Observation of Hysteretic Transport Due to Dynamic Nuclear Spin Polarization in a GaAs Lateral Double Quantum Dot

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FMM
August 17, 2012

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Motivation

- understand / control interaction between electrons and host nuclei

- small difference in $B_{\text{loc}}$ in right and left dot affects the time evolution of the electron spins – sometimes welcome, sometimes unwelcome

- coherence time of electron spin is limited by fluctuation in $B_{\text{nuc}}$
Coulomb- & Pauli-Blockade, DNP

transport enhanced by fluctuations in $B_{\text{nuc}}$

Triplet evolves into Singlet: Pauli-Blockade can be lifted → nuclear polarization

$$\vec{B}_N = \frac{1}{g\mu_B} \sum_{i}^{n} A_i \vec{I}_i$$

statistical fluctuations, random direction: $$\|\vec{B}_N\| = \frac{B_{\text{pol}}}{\sqrt{n_{\text{nuc}}}}$$

Koppens et al., Science 309, 1346 (2005)
Similar things seen before ...

- lateral DQD, direct transport
- **resonant** current is hysteretic in the sweep direction
  

- $^{13}$C nanotube DQD
- net nuclear polarization induced by electron spin flips
  
  H.O.H Churchill et al., Nat Phys **5** (2009)

- vertical DQD
- attributed to $T_+ - S_U$ mixing at positive detuning
  
Sample

- 2DEG: 80 nm deep
- \( n = 2.2 \cdot 10^{11} \text{ cm}^{-2} \)
- \( \mu = 2 \cdot 10^6 \text{ cm}^2/\text{Vs} \)
- \( V_{sd} = -800 \ \mu \text{V} \)
- inter-dot tunnel coupling \( t : V_C \)
- in-plane magnetic field \( B_\parallel \)
- (asymmetric) QPC to read-out \((m,n)\)
Bias triangles and relevant states

- $(1,1)$-$(2,0)$ transition
- negative bias
- CB at negative detuning
- suppression of $I_{\text{dot}}$ at positive detuning $\rightarrow$ Pauli blockade

upper right: $(1,1)$-$(2,0)$-$(2,1)$-$(1,1)$
lower left: $(1,1)$-$(2,0)$-$(1,0)$-$(1,1)$

$\rightarrow$ both sequential tunnel processes are blocked once a triplet state is occupied
Hysteretic features

top: leak currents at $B = 0$ and $\varepsilon = 0$ originate from NS-mediated processes (T-S crossing). Only small contributions of NS-free processes.

observed hysteretic behavior at large negative $\varepsilon$ suggests DNP (by flip-flop)

calculated position of the $T_+ - S_L$ crossing (see (b)):

$$2|g^*|\mu_B(B_\parallel - B_0) = \sqrt{8t^2 + \varepsilon^2 + \varepsilon}$$
**Proposed model**

$T_+ - S_L$ crossing has been previously observed but not in DC transport in the CB regime ($\varepsilon < 0$), which prohibits the charge transfer from (1,1) to (2,0).

Further, $I_{\text{dot}}$ increases with $B_{\|}$.

**Model:** CB is lifted by making the transition from (1,1) to (1,0) through $S_L$, without (2,0)S.

$S_L$ has a finite (2,0)S component at $\varepsilon < 0$ for finite $t$, given by $c(t,\varepsilon)$. DNP generates imbalance in the NS polarization between left and right dot and therewith enhances $I_{\text{dot}}$ $\rightarrow$ positive feedback.
More data

- DNP visible for \( V_C >= -1.21 \text{ V} \)
- \( V_C \) more positive \( \rightarrow \) \( t \) larger \( \rightarrow \) DNP better visible / on a larger range of detuning

\[
c(t, \varepsilon) \equiv |\langle (2, 0) S | S_L \rangle|^2 = \frac{1 + (\varepsilon/t)/ \sqrt{(\varepsilon/t)^2 + 8}}{2}
\]
new hysteretic transport feature observed in the CB regime – attributed to DNP due to $T_+^{-}-S_L$ crossing, explained by a model where $T_0$ has a finite $(2,0)S$ component at $\Delta B_N^Z \neq 0$. Spin-Blockade is lifted.

strong imbalance between the $B_{nuc}$ in the left and right dot.