Gate-Based Single-Shot Readout of Spins in Silicon

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Motivation

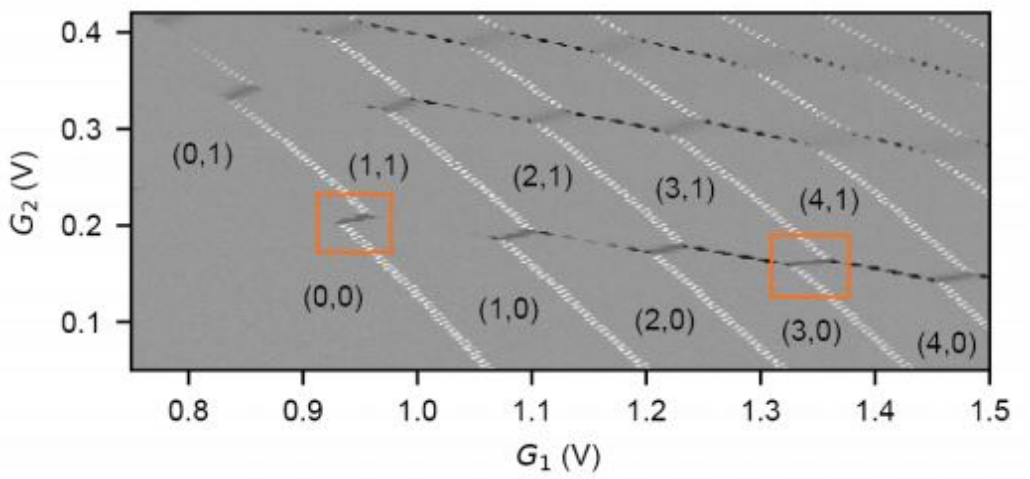
- Spins in silicon quantum dots are good candidates for large scale quantum computers
- Currently, spin information is gained by Pauli spin blockade and charge state readout by SETs
- Scaleability is reduced due to size and complexity of one qubit

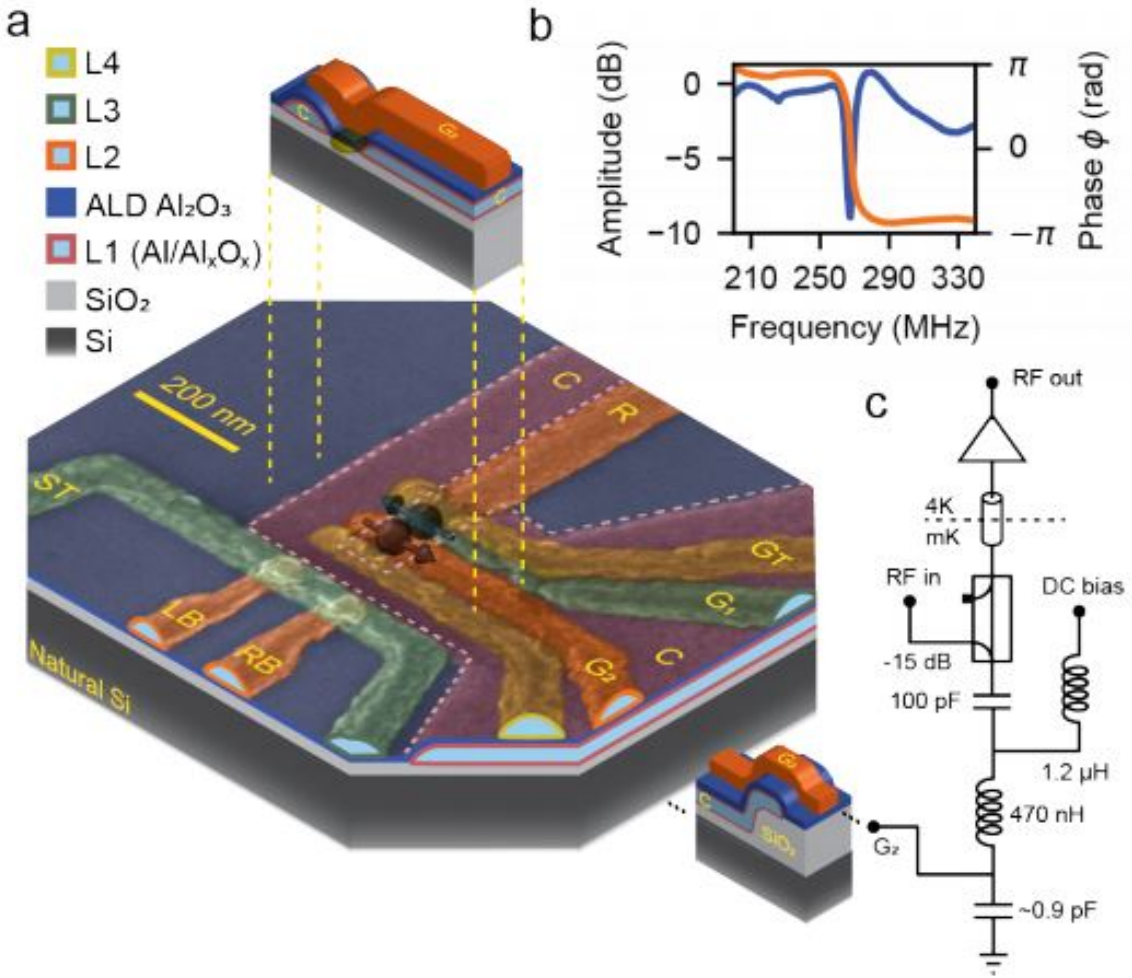
➢ New readout mechanism with rf-reflectometry on the confinement gate

  - Decreases size and complexity
  - Can achieve similar readout fidelity

Device

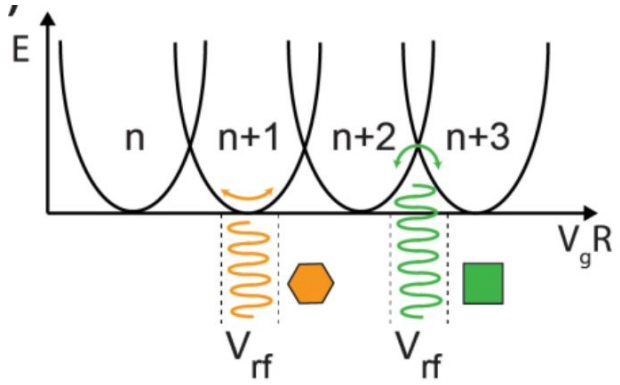
- Si with 5.9 nm thick SiO_2, gates are Al separated with Al_2O_3
- Confinement Gate C under all other accumulation gates
- G_2 embeded in L-C resonant cirquit
  ($f_0 = 266.9$ MHz, $L = 400$ nH, $C_p = 0.89$ pF, $Q = 38$)
- Additional SET for comparison -> shows double dot features
- Important parameter: quantum capacitance C_q



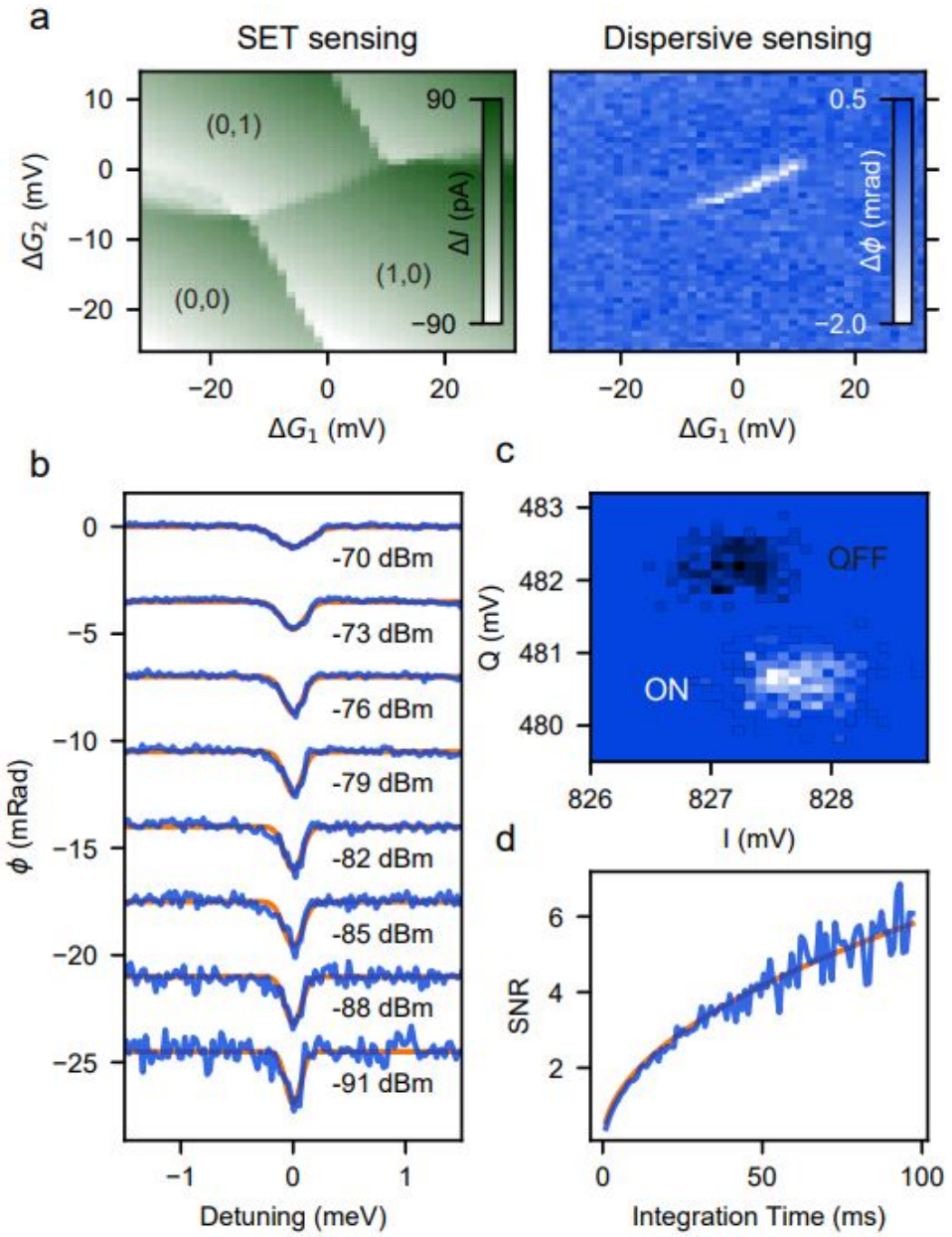


SET and Reflectometry Measurements

- Reflectometry senses change in the quantum capacitance C_q at fixed frequency $f = f_0$: $\Delta\phi \approx -\pi Q C_q / C_p$
- Can only detect interdot charge tunneling (in contrast to SET)
- Intrinsic width of charge transition is set by t_c at low rf probe power with $t_c = 12.0 \pm 1.5$ GHz
- SNR extracted from comparison of I and Q signals at $\epsilon = 0$
  - SNR $= 2$ at $\tau_m = 12$ ms

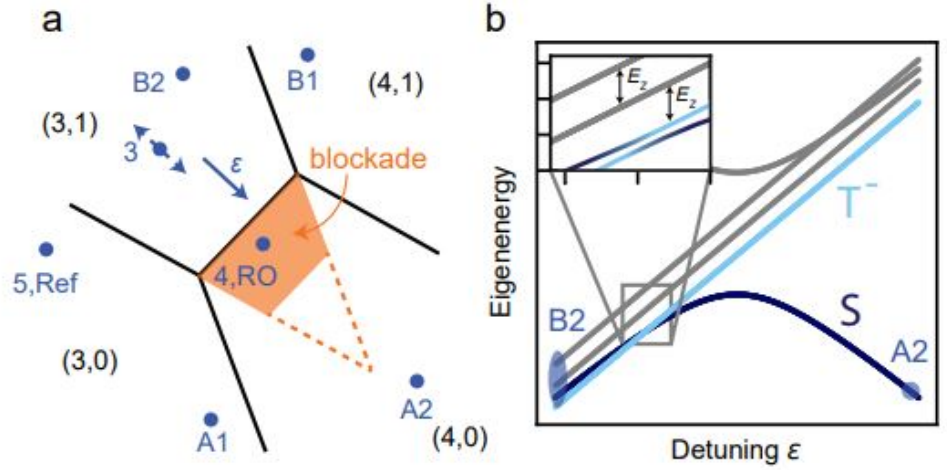


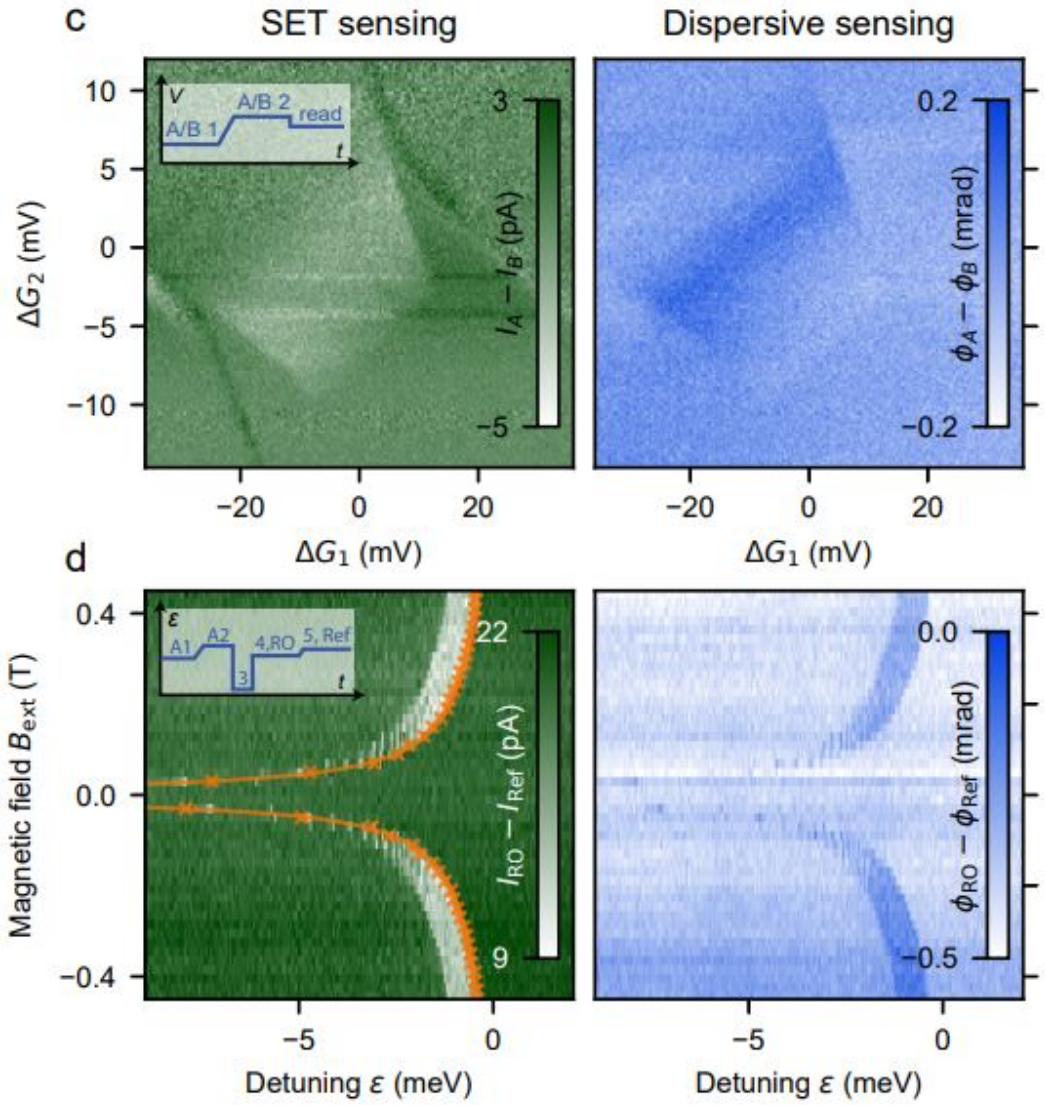
Colless et al., PRL 110, 046805 (2013)



Spin-Readout Capability

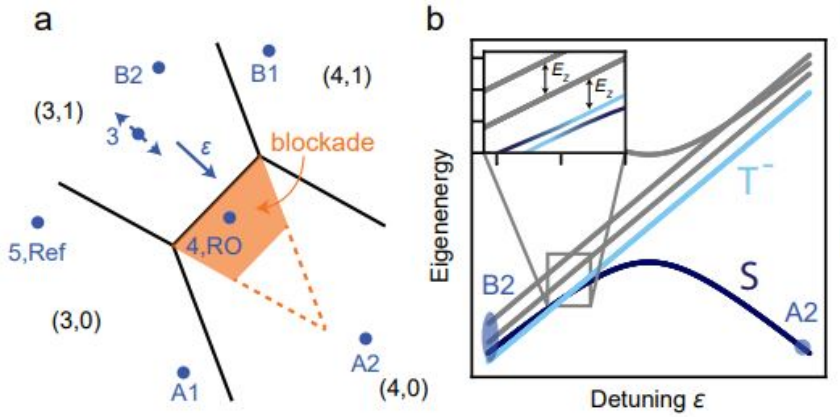
- (4,0)-(3,1) due to low lying orbital states in (1,0)-(0,1)
- Two initialization protocolls
  - A1 -> A2: singlet
  - B1 -> B2: mixture of singlet and triplet
- Verification by subtracting B from A
  - Resulting partial blockade can be seen
- Further verification by coupling S with T^- (A1 -> A2 -> 3 -> 4,RO)
  - Reduced singlet return when ϵ at S-T^- anticrossing

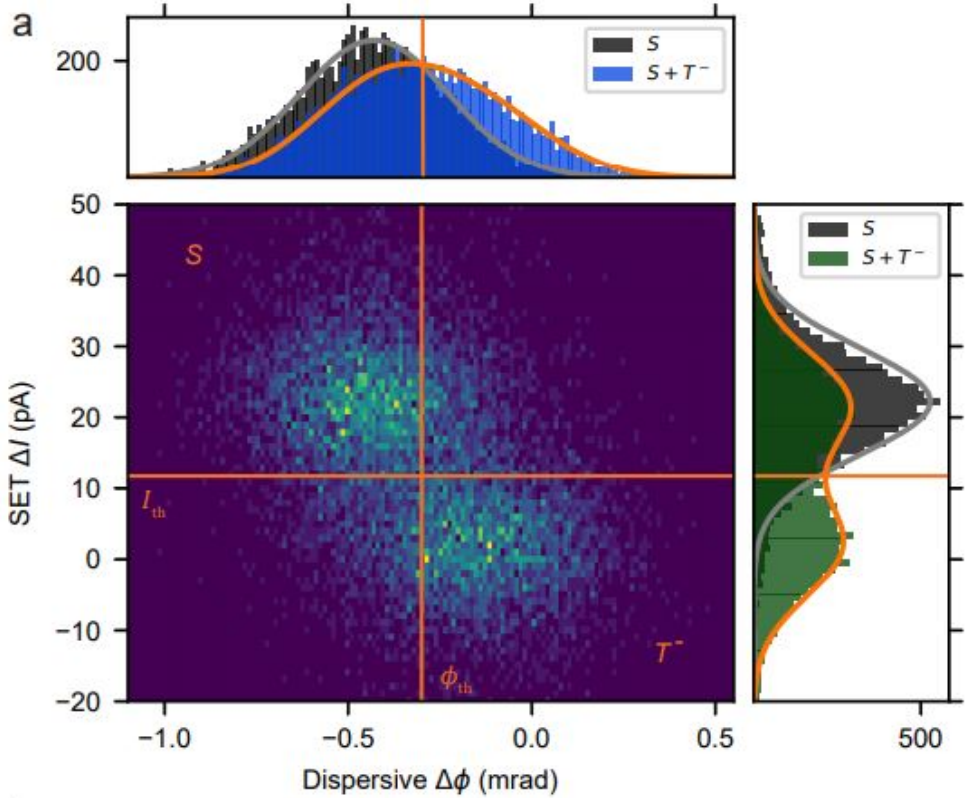


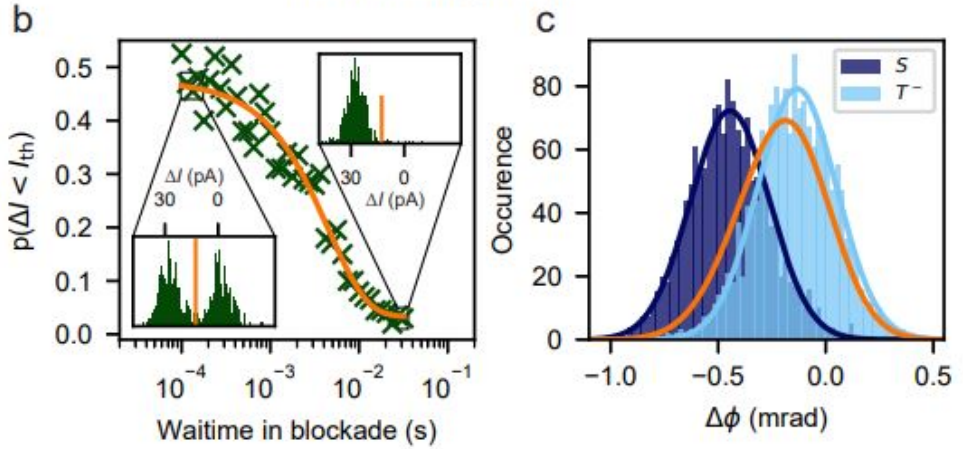


Single Shot Readout

- Slow pulse to $S - T^-$ crossing to initialize evenly mixed $S + T^-$ state, readout at 4,RO
- Clear correlation of dispersive shift and SET current
- Estimation of readout fidelity includes $T_1 = 4.5 \pm 0.5$ ms
  - $F_{avg}^{SET} = 88.2 \pm 1.9$ % with $\tau_m^{SET} = 1.0$ ms
  - $F_{avg}^{dispersive} = 73.3 \pm 1.2$ % with $\tau_m^{dispersive} = 2.0$ ms
- Can be improved by
  - superconducting spiral inductor-based resonators
  - optimized external matching techniques
  - parametric amplification







Conclusion

- Characterization of a gate-based single shot readout of spins in Silicon
- Sufficient signal to noise with less complex gate design (omitting the SET)
- Readout of many spins in parallel possible with compact gate structures