Hyperfine-induced Hysteretic Funnel Structure in Spin Blockaded Tunneling Current of Coupled Vertical Quantum Dots at Low Magnetic Field

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Abstract. We outline the properties of the hyperfine-induced funnel structure observed in the two-electron spin blockade region of a weakly coupled vertical double quantum dot device. Hysteretic steps in the leakage current occur due to dynamic nuclear polarization when either the bias voltage or the magnetic field is swept up and down. When the bias voltage is swept, an intriguing ~3 mT wide cusp near 0 T appears in the down-sweep position, and when the magnetic field is swept, the current at 0 T can be switched from “low” to “high” as the bias is increased.

Keywords: Quantum dots, Hyperfine interaction, Nuclear spin

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INTRODUCTION

Funnel structures in the tunneling current of coupled quantum dots are a signature of the influence of the hyperfine interaction and essentially map out the position of the singlet-triplet crossing points (S-T⁺ or S-T⁻) in the dot detuning- magnetic field plane where electron-spin nuclear-spin flip-flops can occur [1,2]. In most cases, the funnel structure is captured when either there is no significant pumping of the nuclear spin or prior to the onset of nuclear spin pumping so the nuclear field is fluctuating around zero.

Recently, Baugh and coworkers described an elegant method to determine the pumped nuclear field (BN) by sweeping the bias voltage (Vsd, controlling the dot detuning) through the spin blockade (SB) regime [3] of a coupled vertical quantum dot device and monitoring the position of hysteretic steps in the current at different magnetic (B-) fields [4,5]. The method was applied for a gate voltage close to where the N=1 and N=2 CB diamonds touch. We too observe hysteresis on sweeping Vsd up and down. Figure 1 also shows cuts for five different gate voltages through the SB region (identified i-v) with the out-of-dot-plane B-field stepped from -45 to +45 mT in increments of 3 mT. A clear funnel structure is revealed by plotting the residue in current Iup-Idown. The outer (inner) edges of the finite width funnel identify the current step on the up (down) sweep. The funnel is not strongly dependent on the gate voltage although the low-Vsd portion of the funnel that is visible depends on the extent of the CB.

On a subsequent cool-down, the funnel structure was examined in more detail. Figure 2 shows the funnel captured with the B-field stepped from -80 to +80 mT in increments of 0.4 mT (black traces). A dramatic cusp of width ~3 mT in the step position emerges near 0 T for down bias sweeps only (blue trace). Applying the method described in Refs. [4,5], the nuclear field BN is determined to be ~20 mT and is almost constant for B-fields in the range of 5-45 mT. Not only on sweeping Vsd, but sweeping the B-field also reveals a hysteretic funnel (see Fig. 3: sweep rate is 30 mT/min). As Vsd is made progressively more

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positive, interestingly, the current at zero field transitions from a “low” to a “high” state near $V_{sd} \approx 3$ mV [see Fig. 3 (a) traces p-t].

In summary, clear hysteresis in the leakage current due to dynamic nuclear polarization is observed when the bias voltage is swept and when the magnetic field is swept for which there are few reports (see Ref. 8 for coupled lateral quantum dots). Properties of the funnel structure captured may reveal microscopic details of how the nuclear field is pumped and what limits it.

FIGURE 1. Differential conductance in $V_{sd}$-$V_g$ plane in vicinity of chevron-shaped SB region at 0 T [positive (negative) conductance is black (white)], and funnel structure captured on sweeping $V_{sd}$ and stepping B-field for five different gate voltages identified i-v.

FIGURE 2. Black traces: inner and outer edges of funnel extracted at a gate voltage close to v in Fig. 1. Blue trace: also at the same gate voltage, inner edge of funnel revealed in a high-resolution measurement with 0.1 mT step size. Note the blue trace is expanded horizontally by a factor of four and shifted up by 1.5 mV for clarity.

FIGURE 3. (a) Selected traces of current on sweeping the B-field up and down at fixed gate voltage (close to v in Fig. 1) for five values of $V_{sd}$ identified in (b). (b) B-field position of current steps as bias voltage is stepped.

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REFERENCES