Long Spin Relaxation and Coherence Times of Electrons in Gated Si/SiGe Quantum Dots

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- Introduction
- Setup and Device Fabrication
- Electron Spin Resonance in QD
- Summary
Spin qubit in Quantum Dot

GaAs quantum dot
$T_2$ limited by nuclear spins

Si quantum dot
- (Expected) long $T_1$ and $T_2$
  - a. weak hyperfine
  - b. small spin-orbit coupling
- Integration with current microelectronics

Petta, et al., Science 2005
Ensemble ESR in $^3$He system

- Ensemble measurement: $10^8$ unpaired spins
- Zeeman Splitting: $0.35 \text{ T} \sim 10 \text{ GHz} \sim 0.46 \text{ K}$
- ESR: $g$-factor $\sim 2$
  linewidth $\sim 100 \text{ mG}$
Device Fabrication

- Undoped natural Si/SiGe: 
  \( \mu > 800,000 \text{ cm}^2/\text{Vsec} \)
  \( n_e \approx 10^{10} /\text{cm}^2 \)
- \( 2 \times 10^8 \text{ dots/cm}^2 \approx 1 \text{ cm}^2 \text{ total area} \)
- Al - Al\(_2\)O\(_3\) (100 nm) - Si/SiGe: low gate leakage

Quantum well 200 nm below the surface
\[ \Delta V_g = V_{\text{top}} - V_{\text{bottom}} = 1.5 \text{ V} \]

~15 meV
\[ \Delta E \approx 1 \text{ meV} \]
Confining Electrons

- Both gates can control $n_e$
- 2DEG (2 valleys) ~ $2.4 \times 10^9$ spins
- QD (1 spin/dot) ~ $1.2 \times 10^8$ spins

$$\frac{\text{Sig}_{2\text{DEG}}}{\text{Sig}_{\text{QD}}} \sim 20 \pm 7.7$$

- Resolve single electron transitions?
$T_1$ and $T_2$ of Electrons in QD

- Echo intensity ratio:
  \[ \frac{I_{2DEG}}{I_{QD}} \sim 17 \]
- Curie dependence

Hahn-echo decays at 0.35 K, 0.5 K, 0.8 K

- $T_1 \sim T_2 \sim 250$ us
- $T_2 \downarrow$ as temperature $\uparrow$
  $T_1$ does not
$T_1$ and $T_2$ vs Gate Voltages

$T = 0.35 \text{ K}$
Spin Relaxation and Decoherence in QD

- Single Phonon: \( T_1 \sim \Delta E^4 / B^7 \)
- \(^{29}\text{Si}\) hyperfine: \( T_1 \gg T_2 \)
- Exchange or dipolar interaction

- Valley splitting?
- Many electron dots?
- Stark effect?
Summary

- Fabricated a large area double gated device on Si/SiGe for ensemble ESR
  - i) low gate leakage
  - ii) 2DEG and QD

- $T_1$ and $T_2$ of high mobility 2D electrons
  - $T_1 \sim 10 \, \mu s$, $T_2 \sim 6.5 \, \mu s$ at $T = 0.35 \, K$

- Single spin qubits in QD
  - $T_1 \sim 250\mu s$, $T_2 \sim 250 \, \mu s$
  - weak dependence on temperature
  - strong dependence on confinement energy

- Relaxation and decoherence not yet understood