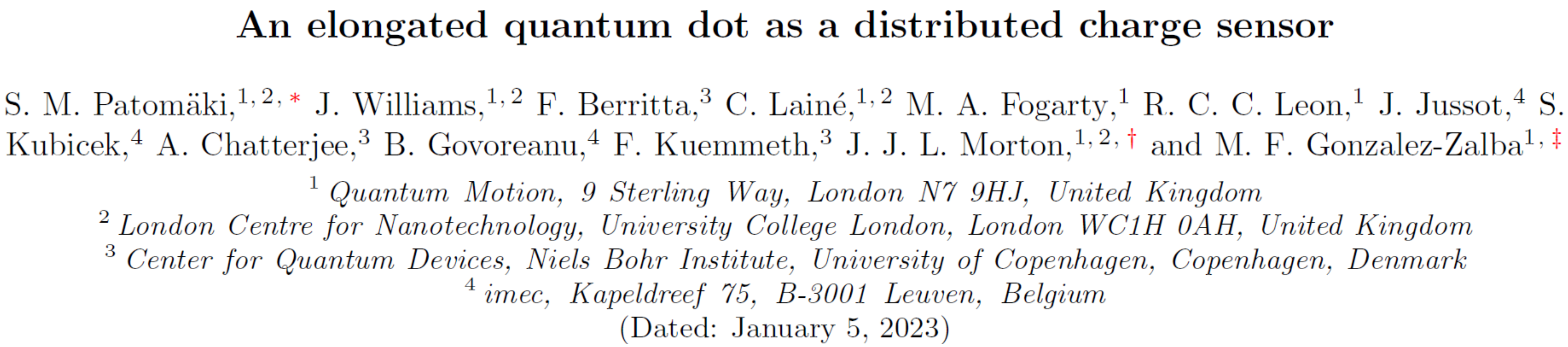

An elongated quantum dot as a distributed charge sensor

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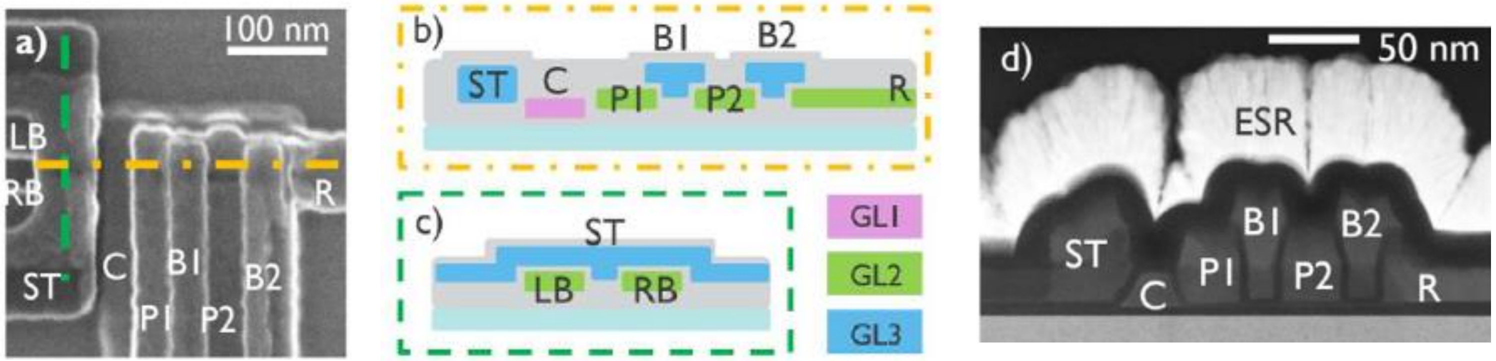
Overview

- Recent preprint form Quantum Motion team
- Reflectometry measurements on Imec Si-MOS devices
- Elongated (“jellybean”) quantum dot (EQD, approx. 340 nm long) is used for sensing dots on the left&right side of the dot (separated by 510 nm from each other)

Device type (Imec)

- Si-MOS QD device (Imec) (no SEM/TEM images shown in the paper)
- n+ phosphorous doped polycrystalline silicon gates, 30 nm thick (‘all-Silicon’ approach, e-beam)
- Triple gate layer stack on 8 nm thermal SiO_2 film, patterned on high-R p-type Si wafer
- Gates isolated by 5nm ALD-based SiO_2

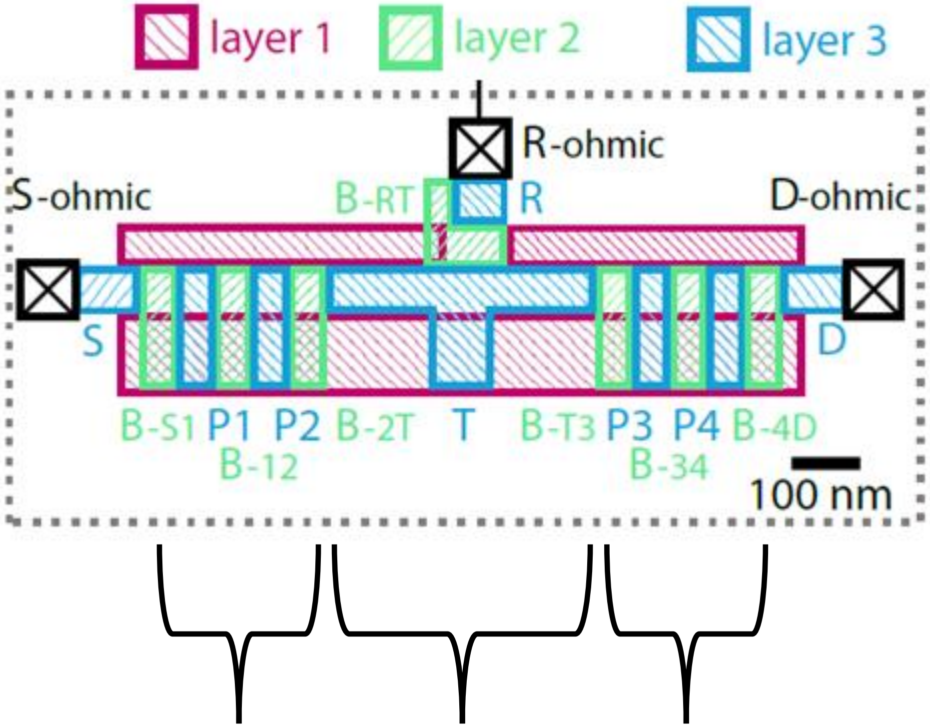
Same type of gate stack as other Imec devices (different design):



(from N. I. Dumoulin Stuyck et al., 2021 Symposium on VLSI Circuits. 2021; p. 1-2)

Their device

- Confinement for 3 possible paths connecting Ohmics
- Barriers between elongated QD (EQD), QDs and reservoirs
- Plungers to control occupation of EQD, QDs and extension of 2DEG from under accumulation gates for reservoir (R), source (S) and drain (D)



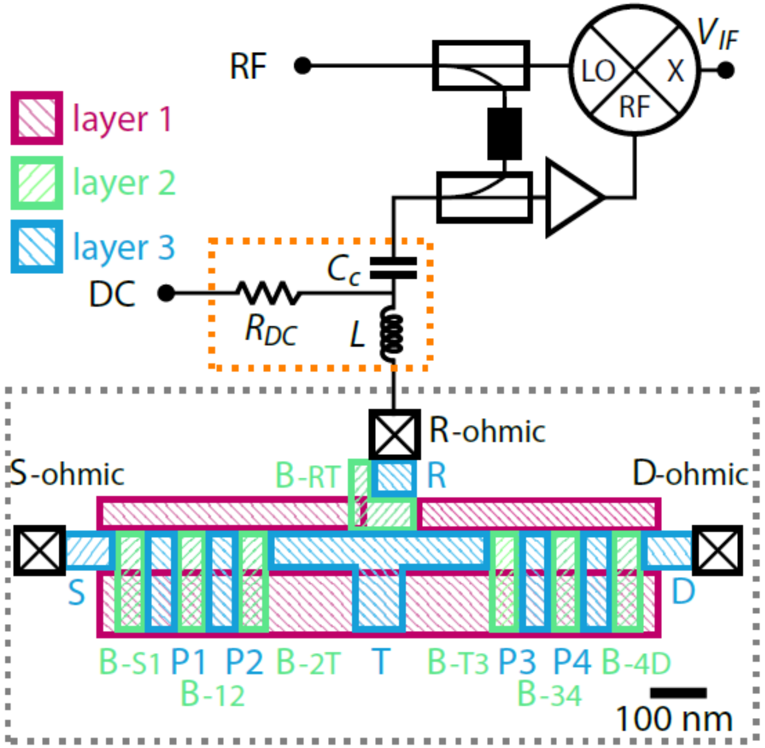
Left QD(s) EQD Right QD(s)

Their setup

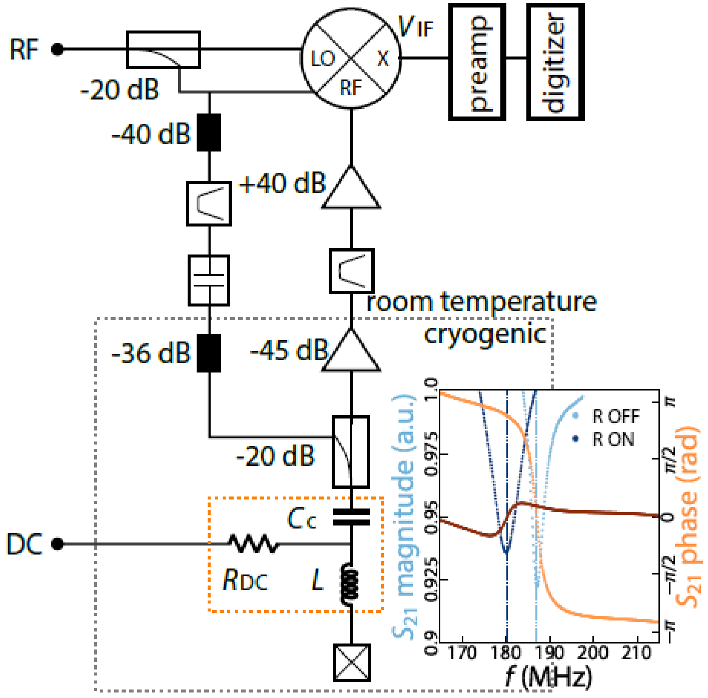
- Oxford Instruments Triton fridge
- QDevil DACs&Thermalizing filters, sample holder
- Reflectometry with a VNA:

V_{RF} drives single-e tunneling
Currents between R&EQD if not in Coulomb blockade
→ complex Z of device changed
→ f_{res} & matching Z of resonator changed

DAC t_{sample} = 0.1 ms , f_{ramp} = 10 kHz
Start of DAC ramp triggers digitizer
V_{IF} digitized @ 1 MS/s, preamp
f_{LP} = 10 kHz, n_{avg} = 10
→ Tint = n_{avg}/f_{LP} = 1 ms



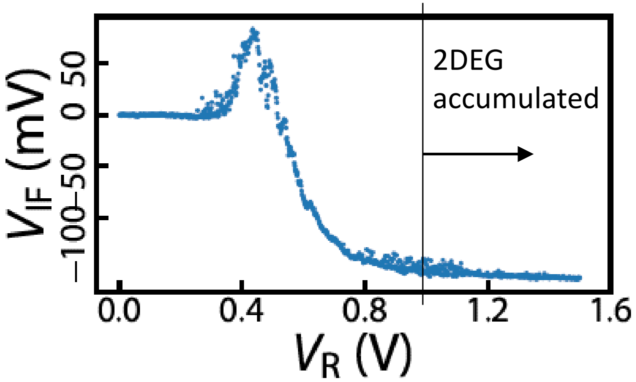
More detailed:



$R_{\mathrm{DC}} = 49.99\ \mathrm{k\Omega},\ L = 820\ \mathrm{nH},\ \mathrm{and}\ C_{\mathrm{c}} = 22\ \mathrm{pF}$

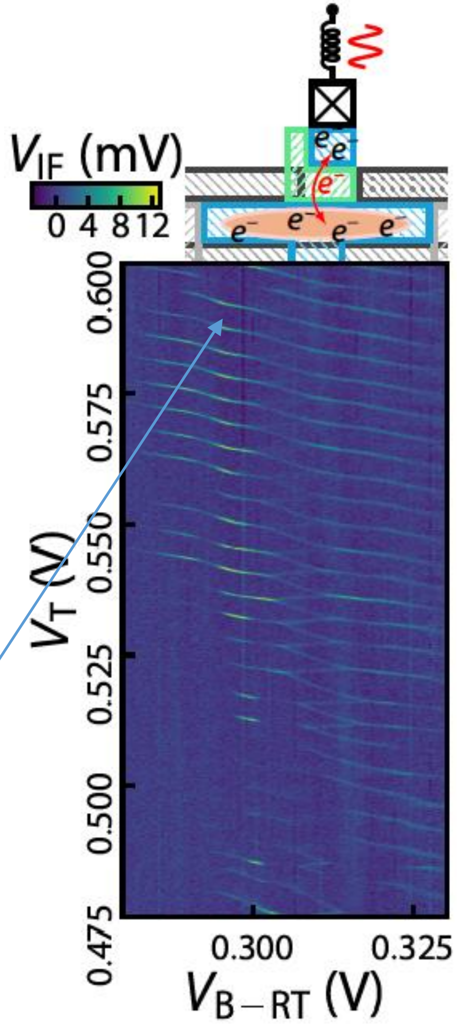
Single-electron box (SEB) operation

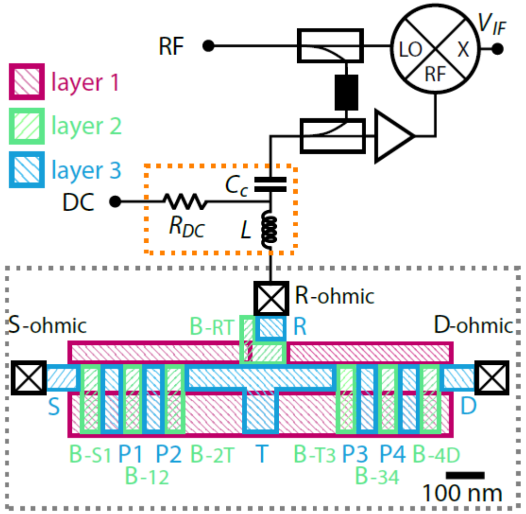
- Positive voltage at gate R → extend 2DEG close to active region of device from nearby ohmic contact



- Tune EQD plunger gate T above pinchoff, adjust tunnel rate via barrier gate B-RT:

To maximize signal, they later choose $V_{B\text{-}RT}$ ~ 0.3 V
And V_T ~ 0.7 V (not shown)





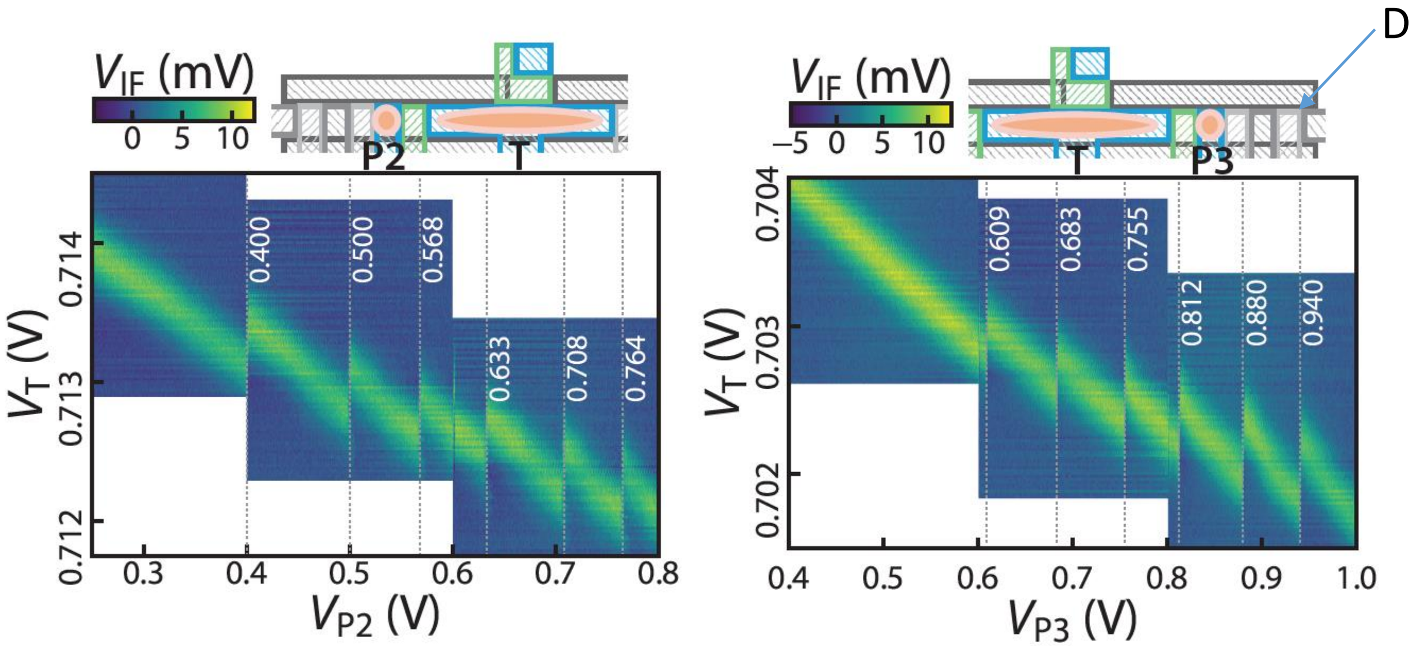
~single dot

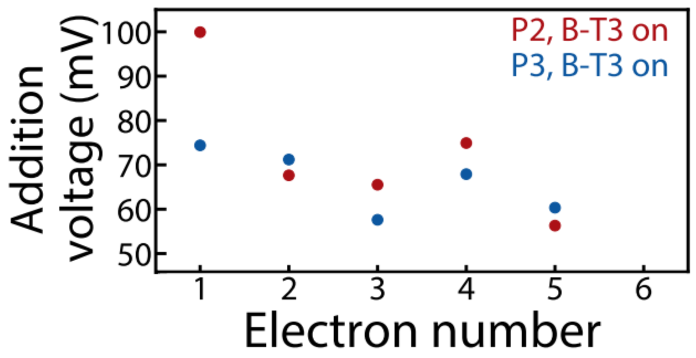
~2+ coupled dots

Charge sensing of quantum dots

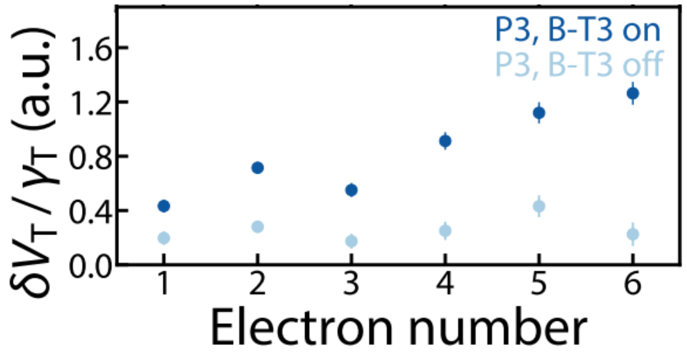
- EQD is operated as a SEB to sense first electron transition
- Signal-to-noise ratios $\mathrm{SNR}_{\mathrm{P2}} = 10.7 \quad \mathrm{SNR}_{\mathrm{P3}} = 14.6$

at one electron & 1 ms t.c. (at Sensor peak)





- Increase in V_{add} on 4th->5th electron; lowest two ±z valley-orbit states



- Shift in VT vs. SEB transition linewidth
- $V_{\mathrm{B\text{-}T3}} = 0.225$ V (on)
- B-T3 off: electrons loaded via D

Charge sensing coupled quantum dots (I)

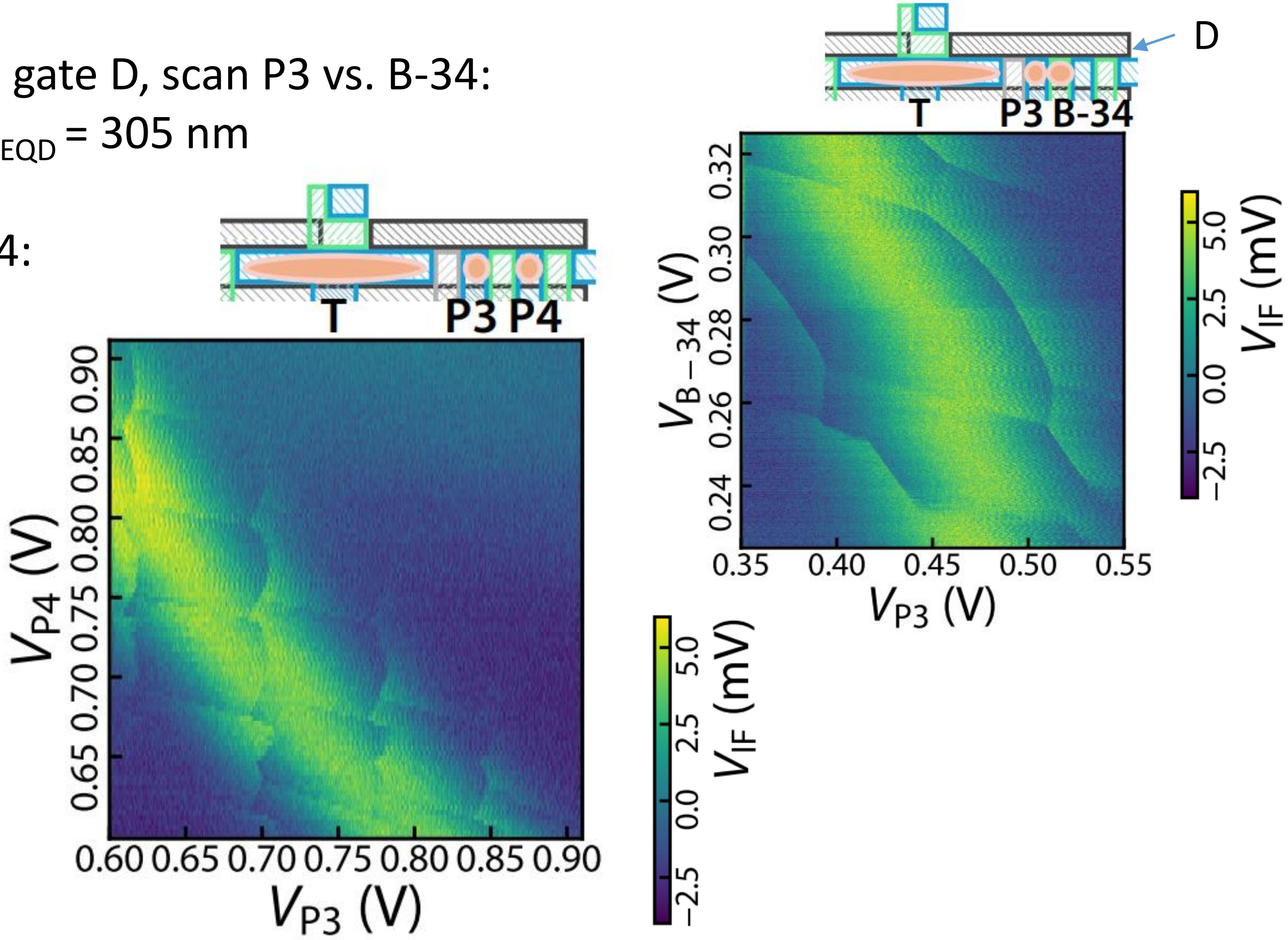
- Right reservoir 2DEG extended with gate D, scan P3 vs. B-34:

→ honeycomb, center-center $d_{\text{right dot–EQD}} = 305$ nm

- Next, DQD is formed with P3 and P4:

→ Latching along P3 axis, suggests P3-P4 or P4-D tunnel rates on order of ramp frequency

→$d_{\text{right dot–EQD}} = 355$ nm seems to be Their limit here



Charge sensing coupled quantum dots (II)

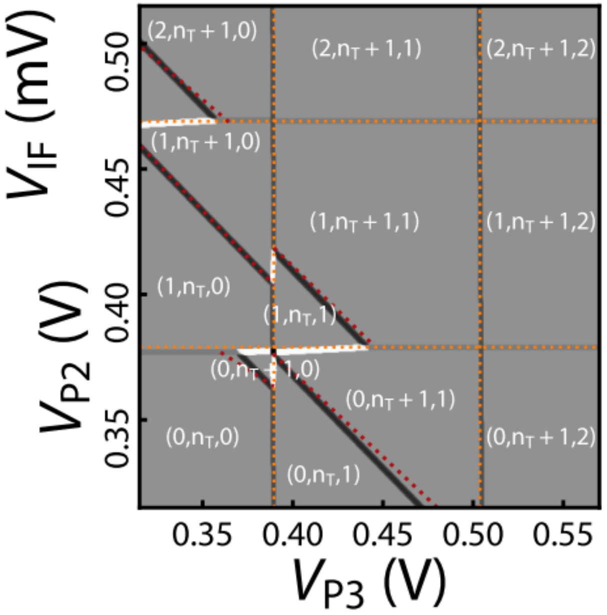
- Lastly, they form a triple dot with the EQD:

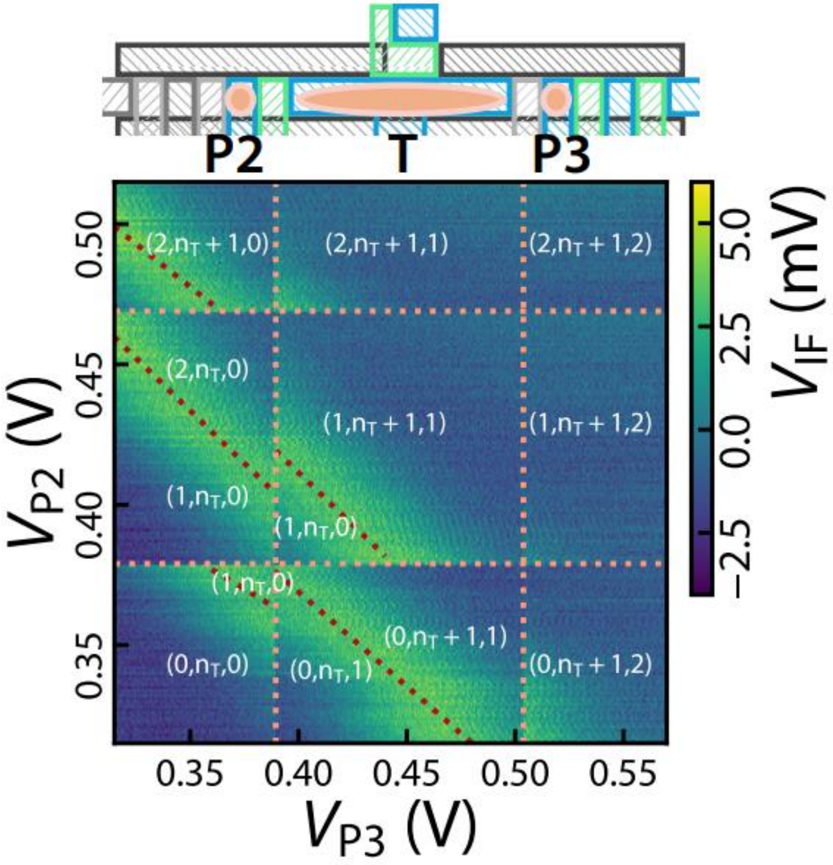
- Labels based on stability diagram simulation that uses Experimentally estimated lever arms & charging energies

- Lever arm ratios from fitted SEB peaks (red) show close to zero P2-P3 crosstalk

- One SEB charge transition is capacitively shifted by both P2 and P3 → EQD extends approximately over region T

Simulation:





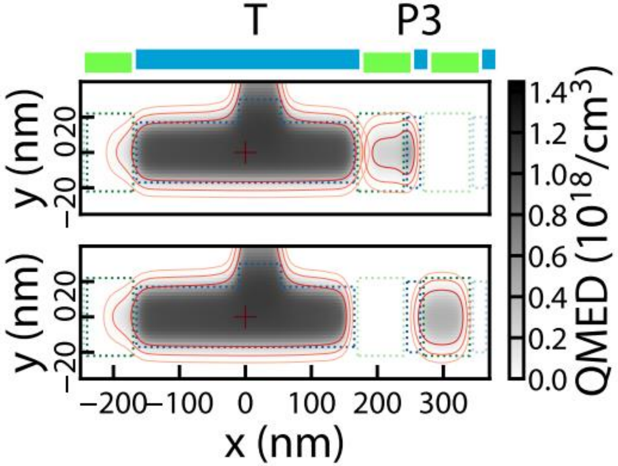
Simulated quantum-mechanical electron densities

- Self-consistent Schroedinger-Poisson solver to evaluate quantum-mechanical electron densities (QMED)

→ Estimate shapes of many-electron charge states

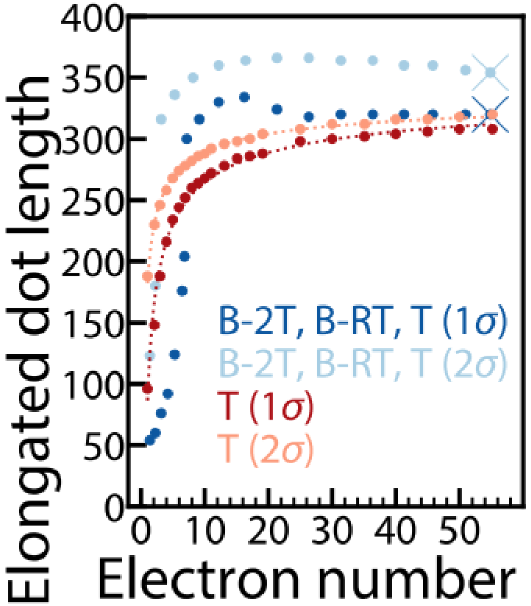
- EQD length obtained from simulated 1σ and 2σ contours

→ Studied for different #electrons (different V_T)



Top: B-T3 positive bias

Bottom: B-T3 @ 0



$$x_{\mathrm{EQD}} = a n_{\mathrm{T}}^{-1/2} + b$$

a<0

n_T: sim. Electron number

b = 347 nm

b = 339 nm

→When only gate T is biased, the EQD length increases monotonically

→With other gates involved, EQD length behaves more complicated (e.g. B-RT gate pulls electrons)

Summary&Outlook

- Demonstrated EQD as a rf-SEB charge sensor sensing QDs up to 355 nm away from EQD (QD-QD distance >700 nm), supported by simulations

- Potential for scalable QD unit cells, e.g. with a single sensor for multiple closeby quantum dots → novel QD unit cell layout requiring potentially less gate structures for readout

- Another potential application: Mid-ranged spin qubit coupler [1]

[1] F. Malinowski et al., Nat. Comms. 2019