IMPERIAL

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Charge Noise in Semiconductor Spin Qubits for Quantum Computing

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Quantum Dots / Spin Qubits

Quantum dots are man-made submicron structures in a solid.

How to define the quantum states in QDs?

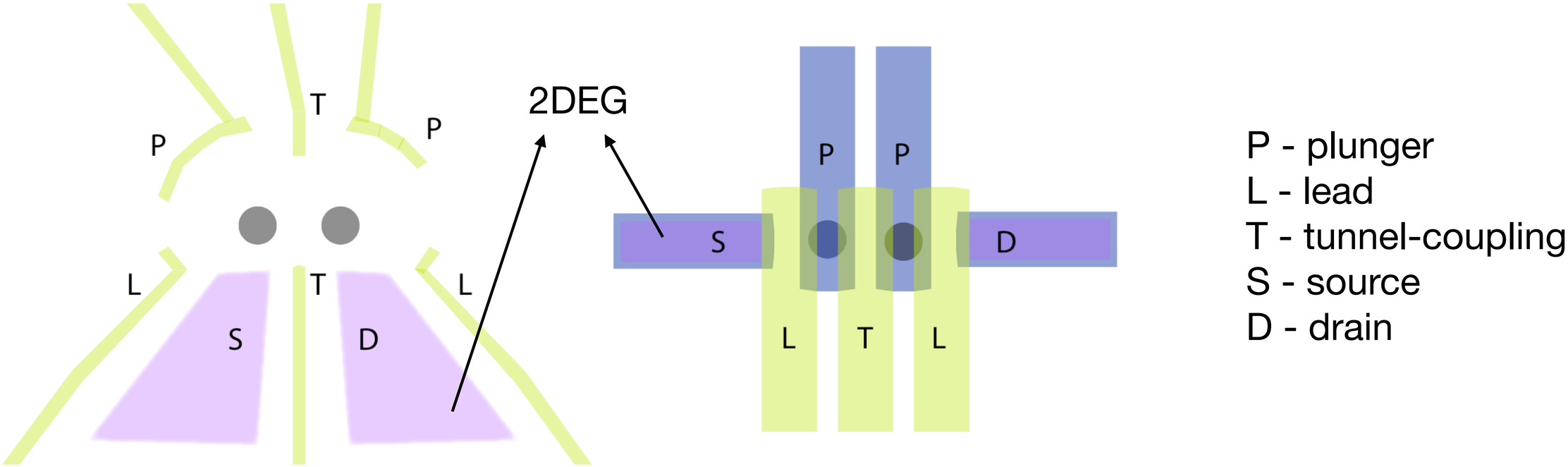
Spin qubits	**Single QD**	**Multiple QDs**
Described in	Single-spin qubit	Charge qubits / Singlet-Triplet and hybrid qubits / Triple-dot qubits
Defined by	Spin state	Location of spins in QDs, or their charge state
Controlled by	Magnetic fields	("Charge-like" qubits) use voltages to shift the electron between dots

Why use semiconductor spin qubits for quantum computing?

- Scalability with existing semiconductor technology.
- Long coherence times.
- Small size, high density, …

Double QDs

Two variations of a typical set of **gate electrodes** used to **define double quantum dots**:



Stadium style

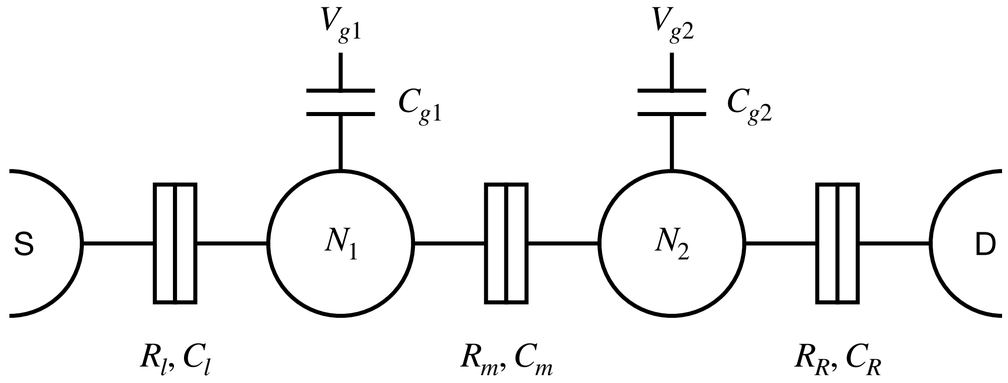
Overlapping style

P - plunger
L - lead
T - tunnel-coupling
S - source
D - drain

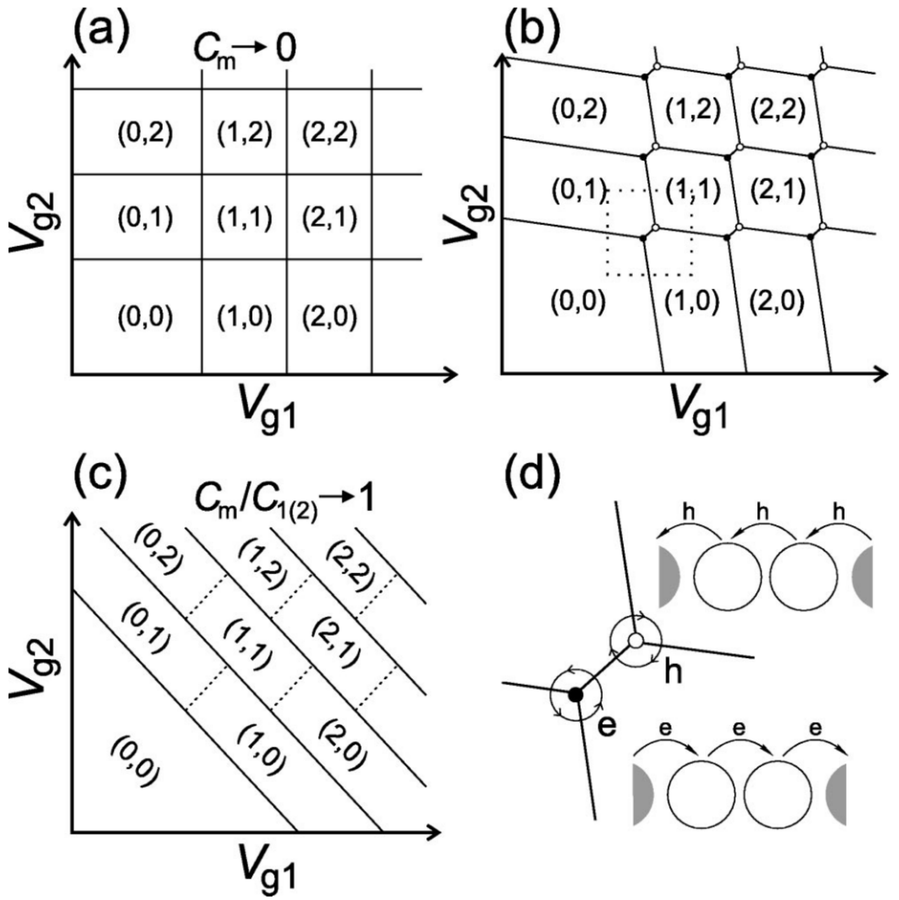
[1] Harvey, 2022

Charge Stability Diagram

Charge stability diagram maps out the different charge states of the quantum dots as adjusting the gate voltages.



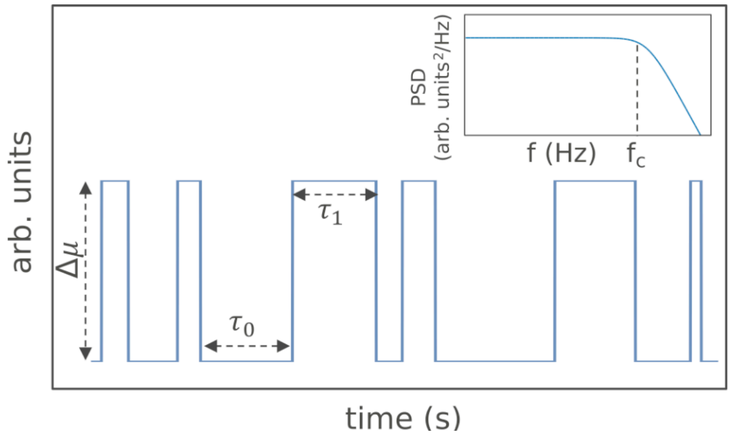
- Gate coupling: V_{g_1,g_2}, C_{g_1,g_2}
- Tunnel barriers connect the source and drain: $R_{L,R}$, $C_{L,R}$
- Inter-dot coupling: R_m, C_m



Inter-dot coupling (a) small (b) intermediate (c) large

Charge Noise

Charge noise: random fluctuations in the electric field within a semiconductor environment.



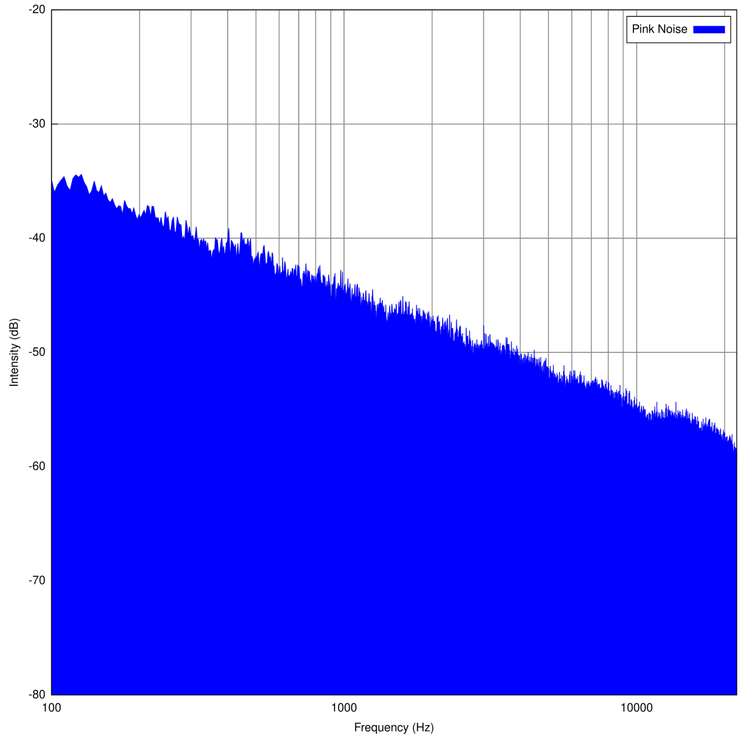
Sources of charge noise

- structural defects
- atomic vacancies
- strain in the material

…

➡ Charge traps

Two-Level Fluctuators (TLFs) $\rightarrow$ $1/f$ noise



Charge Noise

Impact

- **Single-spin qubit operations**
  - Interfere g-factor and disrupt drive pulse, especially with micromagnets.
- **Spin-cavity coupling**
  - Complicate long-range qubit interconnects.
- **Two-qubit gates**
  - Cause fluctuations in exchange interaction, reducing fidelity.

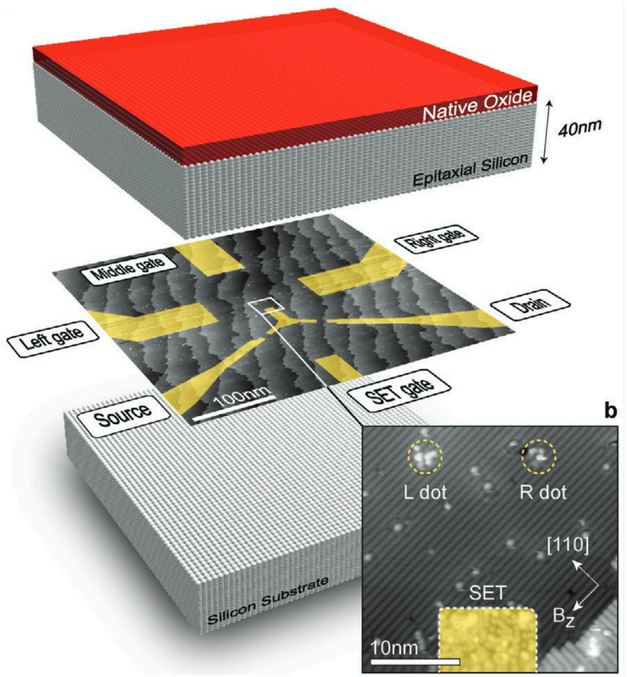
Mitigation strategies

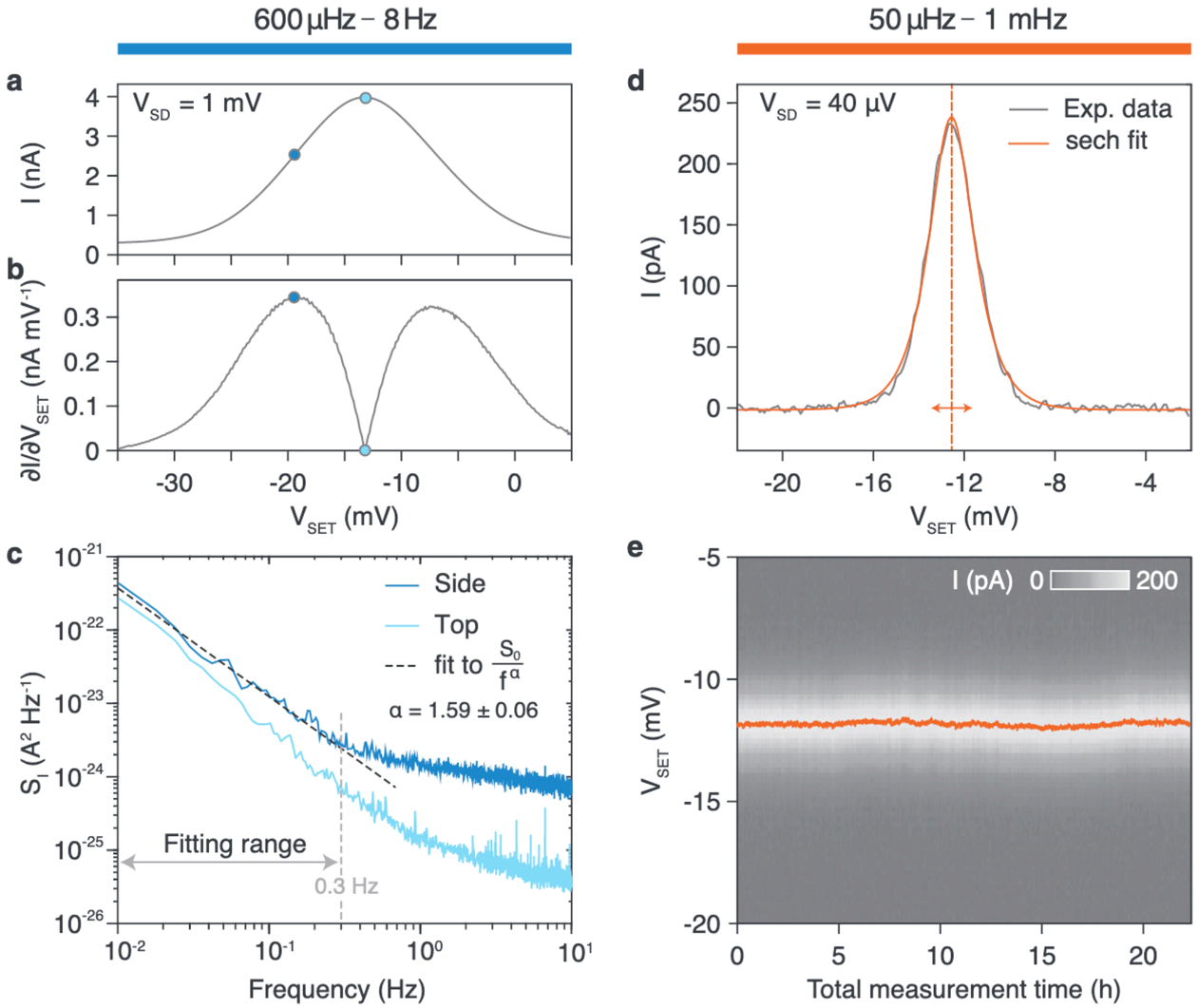
- **Dynamic decoupling**
  - use control pulses to average out noise effects
- **Improved material design**
  - high-purity materials
  - better fabrication techniques
- **Noise characterisation**

Charge Noise Extraction

Use a Single Electron Transistor (SET) as a noise sensor

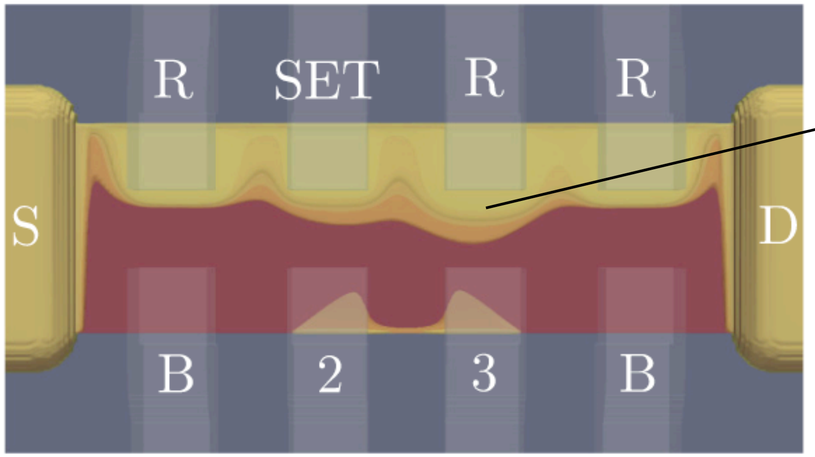
- SET current spectroscopy
- SET peaking-tracking



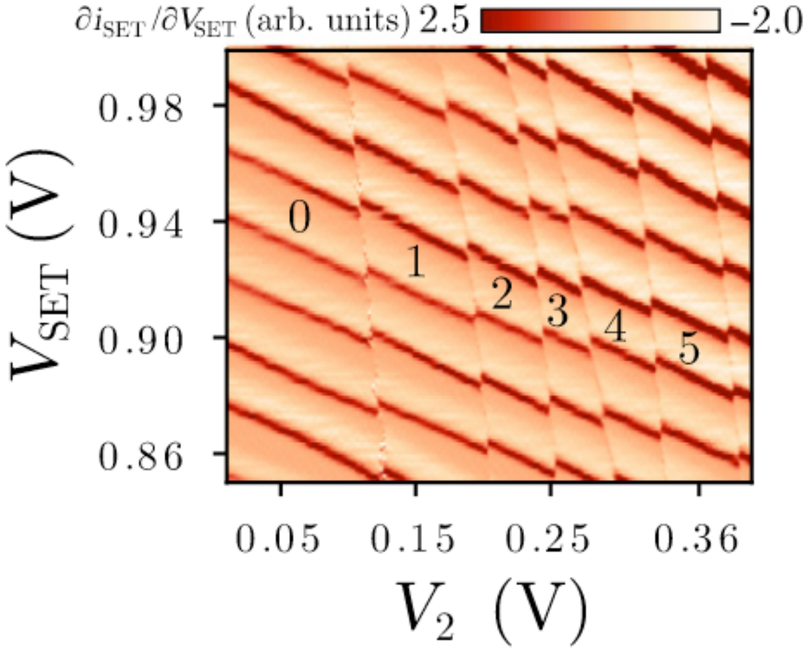


[2] Kranz *et al.*, 2020

Reconfigurable SET for Multi-QD Sensing



Isodensity Surfaces



Challenge with Single SET

- **Limited Efficiency**
  SET reservoir screens capacitive coupling, reducing sensitivity to a single QD.

→ **Serial SETs**

[3] Chanrion *et al.*, 2020