The Dynamic Nuclear Environment in a Double Quantum Dot

D. J. Reilly\textsuperscript{1}, J. M. Taylor\textsuperscript{2}, E. A. Laird\textsuperscript{1}, J. R. Petta\textsuperscript{3}, C. M. Marcus\textsuperscript{1}, M. P. Hanson\textsuperscript{4} and A. C. Gossard\textsuperscript{4}

\textsuperscript{1} Department of Physics, Harvard University, Cambridge, MA 02138, USA
\textsuperscript{2} Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
\textsuperscript{3} Department of Physics, Princeton University, Princeton, NJ 08544, USA
\textsuperscript{4} Department of Materials, University of California, Santa Barbara, California 93106, USA

Bahram ganjipour
Friday Morning Meeting
Jan. 18. 2008
Outline

- Motivation.
- Experiment Setup.
- Results.
Motivation

• GaAs/AlGaAs has non-zero nuclear spin → fluctuating effective Field $B_{\text{nuc}}$!

• Electron spin dephasing.

• Spin relaxation at a low applied field $B < B_{\text{nuc}}$.

→ investigation of Fluctuating nuclear field important
Experiment setup

Double QD is formed by:

- Ti/Au top gate an GaAs/Al$_{0.3}$Ga$_{0.7}$As
- 2DEG density : $2 \times 10^{15}$m$^{-2}$
- Mobility : 20m$^2$/Vs
- T:=120mK
- $G_{QPC}$ of rf-QPC is sensitive to the charge configuration.
Smaller negative detuning: Singlet and $T_+$ are degenerate.
Charge Configuration

rf-QPC readout, $V_{rf}$, around the (1,1)-(2,0) transition

- Inside the readout triangle triplet states remain blocked in (1,1), (B=0mT, $\tau_S = 25$ns)
Singlet Probability

- Average value of $P_S(\tau_S)$ at $B = 0, \tau_S = 2$ s. Red line is a fit to the theoretical gaussian form.

Average value of $P_S(\tau_M)$ showing contrast dependence, $\tau_S = 50$ ns.
Fluctuations of $P_S$

rf-QPC sensor output $V_{rf}$ as a function of $V_L$ and $V_R$

Similar to (b) but for $B = 0$

Similar to (b) but with S point at S-T$_+$ degeneracy, $B = 100$ mT
Power spectra of $P_s$

- BG measurement noise, $\tau_S = 1\text{ns}$ (1/f form)

For $B > 20 \text{ mT}$, the spectra become independent of $B$
Modeling the Fluctuation of $P_s$

- Theoretical assumptions:
- Dynamic Overhouser field → Fluctuations of $P_s$
- The classical Langvein eq., is used
- For $B >> B_{\text{nuc}}$, correlations of the Overhauser field can be evaluated analytically in terms of a dimensionless operator $A_{\beta z}$ for each nuclear spin species $\beta$,

$$\sum_{\beta} x^{\beta} \hat{A}_{\beta z} \equiv B_{nuc, z}^{l}/B_{nuc}$$

, similarly for right dot, with $x^{75}_{\text{As}} = 1, x^{69}_{\text{Ga}} = 0.6, x^{71}_{\text{As}} = 0.4$

$$\langle \hat{A}_{\beta z}^\beta (t + \Delta t) \hat{A}_{\beta z}^\beta (t) \rangle = \left[ (1 + \Delta t D_{\beta}/\sigma_z^2) \right]^{1/2}$$

$\Delta t$: time difference

$D_{\beta}$: the species-dependent spin diffusion coefficient.

$\sigma_z$: wave function perpendicular to 2DEG

$\sigma_\perp$: wave function in the plane of 2DEG

Finally autocorrelation →

$$\langle P_S(t + \Delta t)P_S(t) \rangle - \langle P_S \rangle^2$$

$$= \frac{e^{-4G^2\langle \Delta \hat{A}_{\beta z}^2 \rangle}}{4} \left[ \cosh(4G^2\langle \Delta \hat{A}_{\beta z}(t + \Delta t) \Delta \hat{A}_{\beta z}(t) \rangle) - 1 \right]$$

$$\langle P_S \rangle = \frac{1}{2}[1 + e^{-2G^2\langle \Delta \hat{A}_{\beta z}^2 \rangle}]$$

$G = \tau_S/T_{2}^*$
Modeling the Fluctuation of $P_S$

A fit of autocorrelation data at $B=100\,\text{mT}$

The fit parameters: $C$ (contrast factor) and $D$ (diffusion coefficient),

$\sigma_z = 7.5\,\text{nm}$, $\sigma_\perp = 40\,\text{nm}$ (from numerical simulation)

the fit gives $D \sim 10^{-13}\,\text{cm}^2/\text{s}$,
Effect of Power spectra of $P_s$
Summary

• $\tau_s$ acts to filter fluctuation:
  when $\tau_s>>T_2^*$, Low frequency correlations in $\Delta B_{\text{nuc}}$ are suppressed in Spectra of $P_s$.

• Experiment and theory both show reduced low-frequency spectral content as $B$ decreases toward zero.

• Fluctuations are found to be broadband over the measurement bandwidth, 40 mHz to 1 kHz, and sensitive to an applied magnet field in the range $B = 0$ to 20 mT.
Thanks