Single-electron spin resonance in a nanoelectronic device using a global field

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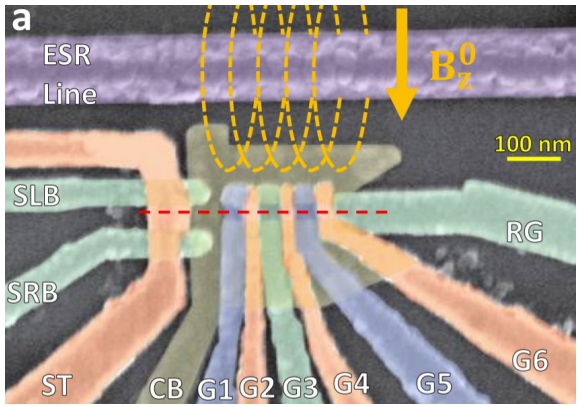
Spin Journal Club

Simon Svab, 15.02.2021

Motivating challenge: Scalability of qubit control

How to deliver microwave control signals to many qubits simultaneously, without disturbing cryogenic environment of processor?

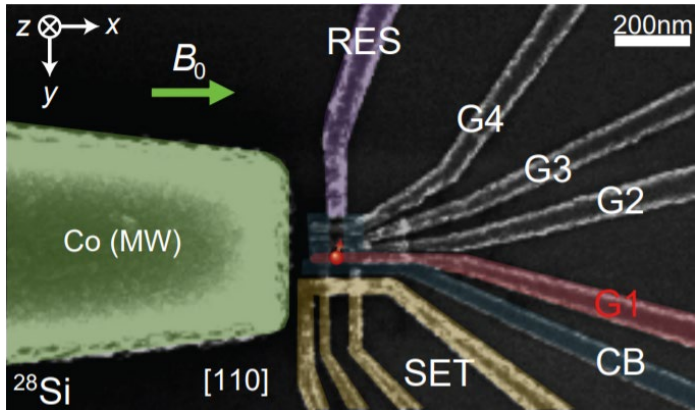
ESR via on-chip transmission line (TL)



[1]

→ # TL scales with total # qubits
→ Multiple high-frequency coax lines needed
→ Large microwave currents (heating)

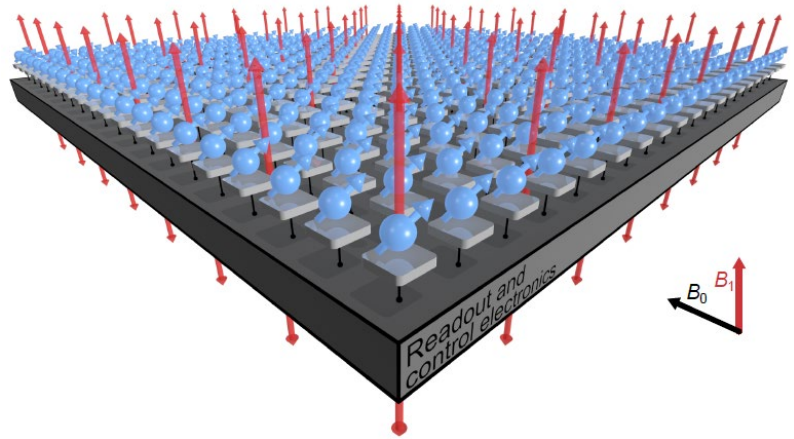
EDSR via nanomagnets (electrons)



[2]

→ Similar challenges as with TL-based ESR; scaling of coaxial lines for qubit control

Vision of this paper: ESR with a global field



→ Single microwave source
→ No direct passage of strong high-frequency currents through processor

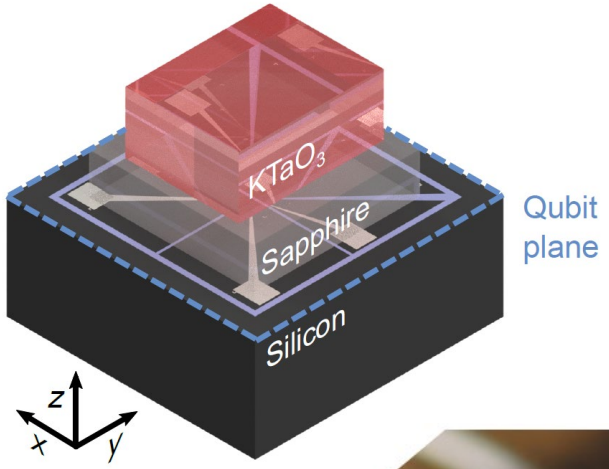
[1] R. Zhao et al., Nat. Comm. 10, 5500 (2019)

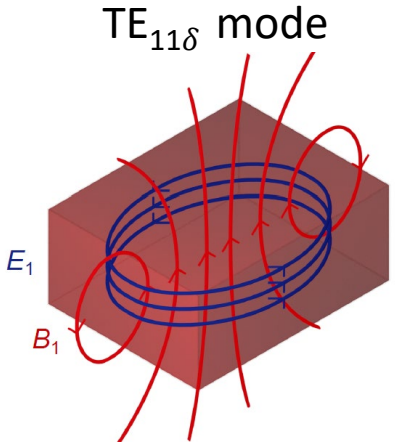
[2] R. C. Leon et al., Nat. Comm. 11, 797 (2020)

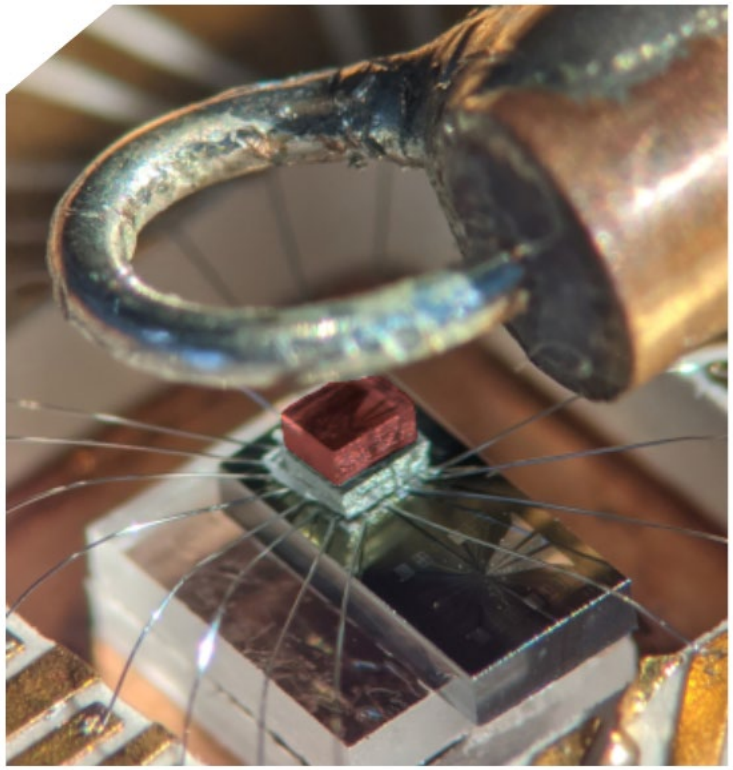
Dielectric Resonator Setup

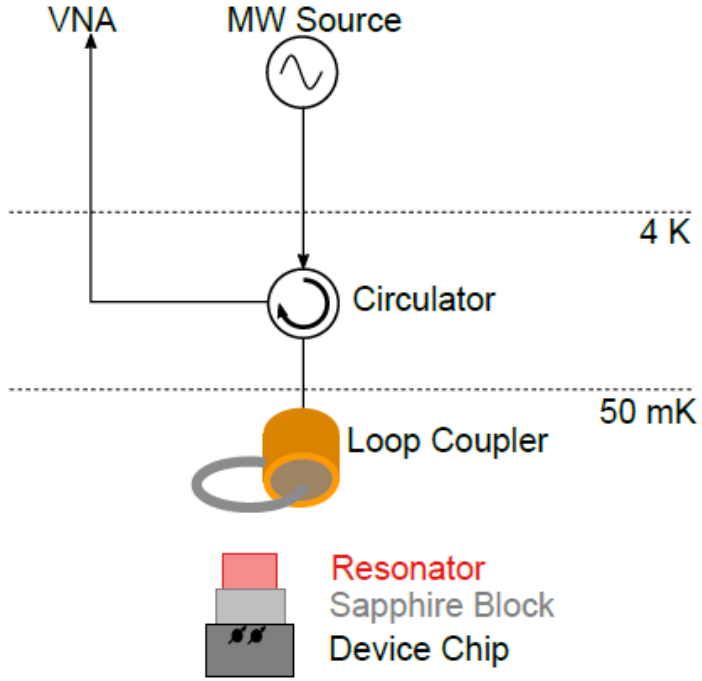
$$B_1 = C\sqrt{P}$$
$$C \propto \sqrt{Q/\omega V}$$
$$\omega \propto 1/(\sqrt{\varepsilon_r} V^{1/3})$$

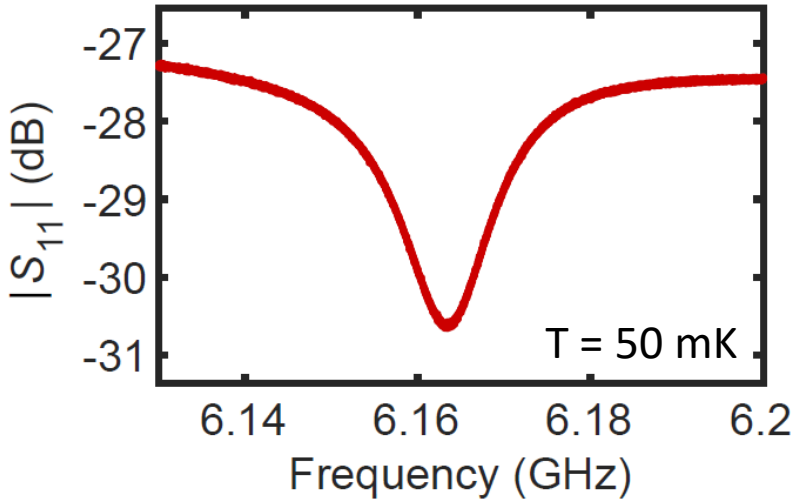
C: Conversion factor
Q: Quality factor of resonator
V: Mode volume







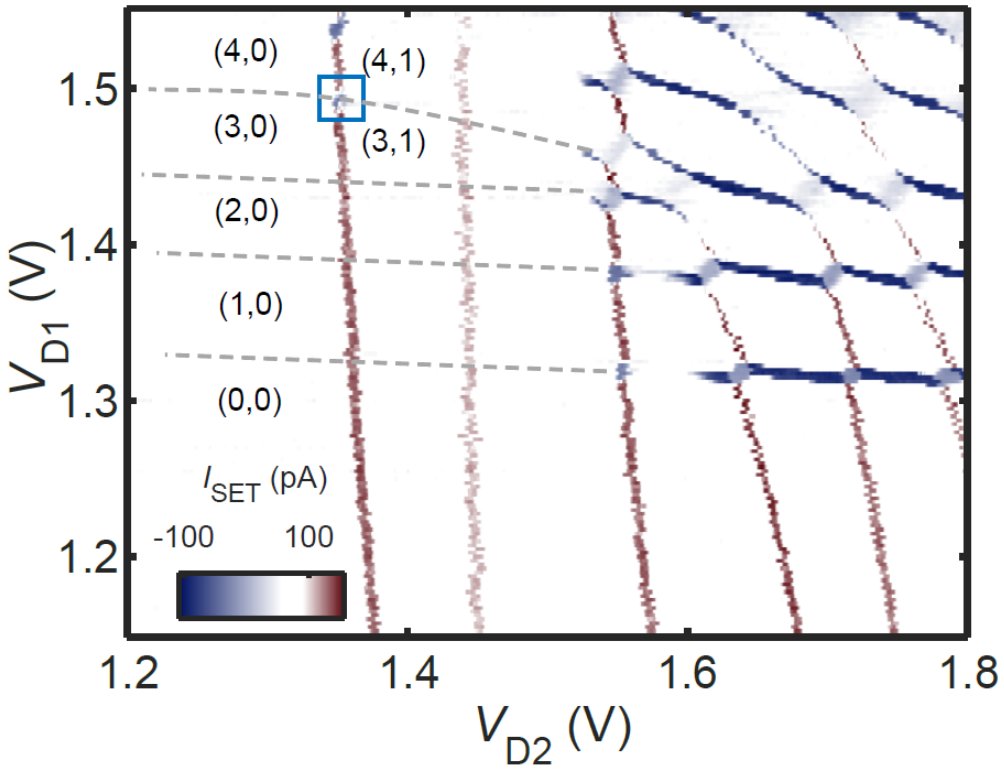


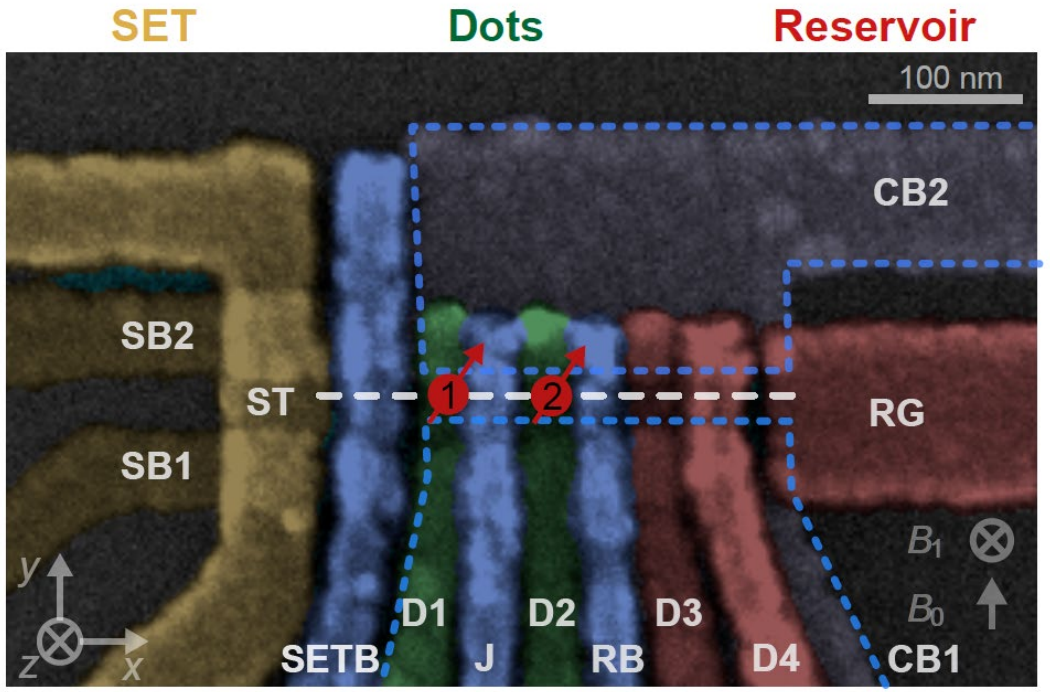


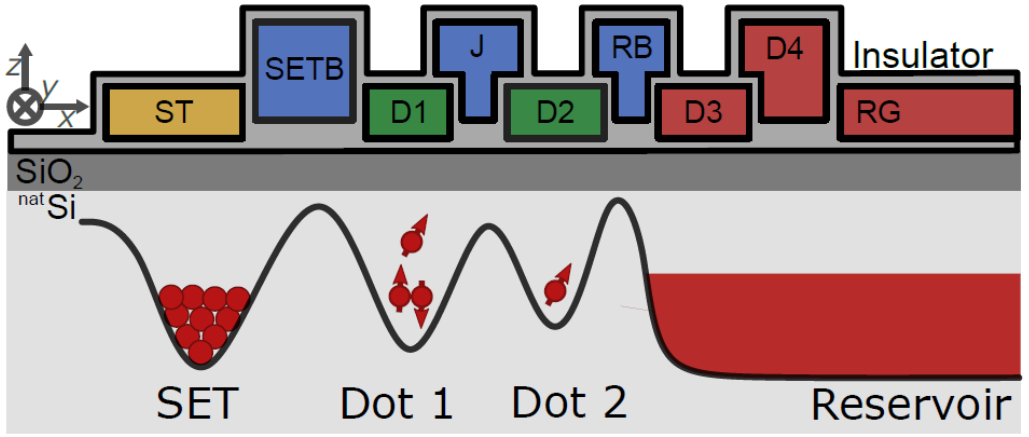
→ High Q, low V resonator desirable
→ Minimize electric field at the chip
→ KTO: $\varepsilon_r \approx 4,300$ for T < 10 K, low losses
→ Operated in $TE_{11\delta}$ mode (B_1 strongest along central axis, extends outside of DR)
→ Q≈500 for device (Q≈60'000 without chip)

Device

- ^{nat}Si (≈4.7% ^{29}Si) MOS DQD device
- Pd gate stack architecture (fabricated as in Ref. [1], but without MW transmission line)





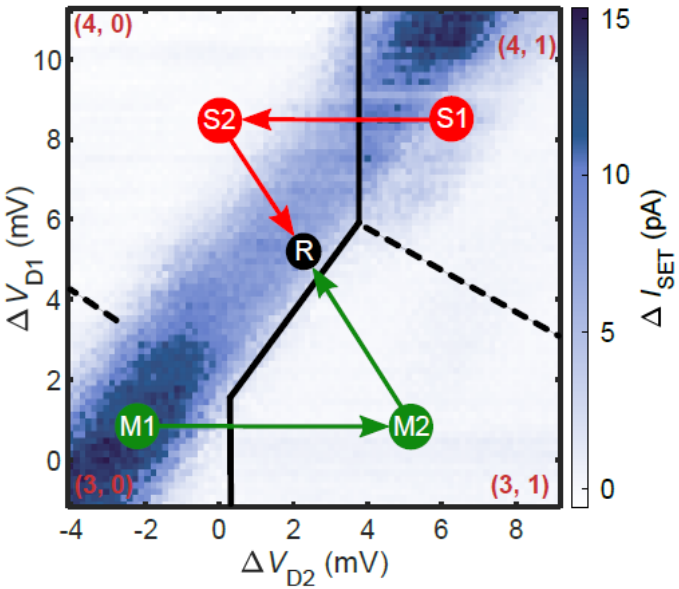


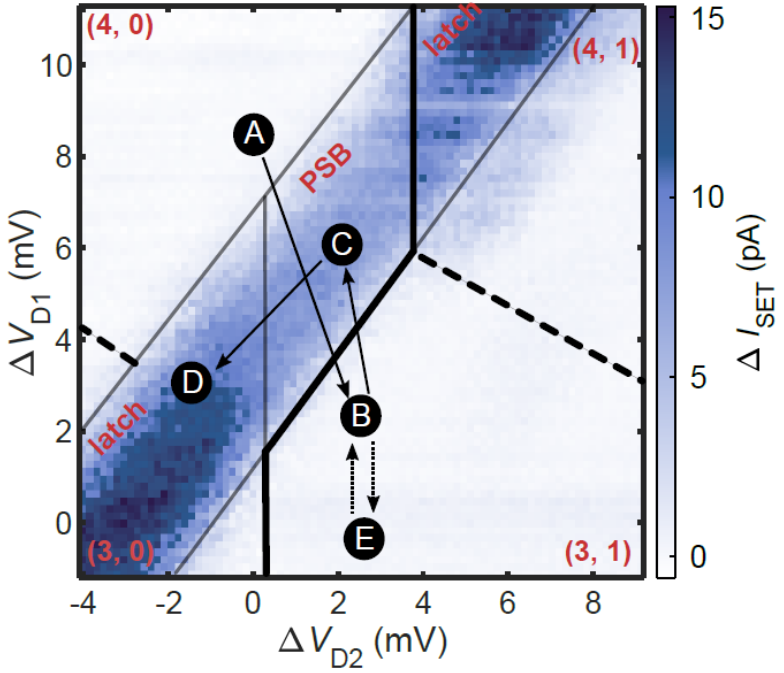
[1] R. Zhao et al., Nat. Comm. 10, 5500 (2019)

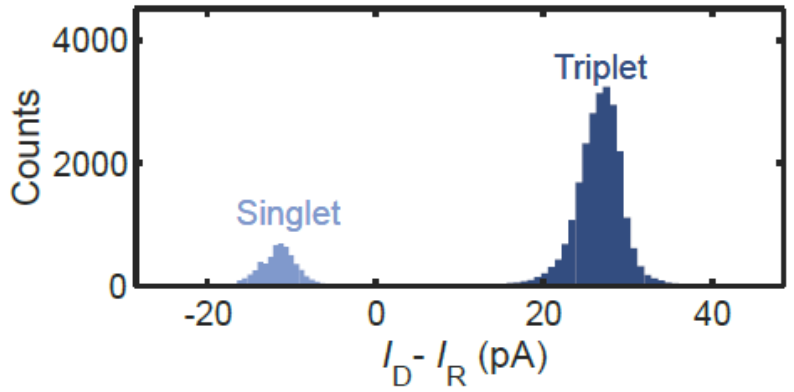
PSB Search & Spin Readout

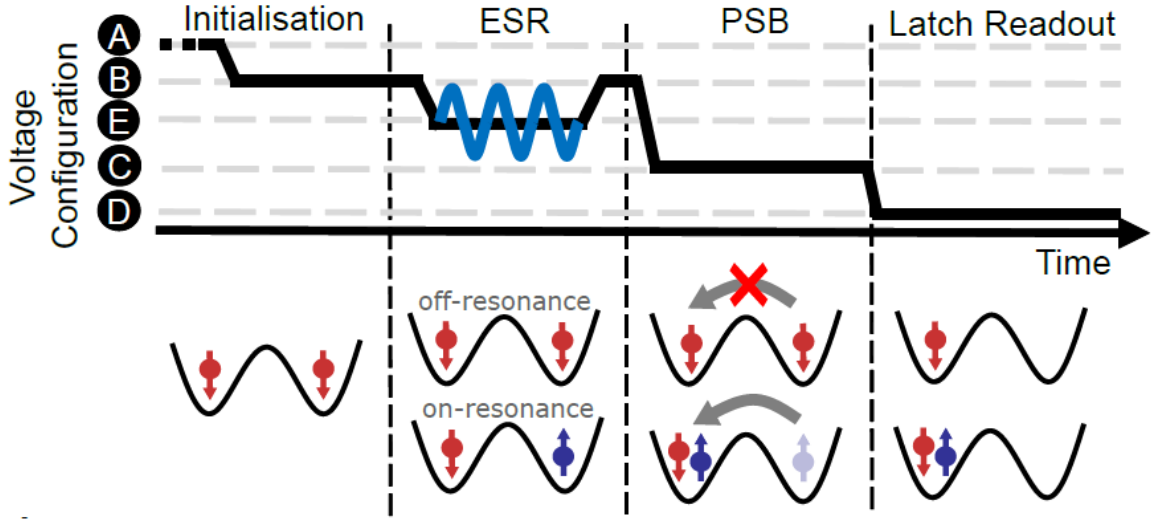
30’000 single-shot measurements
at point D (without ESR-step)

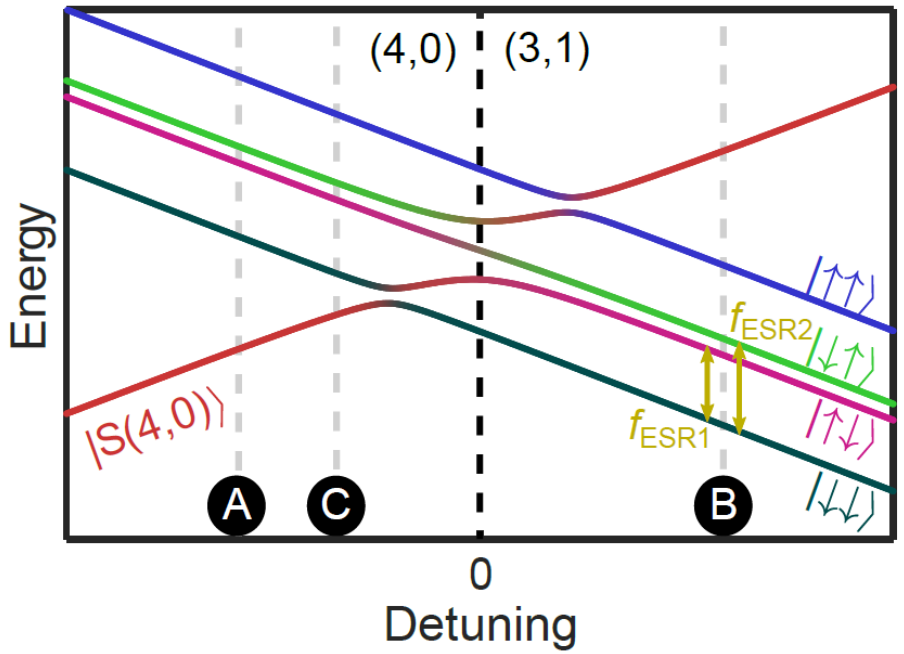
$$\Delta I_{SET} = I_{mix} - I_{Singlet}$$





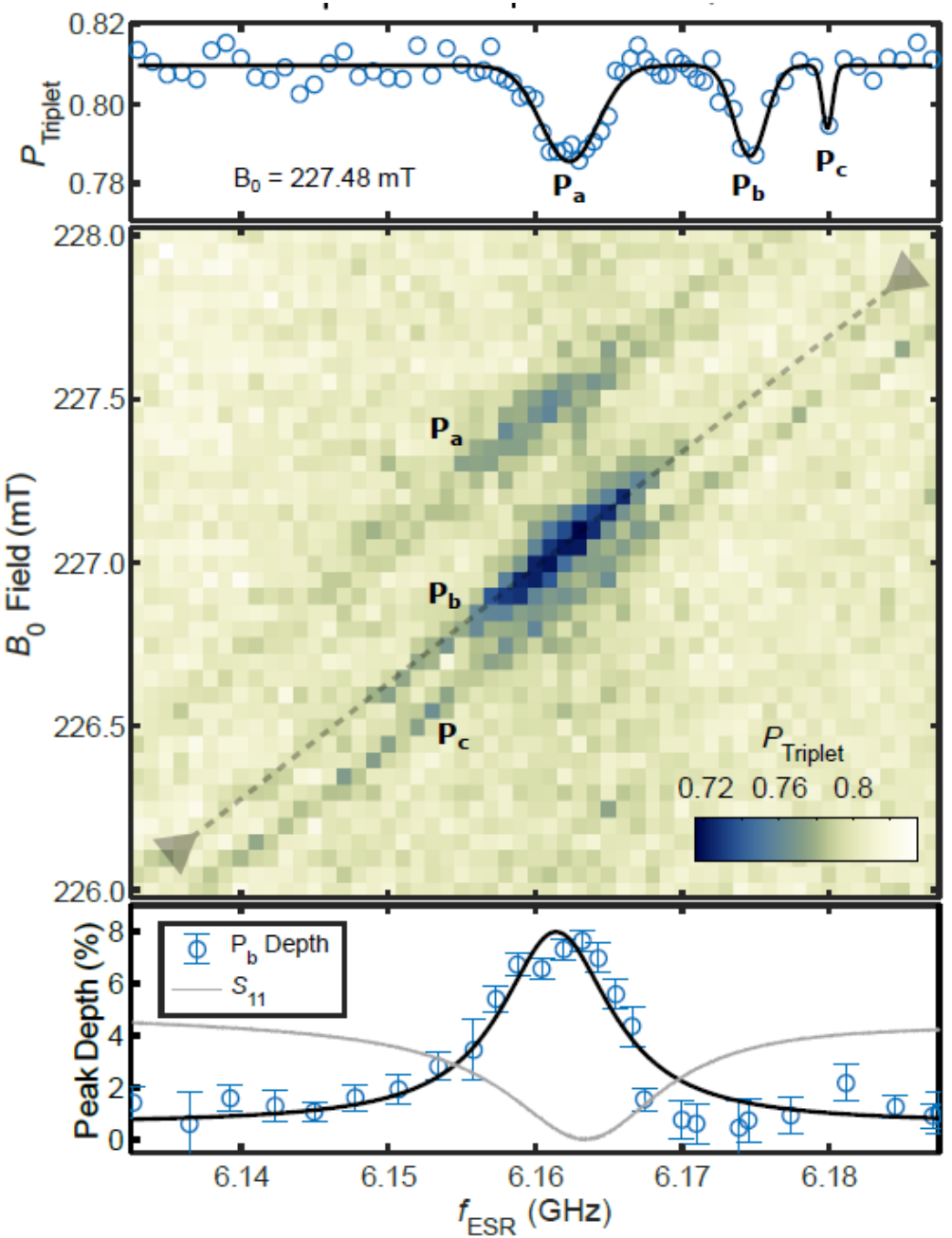






ESR in a global field

- Resonance condition: $f_{\mathrm{res}} = g\mu_{\mathrm{B}} B_0/h$
- P_a, P_b: Double QD system
- P_c: unintended spin state in vicinity
- $g_a \approx 1.935, g_b \approx 1.939, g_c \approx 1.940$
- Visibility of P_a and P_b is enhanced within bandwidth of resonator $TE_{11\delta}$ mode

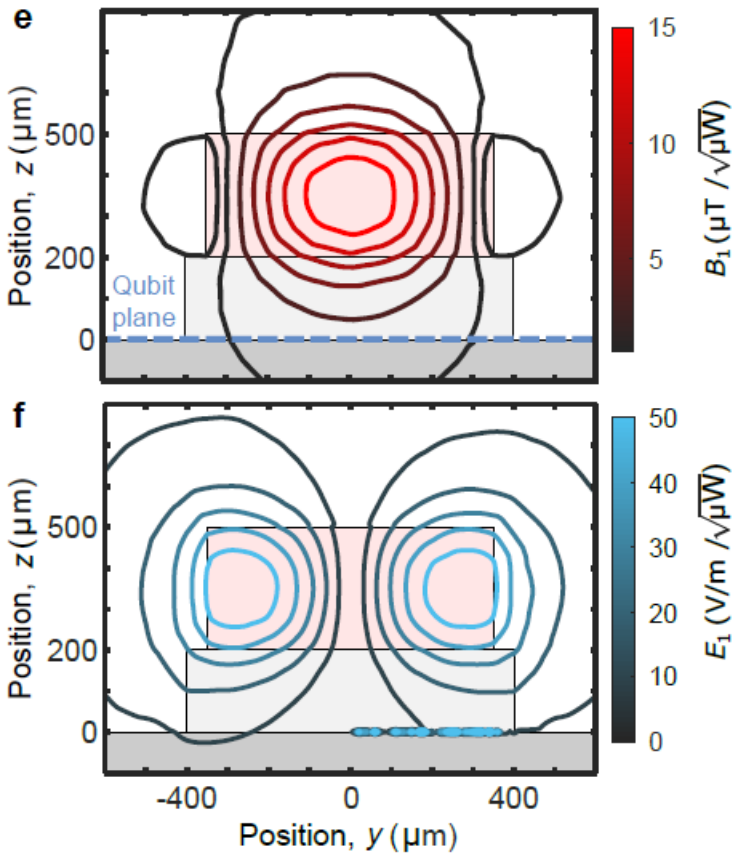


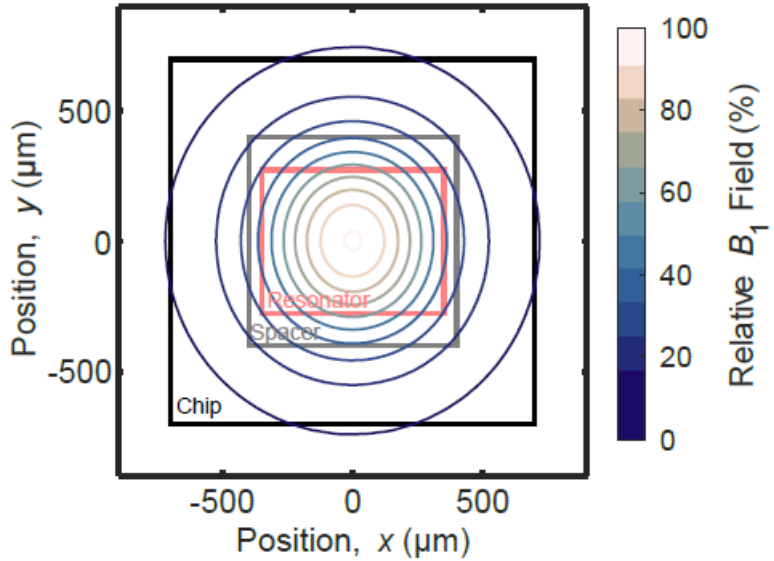
Summary

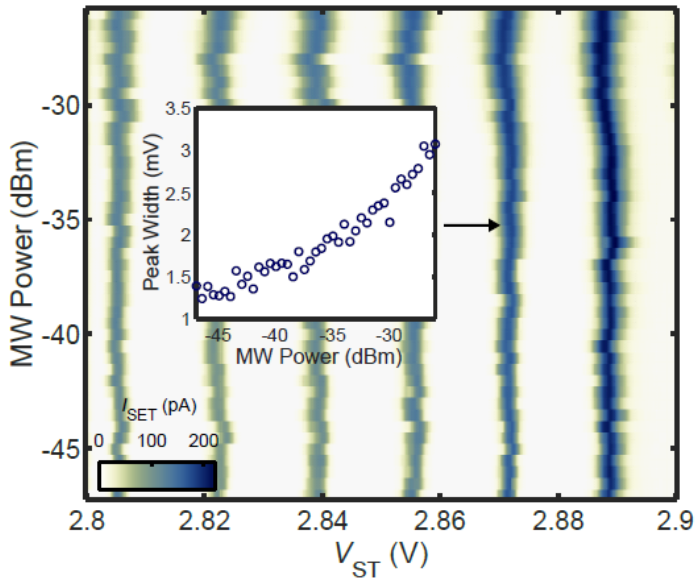
- Demonstration of ESR with a global field
- Limitation: Powers exceeding -32 dBm lead to switches in the SET current; prevents increasing power beyond ESR linewidths (here 2 to 4 MHz)

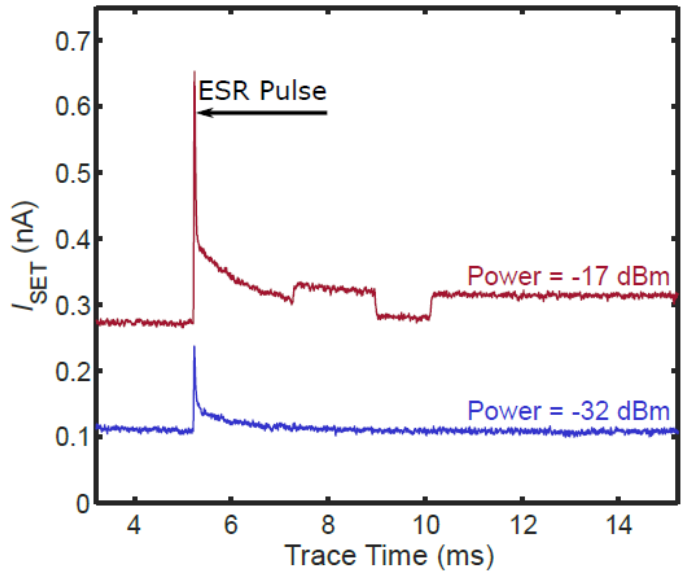
Outlook: Reduce required power for coherent spin control

- Move to isotopically-purified substrate to reduce broadening of ESR peaks
- Improve quality factor of dielectric resonator & device assembly (material limit: Q ≈60’000)


e
Position, z (μm)
500
200
0
Qubit plane
15
10
5
B1 (μT /√μW)
f
Position, z (μm)
500
200
0
50
40
30
20
10
0
E1 (V/m /√μW)
-400
0
400
Position, y (μm)


Position, y (μm)
500
0
-500
Resonator
Spacer
Chip
100
80
60
40
20
0
Relative B1 Field (%)
-500
0
500
Position, x (μm)


MW Power (dBm)
-30
-35
-40
-45
Peak Width (mV)
3.5
3
2.5
2
1.5
1
-45
-40
-35
-30
MW Power (dBm)
ISET (pA)
0
100
200
2.8
2.82
2.84
2.86
2.88
2.9
VST (V)


ESR Pulse
Power = -17 dBm
Power = -32 dBm
ISET (nA)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
4
6
8
10
12
14
Trace Time (ms)