Spin orbit coupling at the level of a single electron


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Outline

• Experimental setup
• Interdot tunneling
• Tunneling rates
• Spinflip probability
• Confirmation of results
• Conclusion
Experimental Setup

- GaAs/GaAlAs heterostructure 90 nm below surface
- Metallic top gates on surface
- Tunnel barrier below 100Hz
- Last electron regime
- No coupling to the reservoirs
- QPC detecting charge state of the dots
Charge Sensing

- QPC is sensitive for the charge state in the QD next to it.
Interdot Tunneling

- Tunelling from dot to reservoir (solid line)
- Interdot tunneling between the quantum dots (fine line)
Single Electron in Dot

- Tunneling rates in directions $(1,0) \rightarrow (0,1)$ are the same as $(0,1) \rightarrow (1,0)$
- Exponential decrease in tunnel events with increasing waiting time
Two Electrons in Dot

- Back and forward tunneling rates between (2,0) -> (1,1) differ by a ratio of 1:4
- At B = 30 mT the spin orbit coupling dominates over the coupling to the core spins
Two Electron States

- (2,0)S singlet state with two electrons in sensed dot
- 4 (1,1) degenerate basis states
- Without magnetic field interaction with core spins randomizes spin direction
- 30mT Magnetic field induces Zeeman splitting lifting degeneracy of (1,1) states by 0.75μeV (thermal energy 5μeV)
• Transition between (2,0)S and |↑↓> and |↓↑> with the spin-conserving tunneling rate \( \Gamma_C \)
• Transition between |↑↑> and |↓↓>, and (2,0)S are spin blocked
Spin Blockade

- Transitions between $|\uparrow \uparrow>$ and $|\downarrow \downarrow>$ and $(2,0)S$ are only possible by spinflip tunneling with rate $\Gamma_{SO}$ or an internal spinflip with rate $\Gamma_{SI}$ and consecutive tunneling with rate $\Gamma_C$. The spinflip rate including both processes is $\Gamma_S$. 
Spinflip Probability

- Spinflip rate is linear with the spin-conserving tunneling rate over two orders of magnitude (@B = 30 mT)
- The offset in spinflip rate at different fields is due to $\Gamma_{S_l}$
  Linearity at B = 30 mT
  $\Rightarrow \Gamma_S = \Gamma_{SO}$ and $\Gamma_S / \Gamma_C = 0.04$
Spinflip Rate Fidelity

• Fraction of missinterpreted events:
  
  \[(1-p)e^{-\Gamma_c \tau} + p(1-e^{-\Gamma_s \tau})\]

• \(p = \frac{\Gamma_c}{(\Gamma_c + \Gamma_s)} = 0.04\), with \(\Gamma_s \ll \Gamma_c\)

• the waiting time to distinguish tunneling events to minize the error
  \(\tau = -\Gamma_c^{-1} \ln(p^2)\)

Fidelity of 99%
Open Circuit(1)

- Bias voltage at reservoirs
- Interdot tunneling rate $\Gamma_C < 10$ Hz
- Tunneling rates to reservoir $\Gamma_R \sim \Gamma_L \approx 60$ Hz
- $B = 30$ mT
• Tunnel rate ratio $(2,0)\rightarrow(1,1): (1,1)\rightarrow(2,0) = 1:20$

• $\Gamma_{SO} \ll \Gamma_C \ll \Gamma_{L,R}$

• $I_{\text{fwd}} = e \Gamma_C$ and $I_{\text{rev}} = 4e \Gamma_{SO}/3$

• $\Gamma_{SO}/\Gamma_C = 0.038 \pm 0.002$
Conclusion

• Extraction of probability $\Gamma_s/\Gamma_c=0.04$ per tunneling event in interdot tunneling in closed DQD system

• Spinflip tunneling occurs due to spin orbit interaction

• Confirmation of found spinflip rates at a fidelity of 99 % and in open DQD system
Thanks for your attention!