University of Basel

PHYSICAL REVIEW APPLIED **19,** 044010 (2023)

Probing Low-Frequency Charge Noise in Few-Electron CMOS Quantum Dots

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21.04.2023

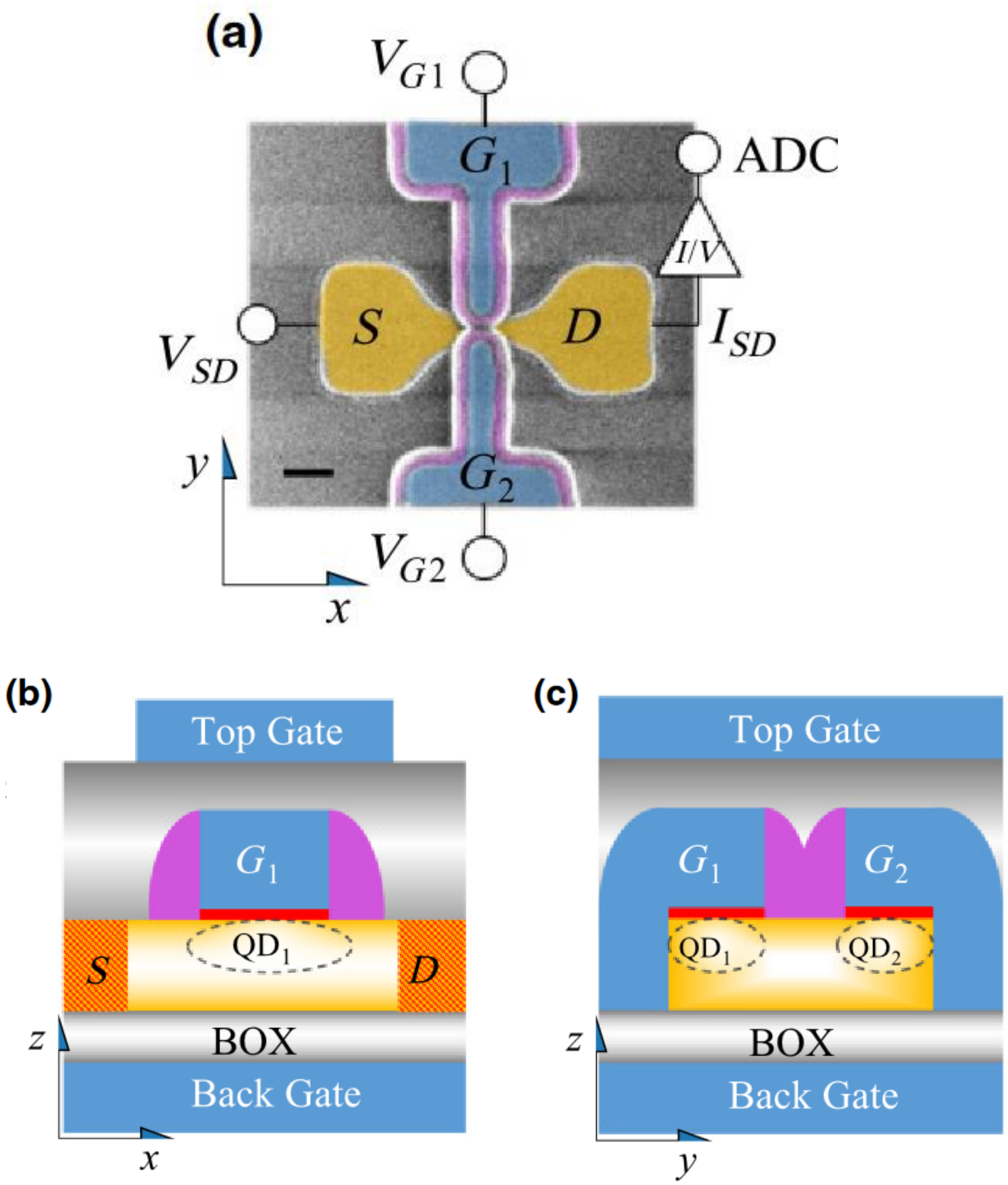
Outline

- characterize the charge noise in a quantum dot
- tune the charge noise 1-100 $\mu eV^2/Hz$
- identify the main sources: **top interface, reservoirs**
- charge noise vs dot occupancy

Introduction

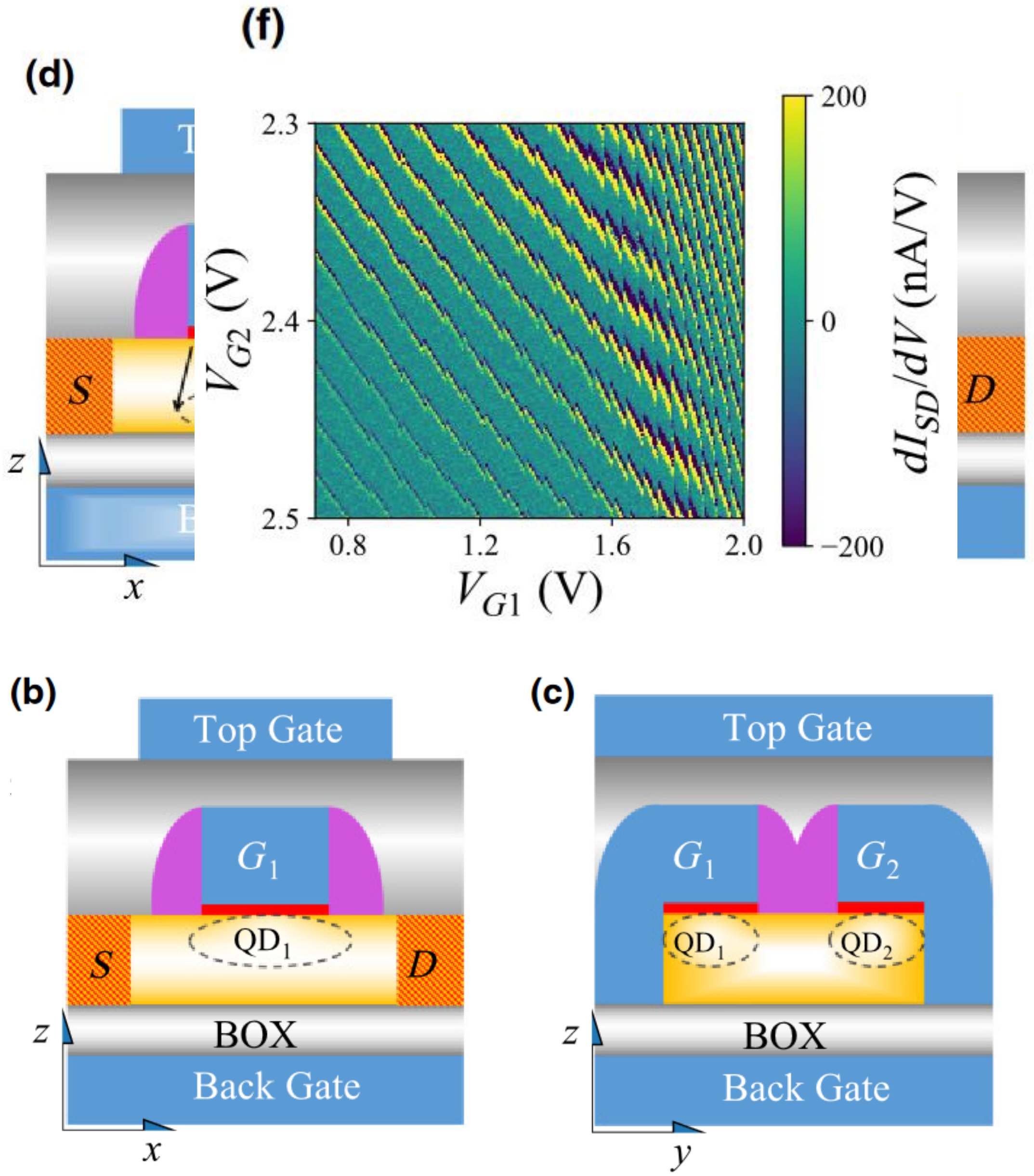
- electrons in silicon quantum dots (CMOS nanowires)
- coherence time given by natural/induced spin orbit interaction and charge noise (CN)
- CN is characteristics of material and qubit architecture
- CN in semiconductors induced by bistable charge traps = two level systems (TLSs):
  - dangling bonds at the semiconductor/oxide interface
  - dopants

Device Design



- 300-mm wafer
- 100 nm channel
- 60 nm wide split gate G_1, G_2
- 60 nm vertical gap
- Silicon nitride spacers (pink)
- doped leads
- Silicon bulk back gate (BG)
  activated by LED below 1 K, photoexcitation - minor change of CN
- metal top gate (TG)

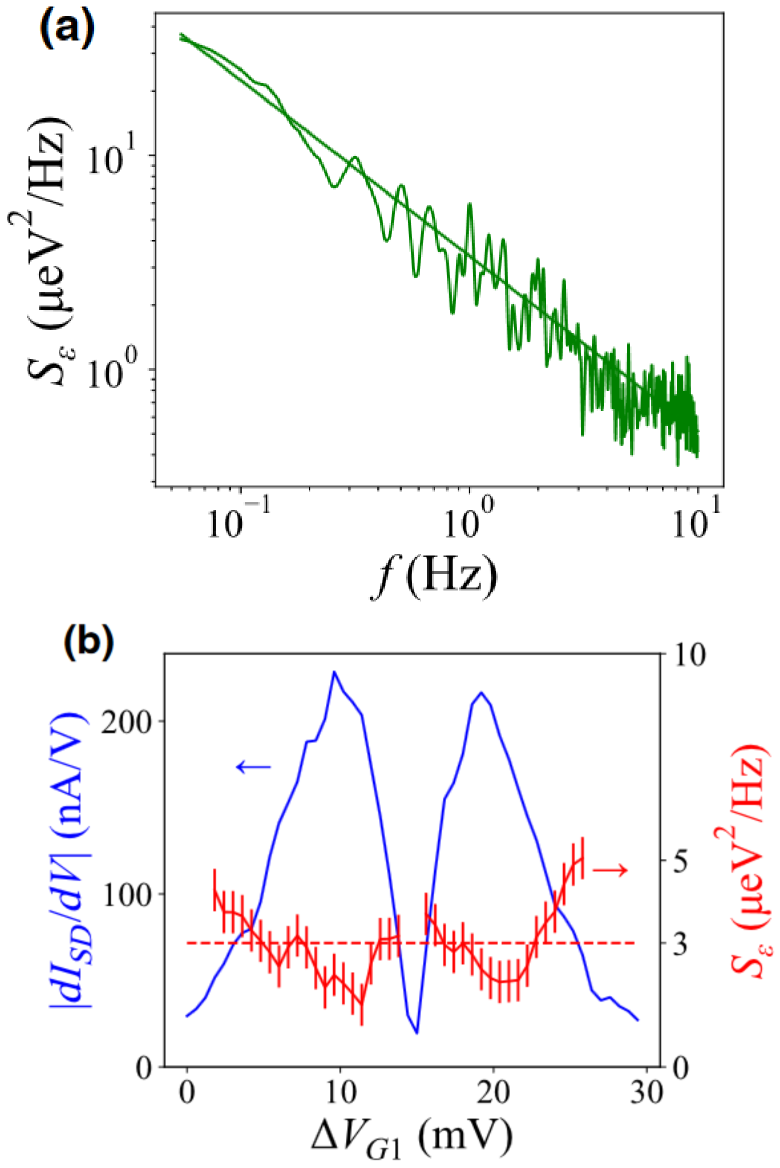
Device Operation



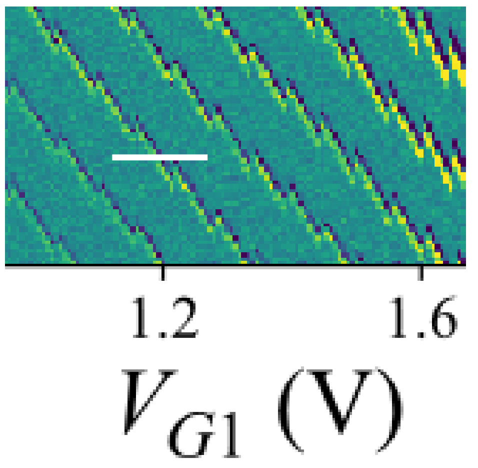
- T = 300 mK
- dots form under G_1 and G_2
- spatial extension and coupling to the leads is controlled by TG and BG
- one of the dots - charge sensor
- dot under G_2 as a sensor

- noise measurements: I_{SD} through dot under G_1 vs time

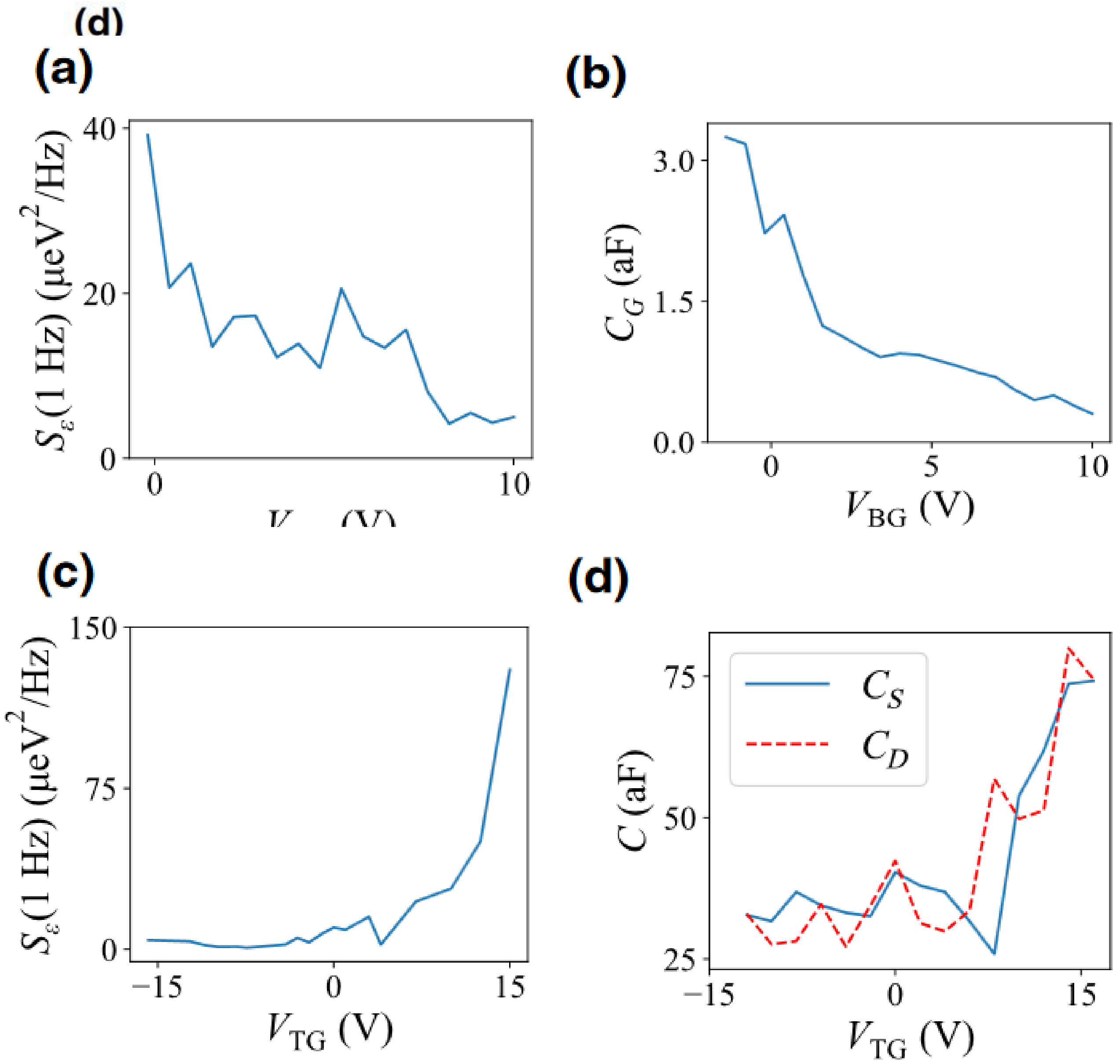
Charge Noise Measurements



- noise measurements: I_{SD} through dot under G_1 vs time
- FFT gives power spectral density (PSD)
- PSD normalized by dI/dV_G and lever arm
- constant PSD across Coulomb pick, 3 μeV^2/Hz at 1 Hz



Charge Noise vs Dot Shape



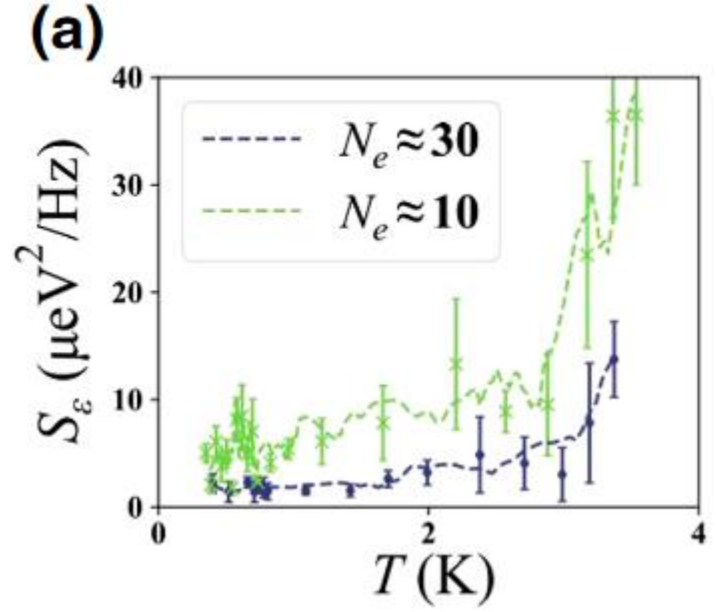
Bottom Gate

- positive BG moves the dot vertically down, decreases G_1 capacitance (C_{G1})
- CN goes down for the dot located away from top interface
- noise origin: large number of charge traps at Si/SiO_2 interface

Top Gate

- coupling to the leads induces CN
  - modify chemical potential of the dot
  - modify tunnel barrier transparency
- possible origin
  - dopants diffused in tunnel junction
  - SiN spacer with high density of TLSs

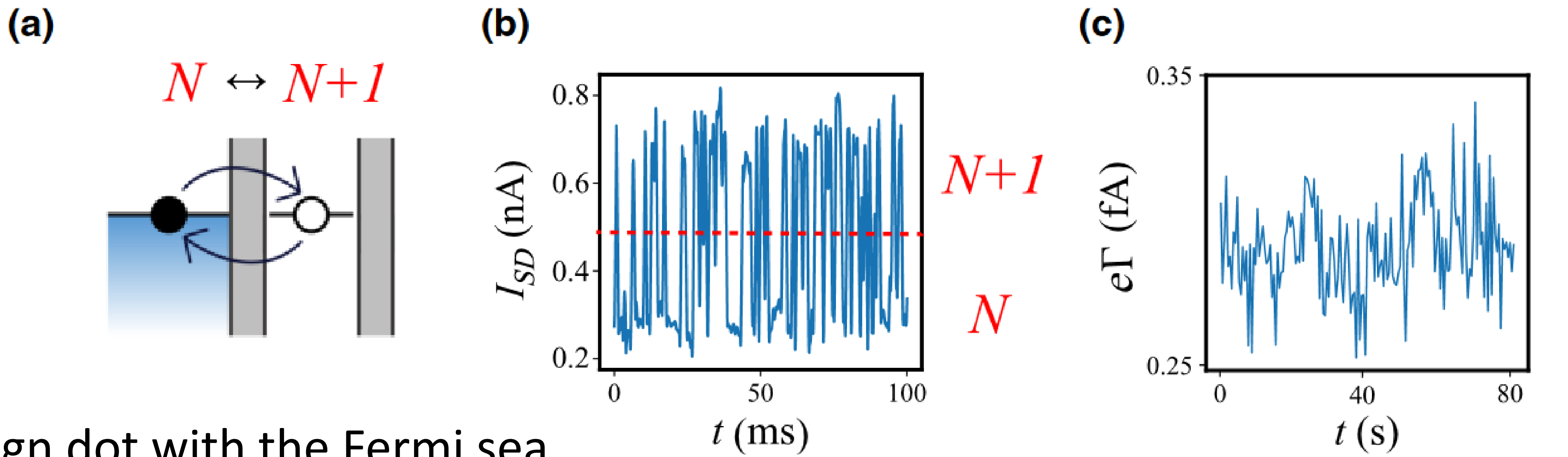
Charge Noise vs Dot Occupancy



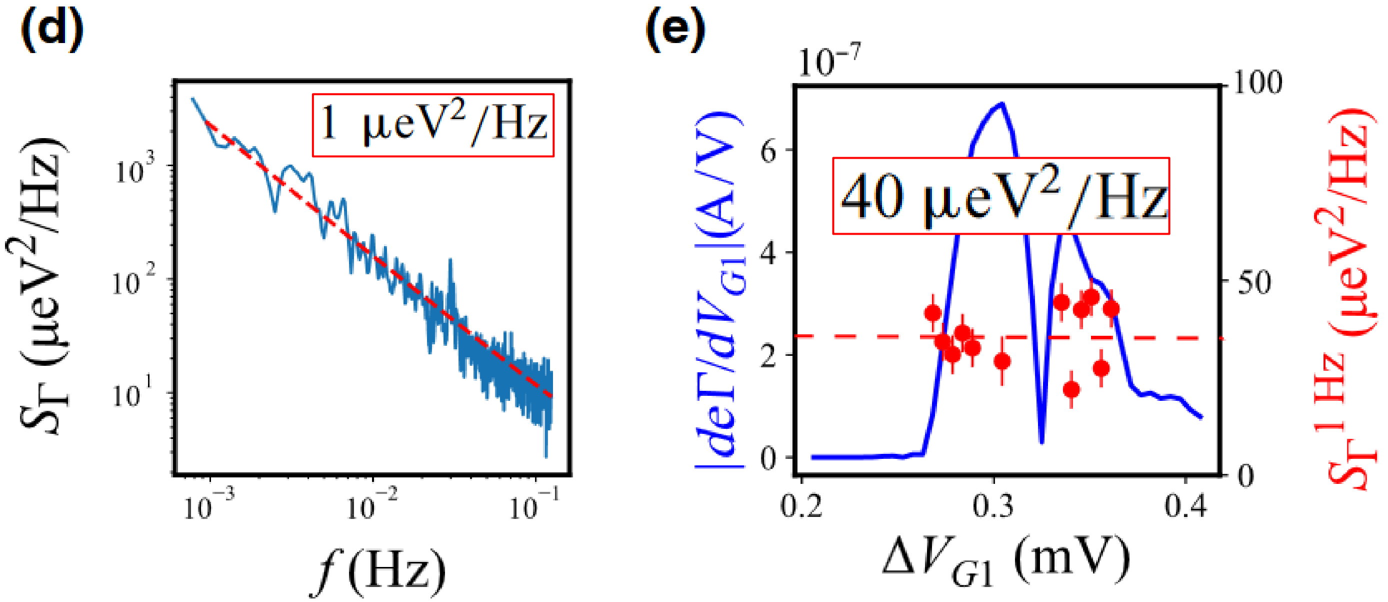
- CN is drastically reduced for dots with many electrons
  - increased self-capacitance
  - increased screening

- use qubit to measure CN
- **extract CN from fluctuations in the tunnel rate and average dot occupancy**

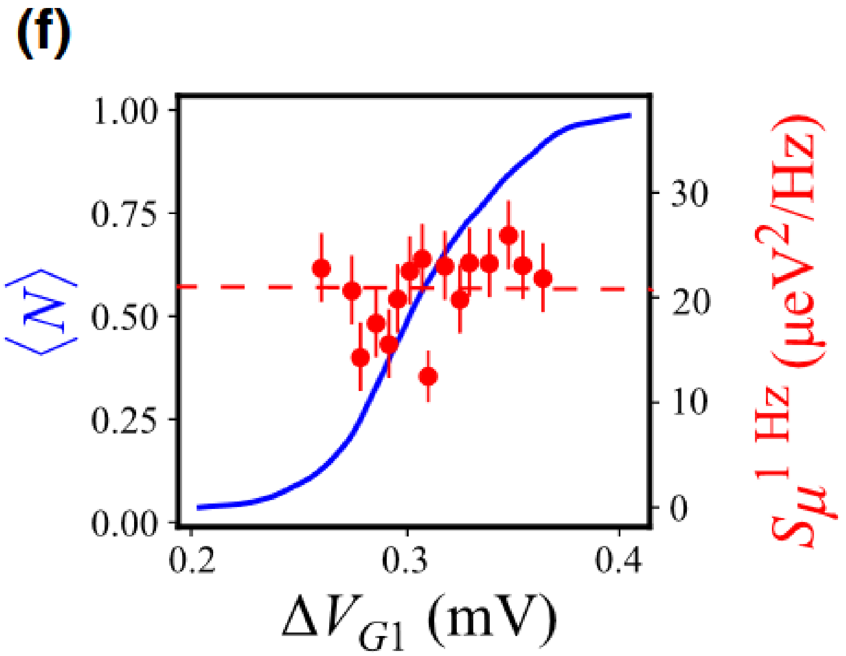
Charge Noise Measurements

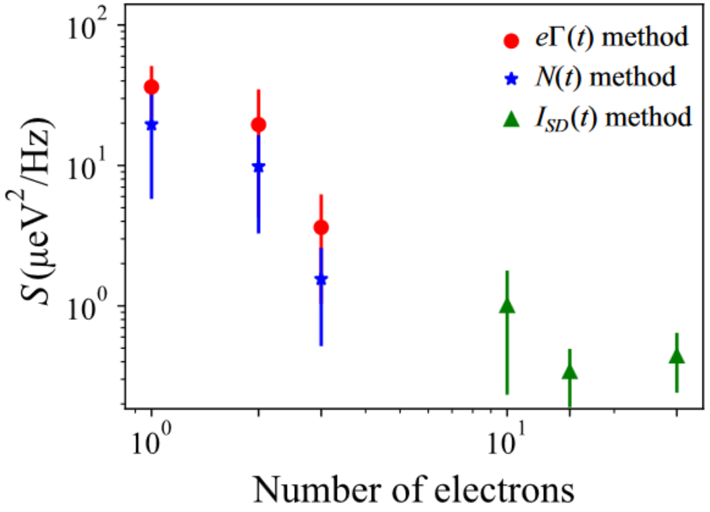


- align dot with the Fermi sea
- count charge transitions
- calculate tunnel rate and current
- optimal configuration
  $V_{BG} \approx 10$ V, $V_{TG} \approx 0$ V
- typical configuration
  V_{BG} , $V_{TG} \approx 0$ V



Chemical Potential Charge Noise





- mean occupancy of the quantum dot

$$\langle N \rangle = \frac{\langle \tau_{N=1} \rangle}{\langle \tau_{N=1} \rangle + \langle \tau_{N=0} \rangle}$$

- $\langle \tau_{N=1} \rangle$ - average time with 1 electron in the dot
- average charge noise power: 20 μeV²/Hz

- large error bars
  TLS density fluctuations vs gate voltage
- many electrons, smaller charge noise
  - large N, bigger dot, farther from the interface
  - screening effects, secondary
- RF readout needed for N_e = 4 – 10
  10-1000 MHz

Conclusion

- charge noise can be strongly tunable
- for low dot occupancy CN can be extracted using single-shot readout
- disentangle chemical potential noise from tunnel coupling fluctuations

- $1/f^2$, 0.1 Hz TLSs
  SiO2, dielectric
- 1/f, 0.1-100 Hz TLSs
- 10 Hz TLSs
  dopants