Hole Spin Qubit in Ge Hut Wire

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Ge Hole Spin Qubit

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Watzinger et al., Nano Lett. 16, 6879 (2016)
Motivation

- electrically controlled and scalable qubits
- intrinsically strong (and tunable) spin-orbit interaction of holes
  - especially in Germanium/Silicon nanowires
- long spin lifetime and dephasing time (reduced contact hyperfine interaction)
  - due to large HH-LH splitting even longer than in cylindrical nanowires

- study on nature of heavy-hole states in Ge hut wires\(^2\)
- study on spin states in quantum dots in Ge hut wires\(^3\)

\(^2\) Watzinger et al., Nano Lett. 16, 6879 (2016)
\(^3\) Li et al., APL 110, 133105 (2017)
• Stranski-Krastanow growth of Ge on Si buffer layer
  • 3-5 nm thick cap of Si to prevent oxidation
• length 1 μm, triangular cross section
• only [100] and [010] crystal direction

Fig: schematic band structure of the hut wire

Fig: Theory

Fig: STEM and AFM images

References:
[1] Zhang et al., PRL 109, 085502 (2012)
[3] Li et al., APL 110, 133105 (2017)
EDSR spectroscopy

- resonance condition
  $$f_{\text{drive}} = f_{\text{Larmor}} = g\mu_B B/h$$
- strong g-factor anisotropy

Fig: (a) Bias triangles show Pauli spin blockade
(b) Zero detuning current as function of drive frequency and magnetic field\(^\text{[1]}\)

Fig: g-factor anisotropy\(^\text{[1]}\).
\(\phi\): angle between [100] and B-field

Coherent Rabi Oscillations

- initialize in triplet state
- apply microwave burst of duration $\tau_{\text{burst}}$ in Coulomb blockade
- spin readout in spin blockade region
- Rabi frequency up to 140 MHz

**Fig:** Rabi oscillations (B = 127 mT, $f_{\text{drive}} = 5.96555$ GHz)$^{[1]}$

Ramsey

- apply two $\frac{\pi}{2}$ pulses with delay $\tau_{\text{wait}}$
- average $T_2^* \approx 130$ ns

Fig: Ramsey fringes ($P_{RF} = 11$ dBm, $B = 127$ mT, $f_{\text{drive}} = 5.96555$ GHz)\[1\]

Single Shot Readout

- three stage pulsing sequence for spin to charge conversion
- fidelities:
  - spin-down: 0.832 ± 0.005
  - spin-up: 0.923 ± 0.008
  - charge readout: 93 %
- probably limited by $T_1$
  - $88 ± 5\mu s$ at 500 mT
  - $32 ± 2\mu s$ at 1100 mT

Coupling to Superconducting Resonator

- $\frac{\lambda}{2}$ alumina resonator
  - 5.972 GHz
  - quality factor 810
  - $\frac{\kappa}{2\pi}$ = 7.37 MHz
- $\frac{\gamma}{2\pi}$ = 6 MHz
- hole resonator coupling $\frac{g_c}{2\pi}$ = 148 MHz
- spin-resonator coupling $\frac{g_s}{2\pi}$ = 2-4 MHz

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[1] Li et al., Nano Lett. 18, 2091 (2018)
Summary and Outlook

• Ge hut wire: CMOS compatible platform, isotopic purification, strong SOI
• electric dipole spin resonance in double quantum dot
  • Rabi frequency 140 MHz
• Ramsey experiments: $T_2^* \approx 130$ ns

• Single shot readout
• coupling to microwave resonator

• strong spin-resonator coupling?
• long-range coupling and spin entanglement?
Pauli Spin Blockade

(a) Diagram showing levels $S(2,0)$, $S(1,1)$, $T(2,0)$, and $T(1,1)$.

(b) Contour plots for $V_{SD} = -2$ mV and $V_{SD} = 2$ mV.

(c) Graph showing current $I$ as a function of energy $\epsilon$ for $V_{SD} = 2$ mV and $V_{SD} = -2$ mV.