left) to cancel the external magnetic field as shown in the left and central insets of Fig. 1(c). Further increase of ε triggers off another unstable dynamics causing significant transverse component of $\vec{p}_L$ (the right inset). This is consistent with the calculated DNP flow [small arrows in Fig. 1(d)] and current indicating the complete lifting of spin blockade.

[1] K. Ono et al., Science 312, 1634 (2002). [2] S. Sharmin et al., to be submitted.

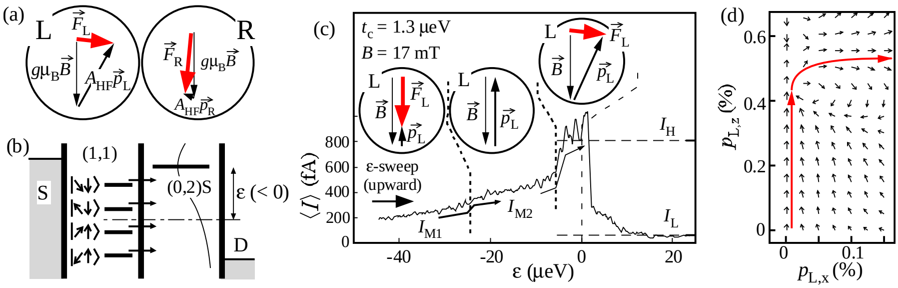

Fig. 1 (a) Total (thick arrows), magnetic (thin arrows) and Overhauser fields (middle-thick arrows) in the two dots. (b) Schematic energy diagram with non-orthogonal spin states to the singlet (0,2)S. (c) Current trace with complete lifting of Pauli-spin blockade ($I > I_H$). The developing fields in the left dot are shown in the insets. (d) DNP flow (small arrows) and a schematic trajectory (large arrows).