Single-Shot Measurement of Triplet-Singlet Relaxation in a Si/SiGe Double Quantum Dot

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Introduction

✦ singlet-triplet system in a double quantum dot
✦ lifetime of two-electron spin state investigated
✦ single-shot readout and lifetime measurements of s-t system in SiGe
✦ Si/SiGe heterostructure

- lattice constants 0.543nm and 0.564nm: strained layers
- indirect bandgap
- $m_T=0.19$ and $m_L=0.98$
- doped with phosphorus
- isotopes without nuclear spin exist e.g. $^{28}\text{Si}$
Setup, sample and pulse scheme

- Si/Si$_{0.7}$Ge$_{0.3}$
- Quantum well 75nm below surface
- Palladium gates
- Base temperature 15mk, $T_e=?$
- Gate pulsing 100Hz to 1GHz
- Charge sensing: $\Delta = 1$kHz

- Initialize in S(0,2) state
- Pulse to (1,1) configuration
- Read out at (0,2)
- Spin block, reg. by charge sensor

$\tau_c = 2.8 \pm 0.3 \mu$eV
Read-out and B-field dependence

- spin block. reg. by charge sensor
- signal amp. quite low, but SNR good
- different starting points of the pulses
- vary magnetic field $B_{||}$
Results & Interpretation

- Statistics for (un)blocked times
- Extract characteristic times
- B-field dependence
- Different "channels" observed

![Graphs showing time dependence](image)
times in blockade due to $S_{11}$ and $T_0$ are field independent

characteristic time in blockade due to $T_-$ increases with field
Zero field rate equations

\[ P_R = e^{-T/\tau_u} \]  \text{probability for remaining unblock during one single pulse cycle}

\[ P_N = e^{-T/\tau_b} \]  \text{probability for being blocked}

T = period of one pulse cycle, for \( t < T/2 \quad \varepsilon < 0 \) \quad \text{while for} \ T/2 < t < T \quad \varepsilon > 0

Physical mechanisms are inter-dot tunneling between \( S_{11} \) and \( S_{02} \) and S-T mixing due to hyperfine interaction

Mixing rate will depend on S-T splitting \( J \approx \frac{t_c^2}{\varepsilon} \)

Important point is to take into account that detuning is change during the pulse !!!

For first half of pulse mixing between the triplet states and \( S_{11} \) is allowed with rate \( \rho_- \)

For second half of pulse mixing between the triplet states and \( S_{02} \) is allowed with rate \( \rho_+ \)

Included states are \( S_{11} \ T \ T_0 \ T_+ \) and \( S_{02} \) with probability \( p_1, p_2, p_3, p_4 \) and \( p_5 \)
Zero field rate equations

\[ \dot{p}_1(t) = (p_2(t) + p_3(t) + p_4(t) - 3p_1(t)) \rho_- \] (3)
\[ \dot{p}_2(t) = (p_1(t) - p_2(t)) \rho_- \] (4)
\[ \dot{p}_3(t) = (p_1(t) - p_3(t)) \rho_- \] (5)
\[ \dot{p}_4(t) = (p_1(t) - p_4(t)) \rho_- \] (6)
\[ \dot{p}_5(t) = 0 \] (7)

\[ \dot{p}_1(t) = 0 \] (8)
\[ \dot{p}_2(t) = -p_2(t) \rho_+ \] (9)
\[ \dot{p}_3(t) = -p_3(t) \rho_+ \] (10)
\[ \dot{p}_4(t) = -p_4(t) \rho_+ \] (11)
\[ \dot{p}_5(t) = (p_2(t) + p_3(t) + p_4(t)) \rho_+ \] (12)

- Numerically solve equations to get \( P_N \) and \( P_R \) as function of \( \rho_+, \rho_- \)
- Optimize values to best match measured \( P_N \) and \( P_R \)

\[
P_R = p_5(T)
\]
\[
P_N = \sum_{n=1}^{4} p_n(T)
\]
Summary & Outlook

+ single shot readout and spin lifetime measurements in Si/SiGe

+ well know pulse scheme, (0,2) - (1,1), standard method for new system

+ spin lifetime as a function of a parallel magnetic field

+ $B=0$: lifetime 5-25ms or 2 order of magnitude more than in GaAs

- characteristic time in blockade due to $T_-$ increases with field
- charac. times in blockade due to $S_{11}$ an $T_0$ are field independent