A Coherent Beam Splitter for Electronic Spin States

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Main Point

- Coherent control of electronic spin states demonstrated by sweeping the detuning back and forth through the $S-T_\uparrow$ anti-crossing
Sample & Dings

- GaAs/AlGaAs
  - 2DEG 110 nm below surface
  - n = 2 \times 10^{11} \text{ cm}^{-2}, \mu = 200,000 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}

- Ti/Au gates
  - 3 QD pattern \rightarrow 2 QDs + 1 QPC
  - QPC defined by Q_1 and Q_2
    - g_Q measured with 1 nA bias (standard lock-in technique)
    - lever arm = 0.16 \mu\text{eV}\text{mV}^{-1} \rightarrow T_e = 90 \text{ mK} (T_{MC} = 8 \text{ mK})
Sample & Dings

- **Ti/Au gates**
  - pulsing of L and R to move between points in charge stability diagram
    - ~1.1 ns voltage pulses smoothed with passive filters
    - interested in \((N_L, N_R) = (1,1)-(2,0)\) transition

- **Anti-crossing due to hybridization**
  - gap = \(2\Delta\)
  - in this experiment, \(|0\rangle = |S\rangle\) and \(|1\rangle = |T_{+/}\rangle\)

- **Perpendicular magnetic field**
  - controls \(T_-, T_0, T_+\) Zeeman splitting
Measurement of $2\Delta$

- Initialize $(2,0)S$ state at point $P$
  - $[P_S = 1]$
- Move quickly to $\varepsilon_{P'}$
- Pulse to $\varepsilon_S$ (preserves singlet)
- Ramp back to $\varepsilon_{P'}$ over time $T_R$
- Measure $P_S$
Measurement of $2\Delta$

- **Long $T_R$** approaches adiabatic limit
  - should yield $P_S = 0$ (i.e., triplet)
  - spin relaxation repopulates singlet
    (therefore, $P_S$ minimum $\sim 0.3$)

- **Short $T_R$**
  - exponential $\rightarrow$ Landau-Zener*
  - ramp-rate dependent transition
    probability, $P_{LZ} \sim \exp[-2\pi\Delta^2/\hbar v] \sim e^{-T_R}$
  - $2\Delta = 120$ neV

* arXiv:0911.1917v1
Beam Splitting & Interference

- Method:

\[ \phi = \frac{1}{\hbar} \int \{ E_S[\epsilon(t)] - E_{T+}[\epsilon(t)] \} dt \]
Unitary Operations

\[ U |S\rangle = \left( \begin{array}{c}
\sqrt{1 - P_{LZ}} e^{i(\phi_S - \pi/2)} \\
- i\sqrt{P_{LZ}} \\
i\sqrt{P_{LZ}} \\
\sqrt{1 - P_{LZ}} e^{-i(\phi_S - \pi/2)}
\end{array} \right) \left( \begin{array}{c} 1 \\
0 \\
0 \\
0 \end{array} \right) = \left( \begin{array}{c}
\sqrt{1 - P_{LZ}} e^{i(\phi_S - \pi/2)} \\
i\sqrt{P_{LZ}} \\
\end{array} \right) \]
Interference of Two Beams

- $P_S$ as a function of $\tau_S$ for $\varepsilon_S$ amplitudes
  - $B_E = 100$ mT
- St"uckelberg oscillations
  - $P_S \sim 1 - 4P_{LZ}(1-P_{LZ})\sin^2(\phi_S/2)$ ?

![Graph showing interference of two beams with plots illustrating the relationship between $P_S$, $\varepsilon$, and $\tau_S$.](image)
Interference of Two Beams

- Full picture of $\tau_S$ and $\varepsilon_S$
- Bright fringe corresponds to alignment of $\varepsilon_S$ with $S-T_+$
**B_E Dependence**

- Negative shift of \( \varepsilon_S \) and lower frequency
Conclusions

• Beam splitter realized by sweeping $\varepsilon$ through the (1,1)-(2,0) transition of a two-electron, double QD system

• Coherent rotations between singlet and triplet states...
  – occur on nanosecond timescales
  – controllable by local gate voltage pulses
  – feasible to scale up