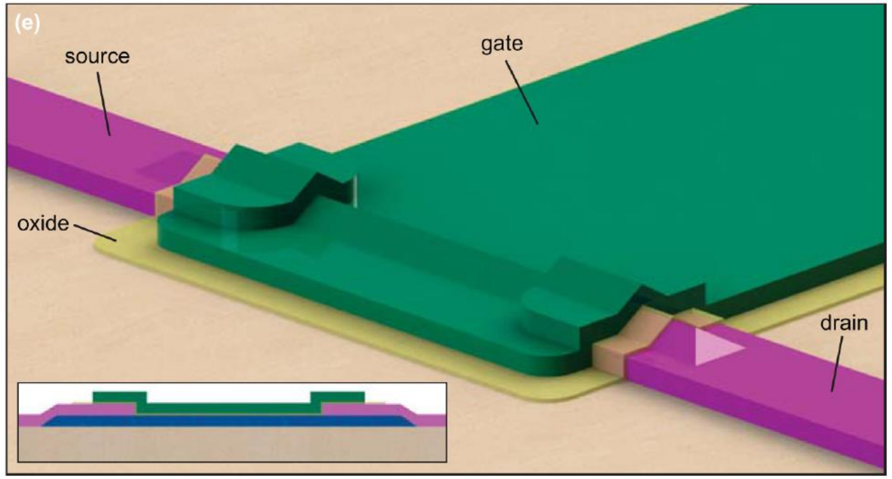
Hole Spin Qubit in Ge Hut Wire

TAM talk - Florian Froning – 24.05.2018



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

Ge Hole Spin Qubit

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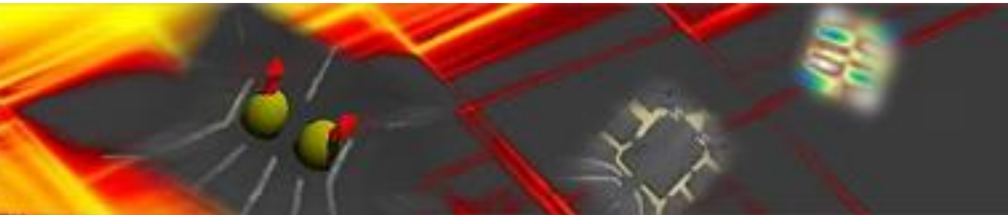
11.04.2018

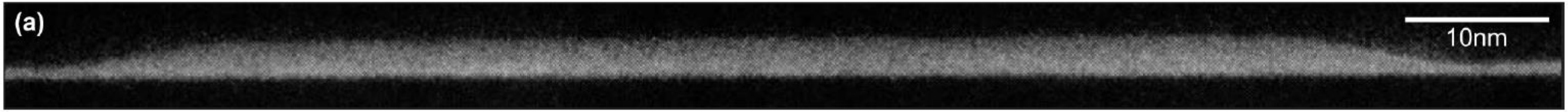
Motivation

- 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

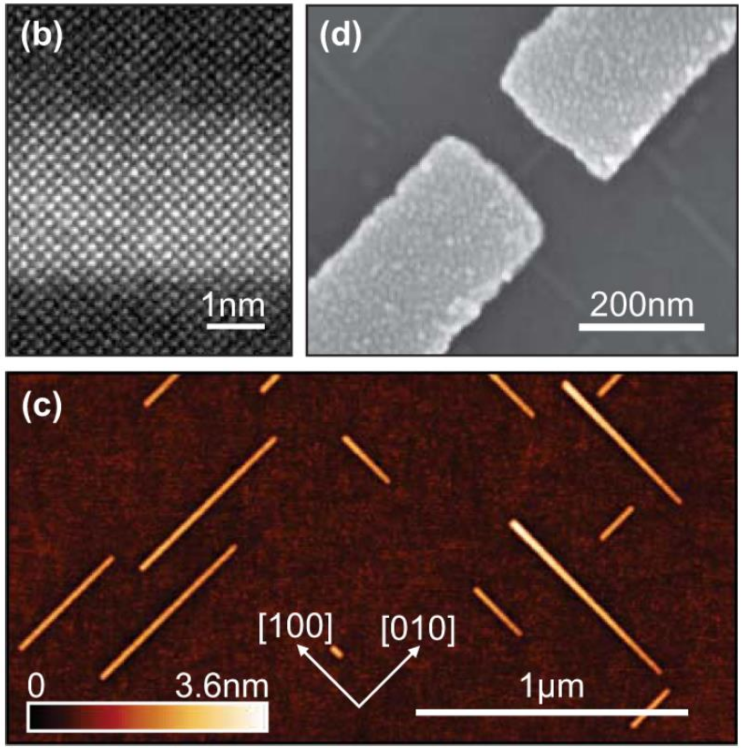
- study on nature of heavy-hole states in Ge hut wires[2]
- study on spin states in quantum dots in Ge hut wires[3]



[1] C. Kloeffel, D. Loss, Annu. Rev. Condens. Matter Phys. **4**, 51 (2013)
[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



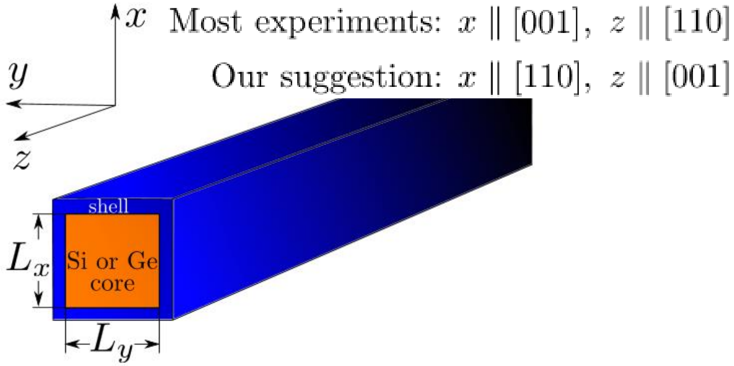


Fig: Theory[4]

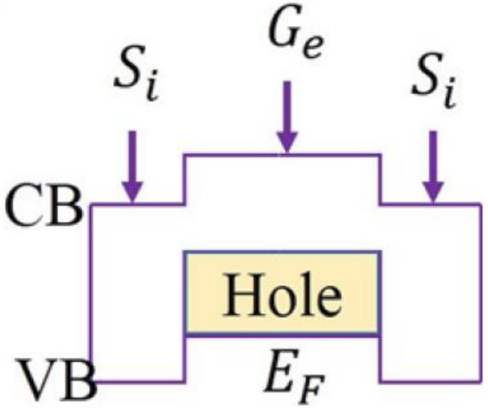


Fig: schematic band structure of the hut wire[3]

Fig: STEM and AFM images[2]

[1] Zhang *et al.*, PRL **109**, 085502 (2012)
[2] Watzinger *et al.*, Nano Lett. **16**, 6879 (2016)
[3] Li *et al.*, APL **110**, 133105 (2017)
[4] Kloeffel *et al.*, arXiv:1712.03476v1
[5] Watzinger *et al.*, APL **2**, 076102 (2014)

EDSR spectroscopy

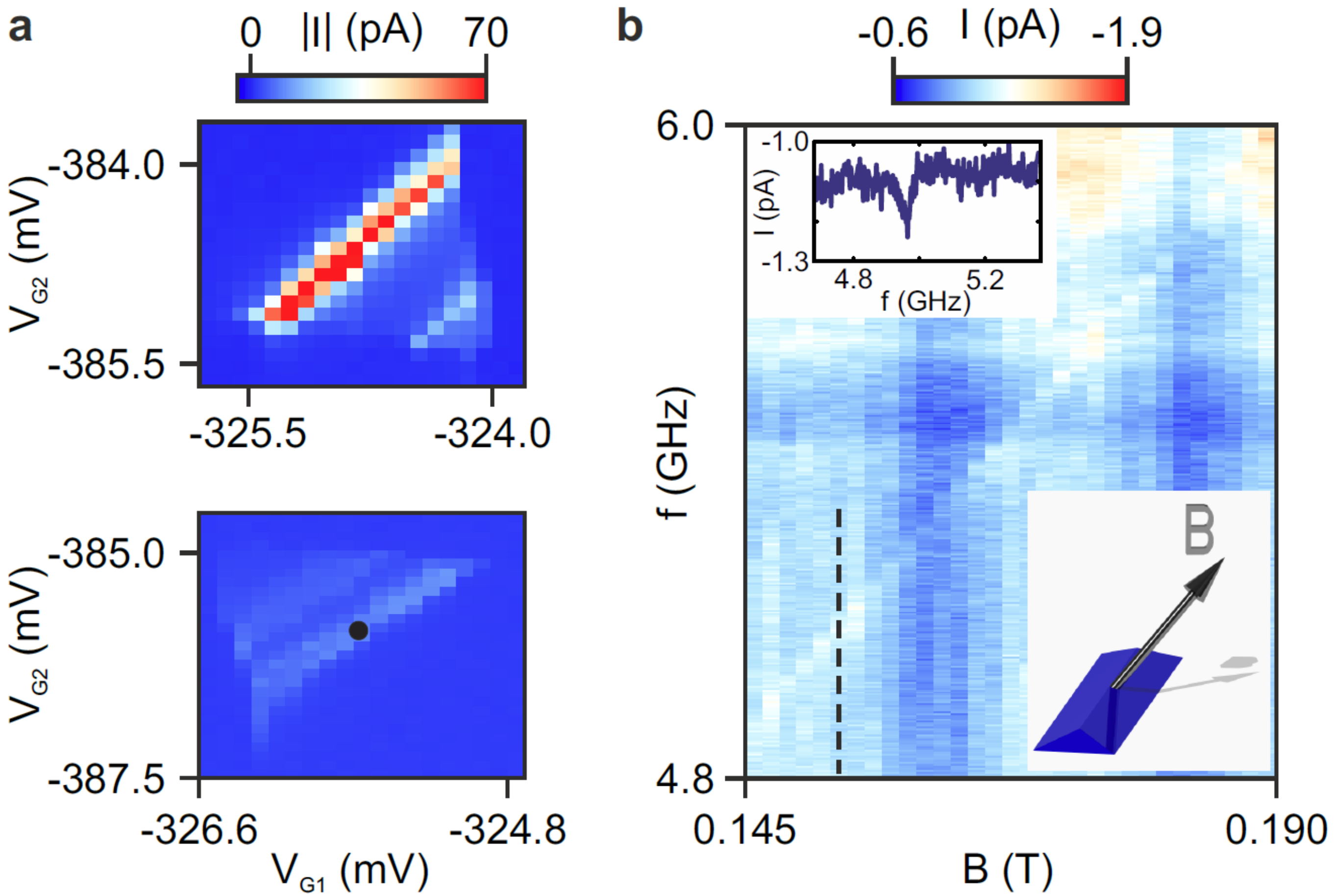


Fig: (a) Bias triangles show Pauli spin blockade
(b) Zero detuning current as function of drive frequency and magnetic field[1]

- resonance condition

$$f_{\mathrm{drive}} = f_{\mathrm{Larmor}} = g\mu_{\mathrm{B}}B/h$$

- strong g-factor anisotropy

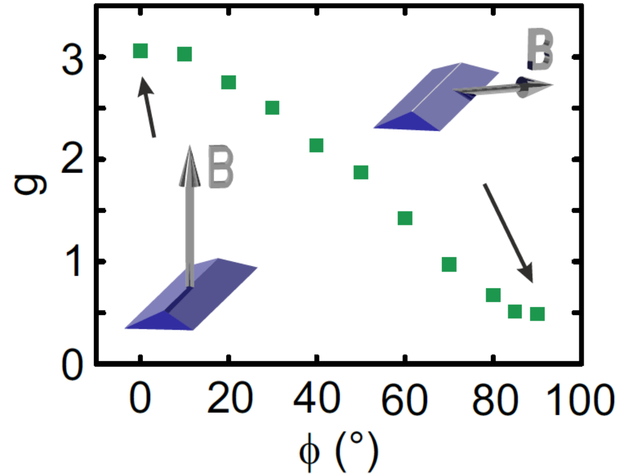
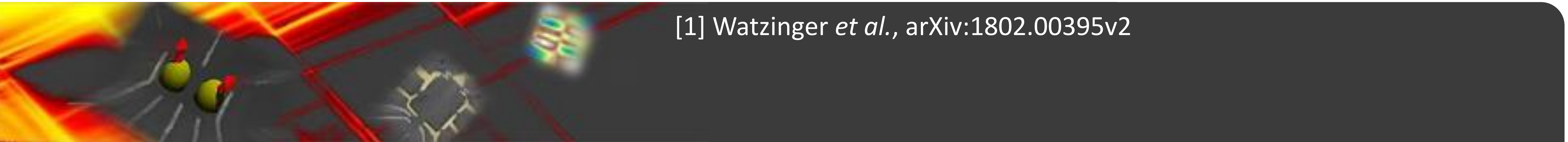


Fig: g-factor anisotropy[1].
ϕ: angle between [100] and B-field



[1] Watzinger *et al.*, arXiv:1802.00395v2

Coherent Rabi Oscillations

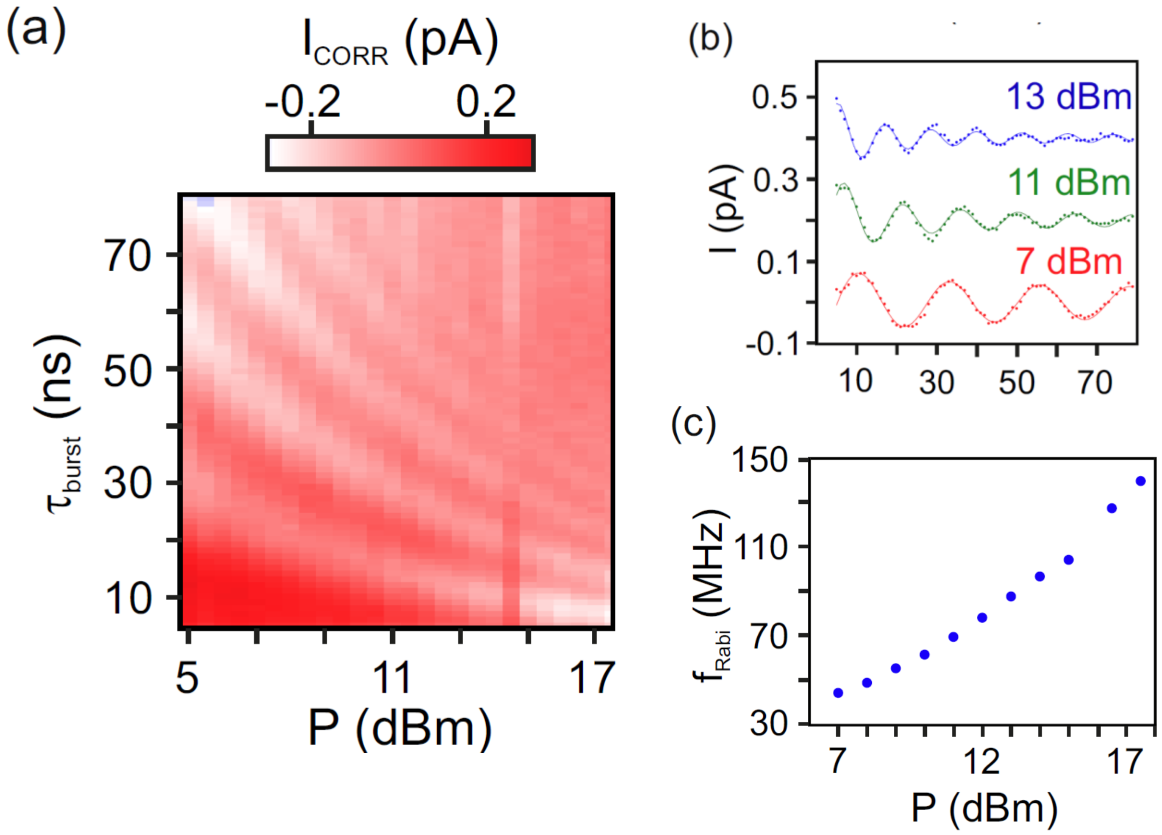


Fig: Rabi oscillations (B = 127 mT, f_{drive} = 5.96555 GHz)[1]

- initialize in triplet state
- apply microwave burst of duration τ_{burst} in Coulomb blockade
- spin readout in spin blockade region

- Rabi frequency up to 140 MHz

[1] Watzinger *et al.*, arXiv:1802.00395v2

Ramsey

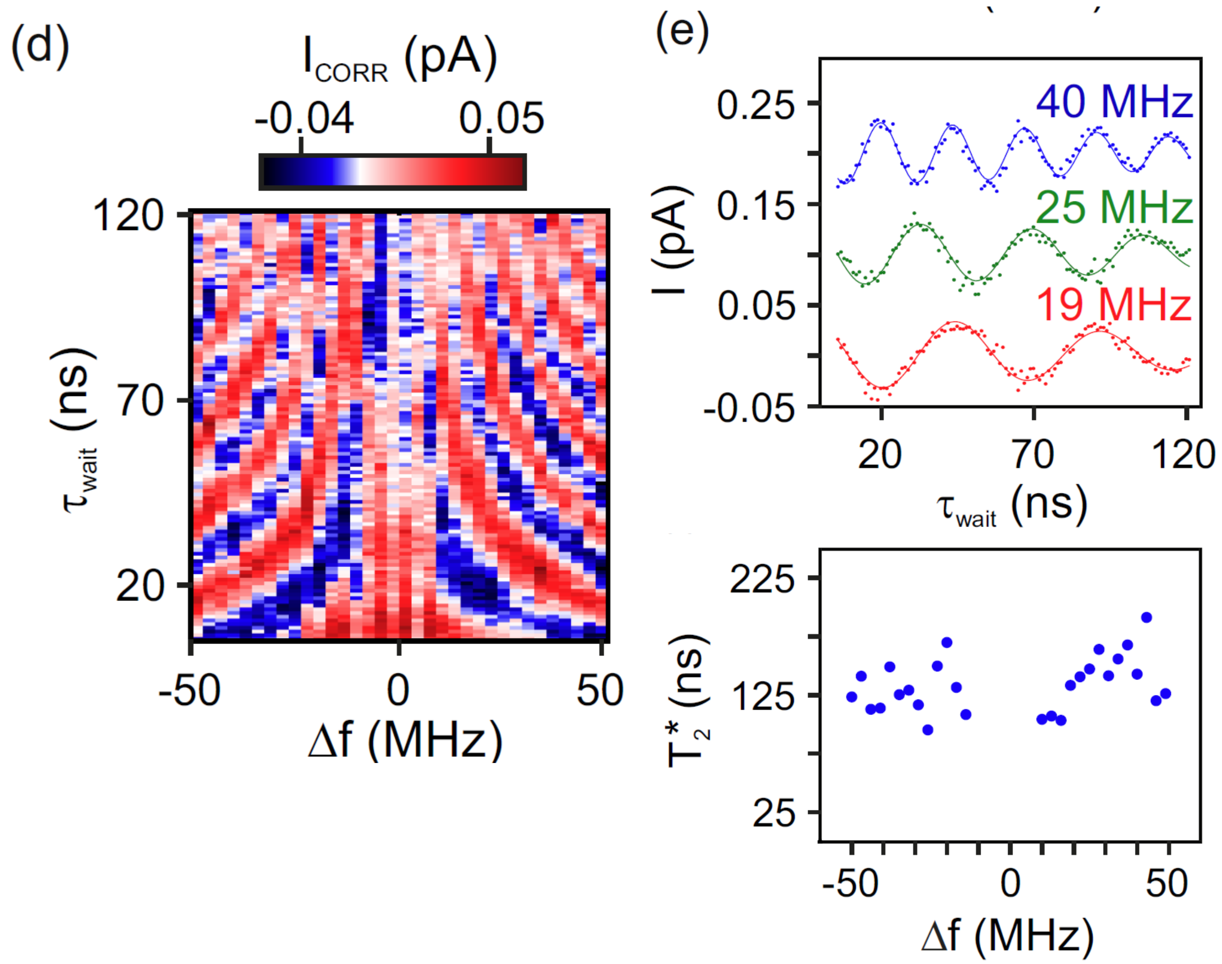
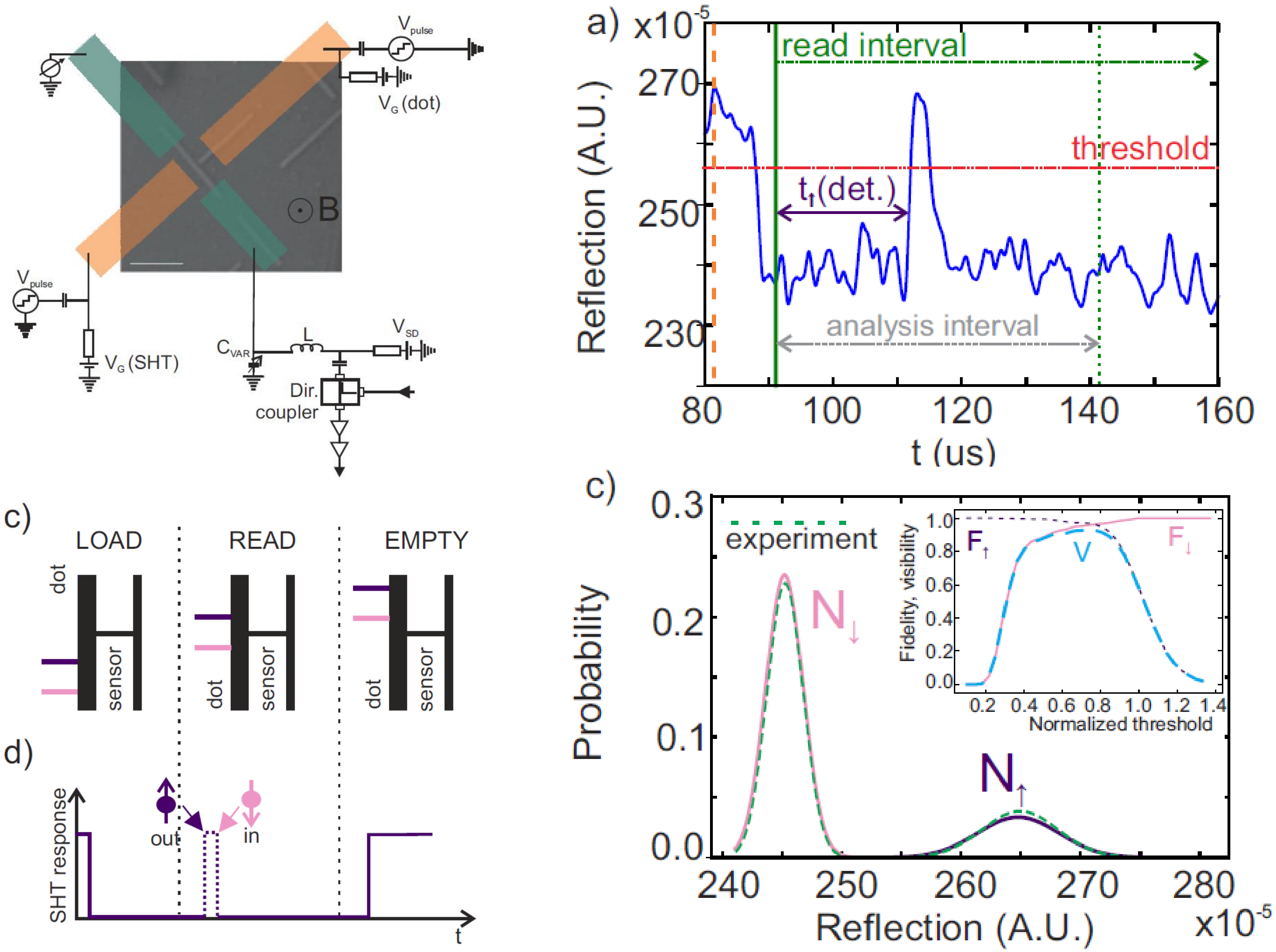


Fig: Ramsey fringes (P_{RF} = 11 dBm, B = 127 mT, f_{drive} = 5.96555 GHz)[1]

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

[1] Watzinger *et al.*, arXiv:1802.00395v2

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 ± 5µs at 500 mT
  - 32 ± 2µs at 1100 mT

[1] Vukušić *et al.*, arXiv:1803:01775v2
[2] Vukušić *et al.*, Nano Lett. **17**, 5706 (2017)

Coupling to Superconducting Resonator

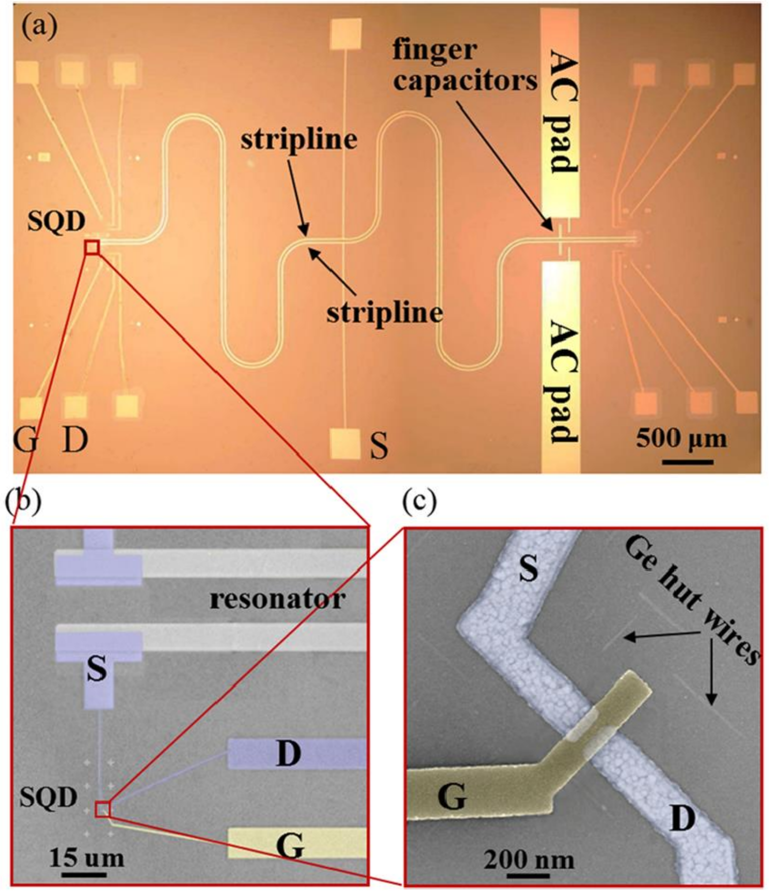


Fig: Resonator with integrated quantum dot devices[1]

- $\frac{\lambda}{2}$ 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

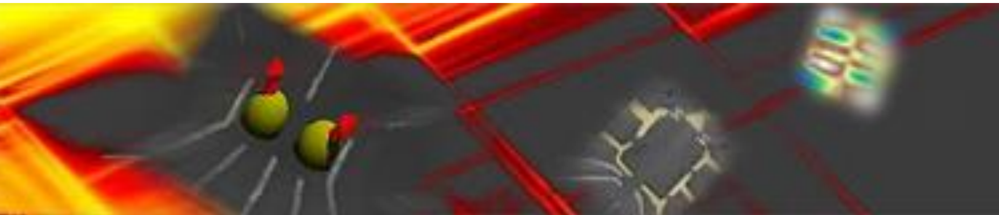
[1] Li *et al.*, Nano Lett. **18**, 2091 (2018)

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