University of Basel | Journal Club

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November 11th 2022
(Fall Semester)

# Microwave-Frequency Scanning Gate Microscopy of a Si/SiGe Double Quantum Dot

**ABSTRACT:** Conventional transport methods provide quantitative information on spin, orbital, and valley states in quantum dots but lack spatial resolution. Scanning tunneling microscopy, on the other hand, provides exquisite spatial resolution at the expense of speed. Working to combine the spatial resolution and energy sensitivity of scanning probe microscopy with the speed of microwave measurements, we couple a metallic tip to a Si/SiGe double quantum dot (DQD) that is integrated with a charge detector. We first demonstrate that the dc-biased tip can be used to change the occupancy of the DQD. We then apply microwaves through the tip to drive photon-assisted tunneling (PAT). We infer the DQD level diagram from the frequency and detuning dependence of the tunneling resonances. These measurements allow the resolution of ~65 $\mu$eV excited states, an energy consistent with valley splittings in Si/SiGe. This work demonstrates the feasibility of scanning gate experiments with Si/SiGe devices.

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# Outline

- Device
- Tunability and Operation Modes (SQD, DQD)
- Influence of the Tip
- Photon Assisted Tunneling —> Method to extract tunnel rates!

# Device

- **Si/SiGe hetero structure:** 5 nm Si QW under 50 nm $Si_{0.7}Ge_{0.3}$ capped by 2 nm Si
- Overlapping **Al gate** electrodes **25 nm**, **45 nm**, **75 nm**
- **Metallic tuning fork AFM** + bias-T for DC & μ-waves
- Experiment in Bluefors XLD **@150 mK**
- They characterized 3 reproducible devices, showing one here

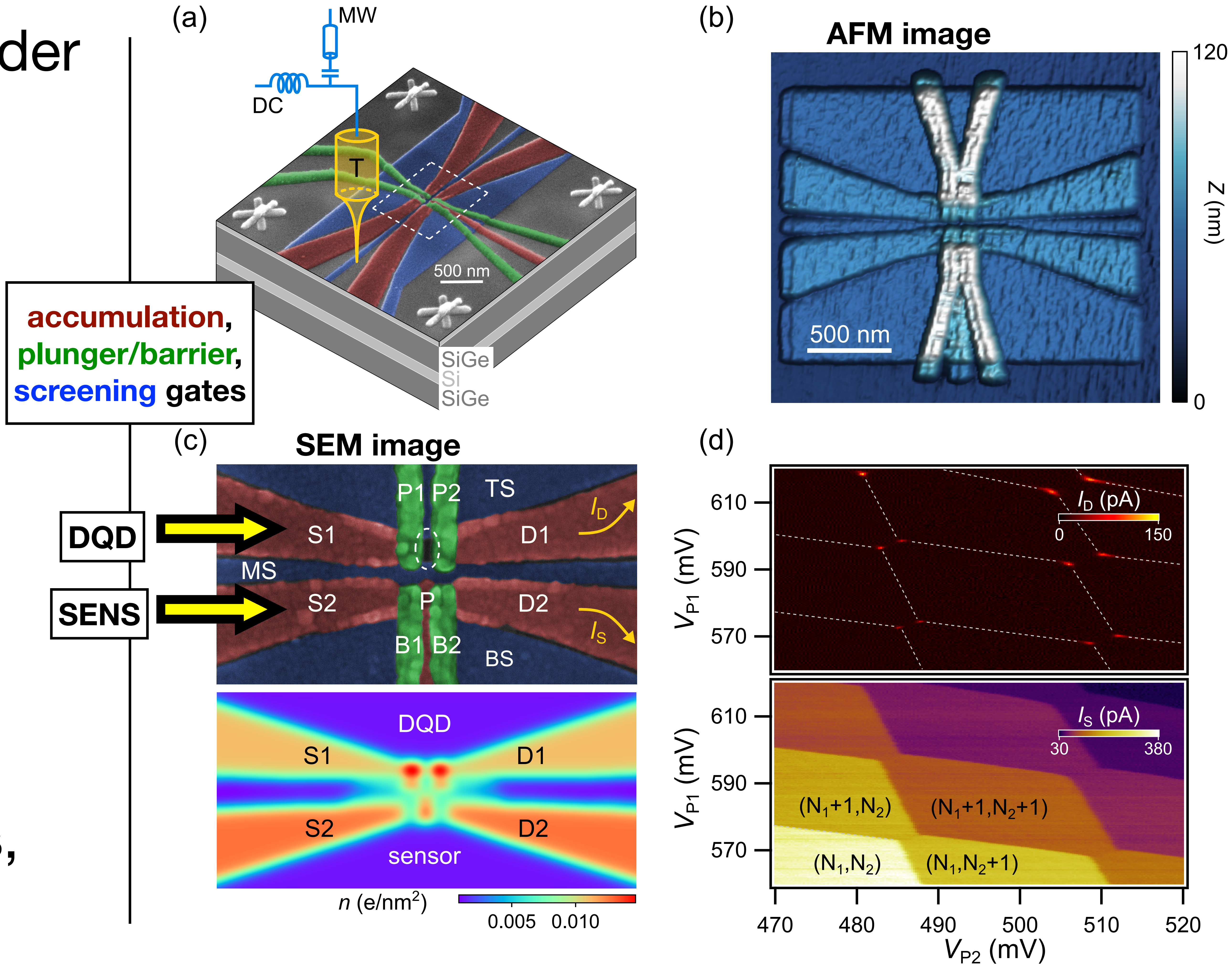
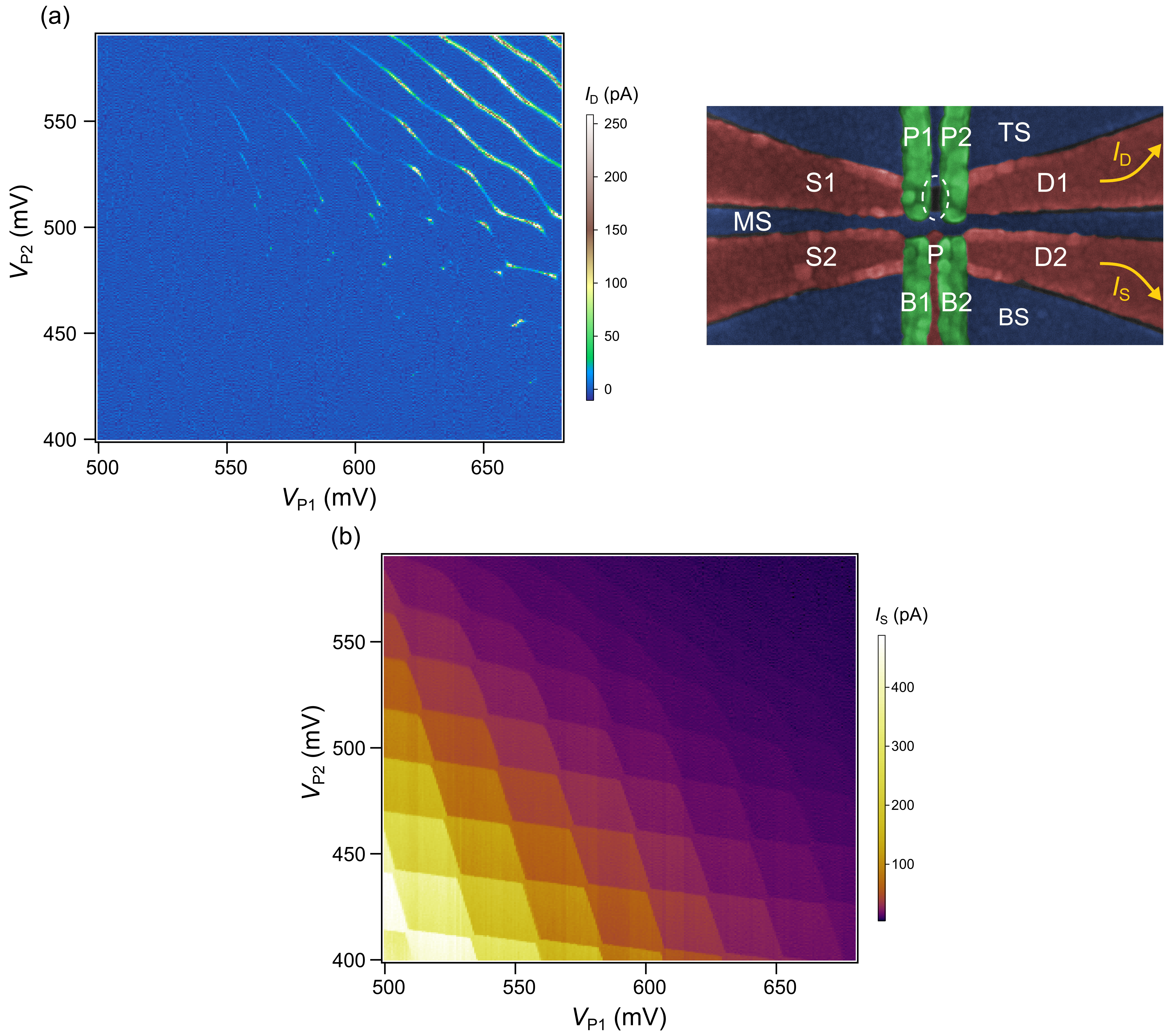



Fig. 1

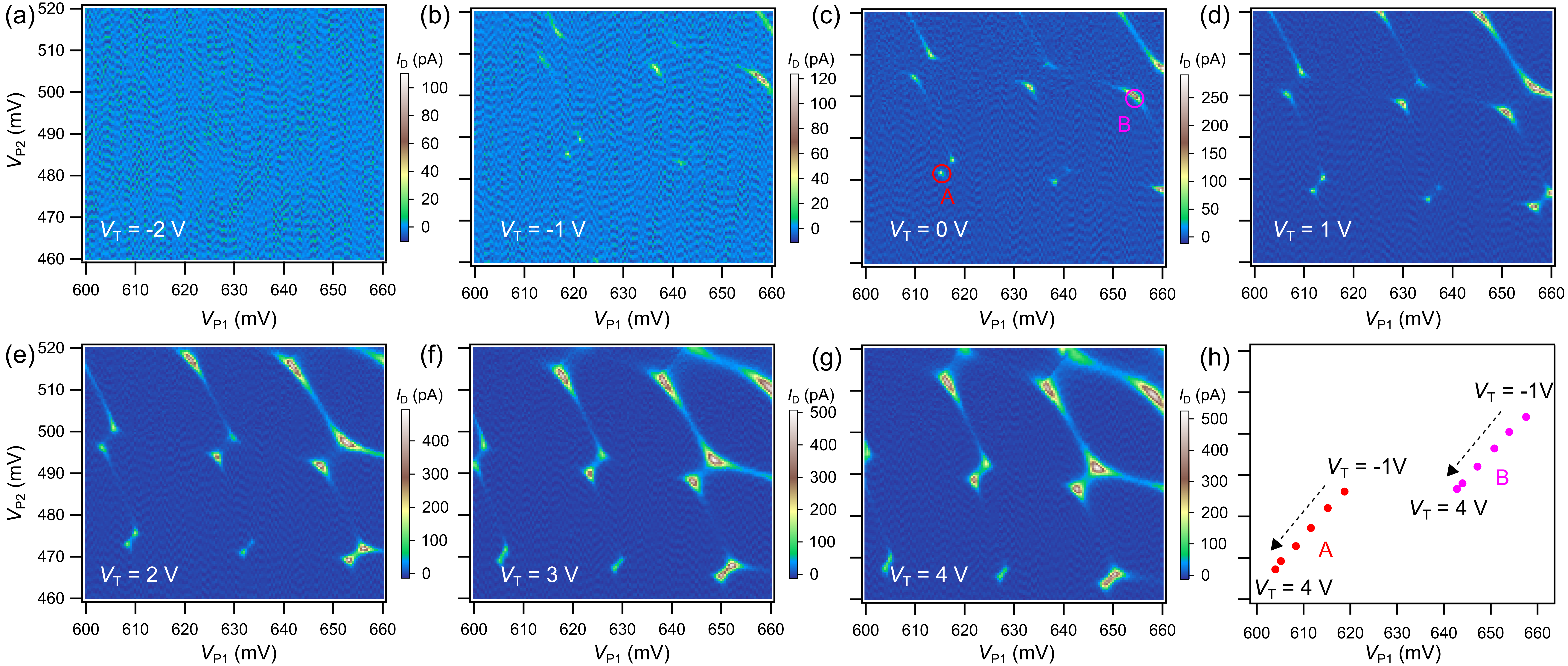
# Tunability

- Accumulation of $e^-$ below **S** & **D**, using **P** & **B** as plungers (also acc. mode)
- lack of interdot barrier for tip access
- **images on right:** $V_T$ = 6 V and ~150 nm above sample
- Sensor insensitive to interdot transitions $N_1 + N_2$ = const.



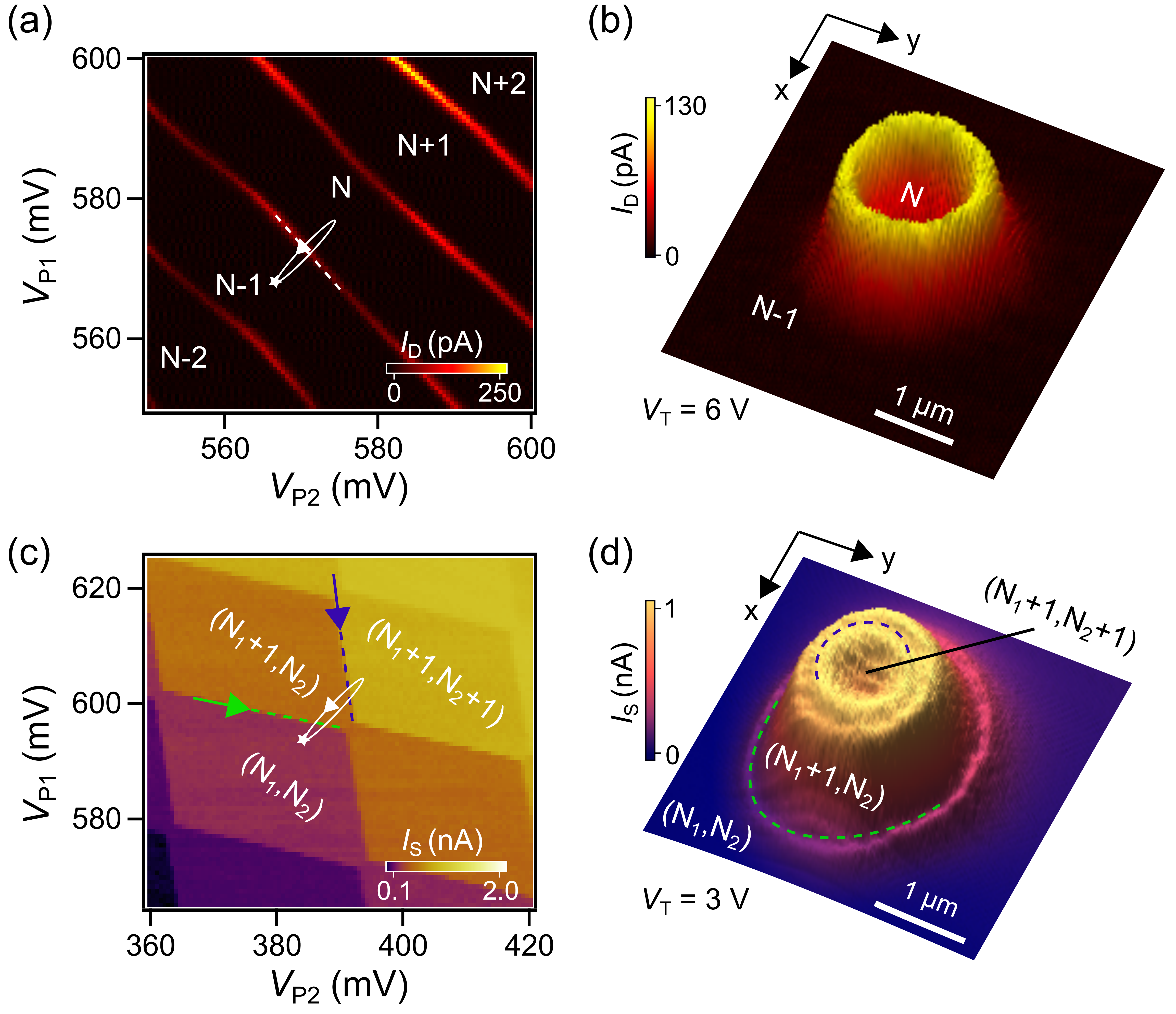
# Influence of Tip

- Tip height ~100 nm

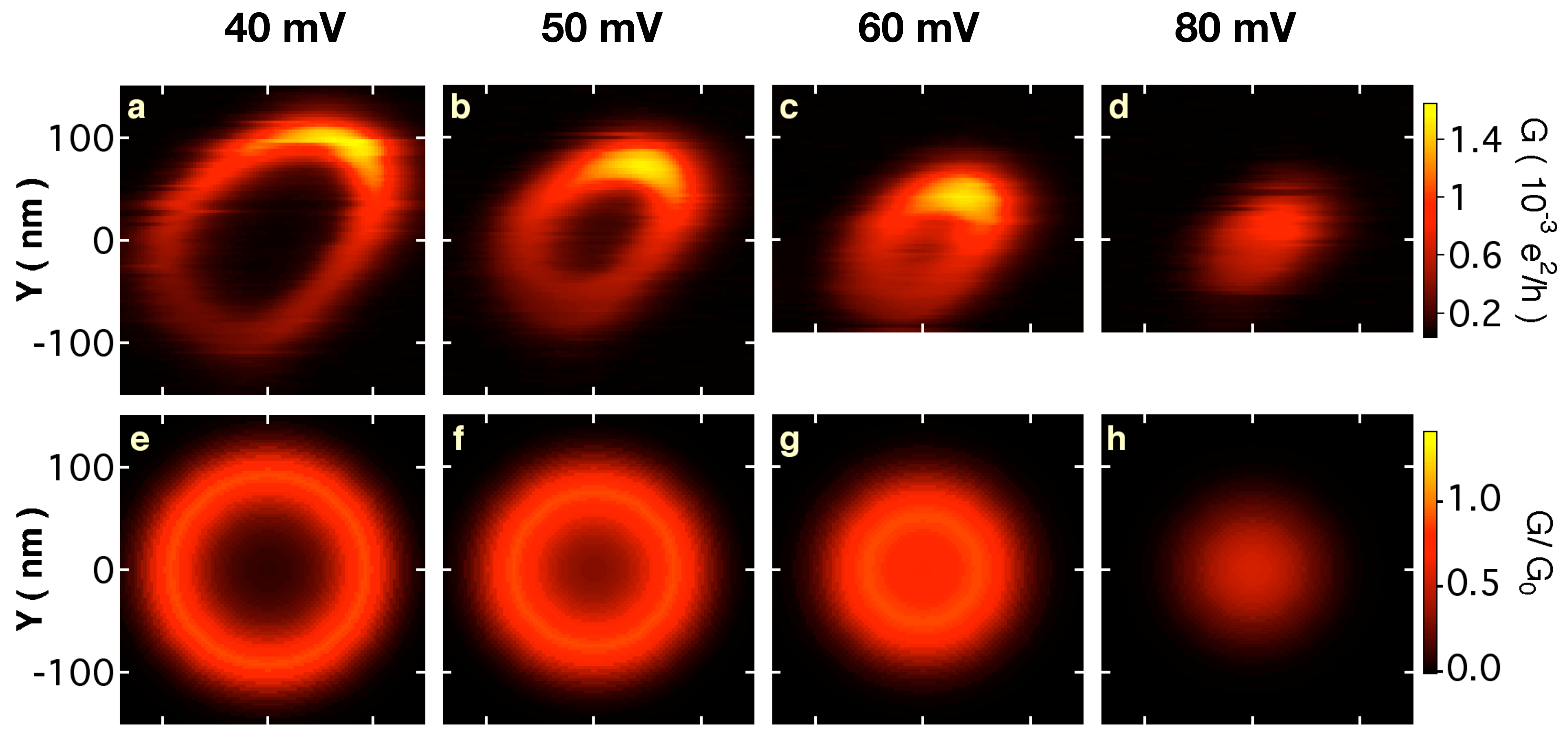


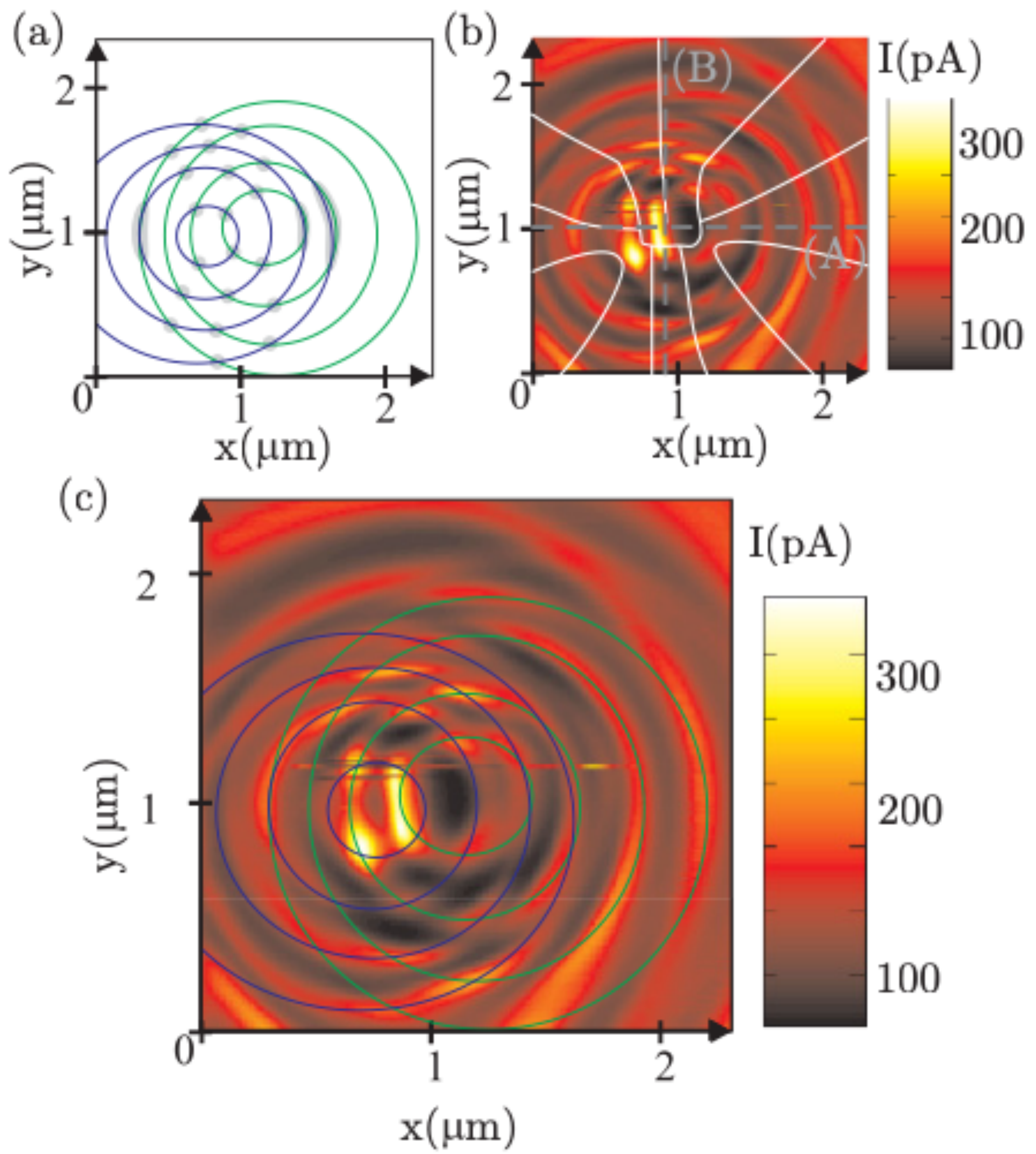
# Single QD Regime

- **Elongated DQ** “initialized” in N-1 state with **tip far away**
- During scanning (SGM), $V_P$’s held constant
- Tip $V_T$ = 6 V and 150 nm above structure
- Coulomb-ring —> constant tip-device interaction



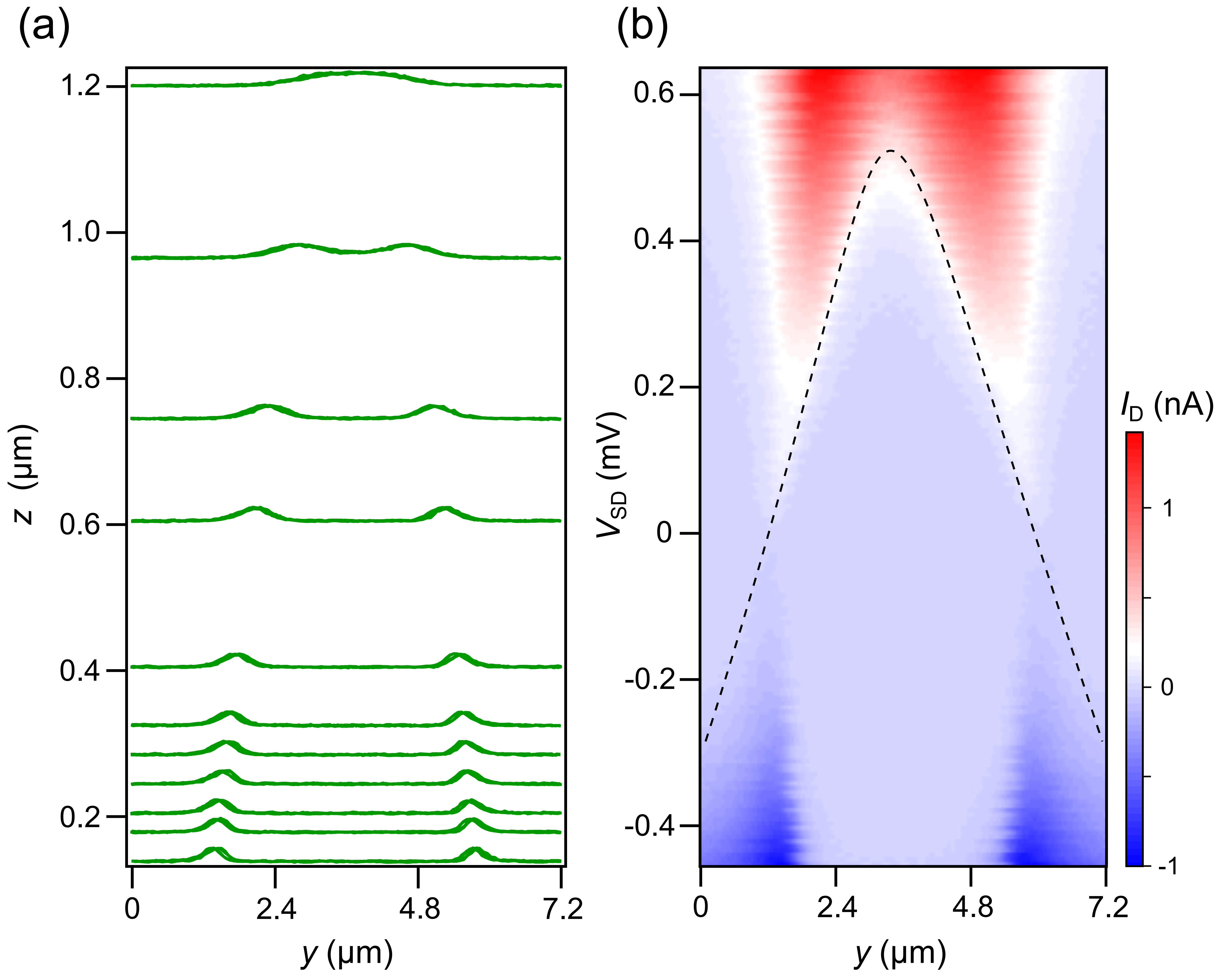
# Previous Work, SQD vs DQD



# Tip Potential

- a) Vary tip height at fixed $V_T = 1.2$ V
- b) Vary y-position at fixed height 100 nm
- —> **y-position** effectively **acts as plunger**



# Leverarm Extraction

$$\begin{pmatrix} Q_1 \\ Q_2 \end{pmatrix} = \begin{pmatrix} 6.6 & 0.5 & 0.031 \\ 1.3 & 5.3 & 0.023 \end{pmatrix} \begin{pmatrix} V_{P1} \\ V_{P2} \\ V_T \end{pmatrix}$$

in aF

- Small tip to dot leverarm due to small window 80 nm x 50 nm
- Screening of tip by gates

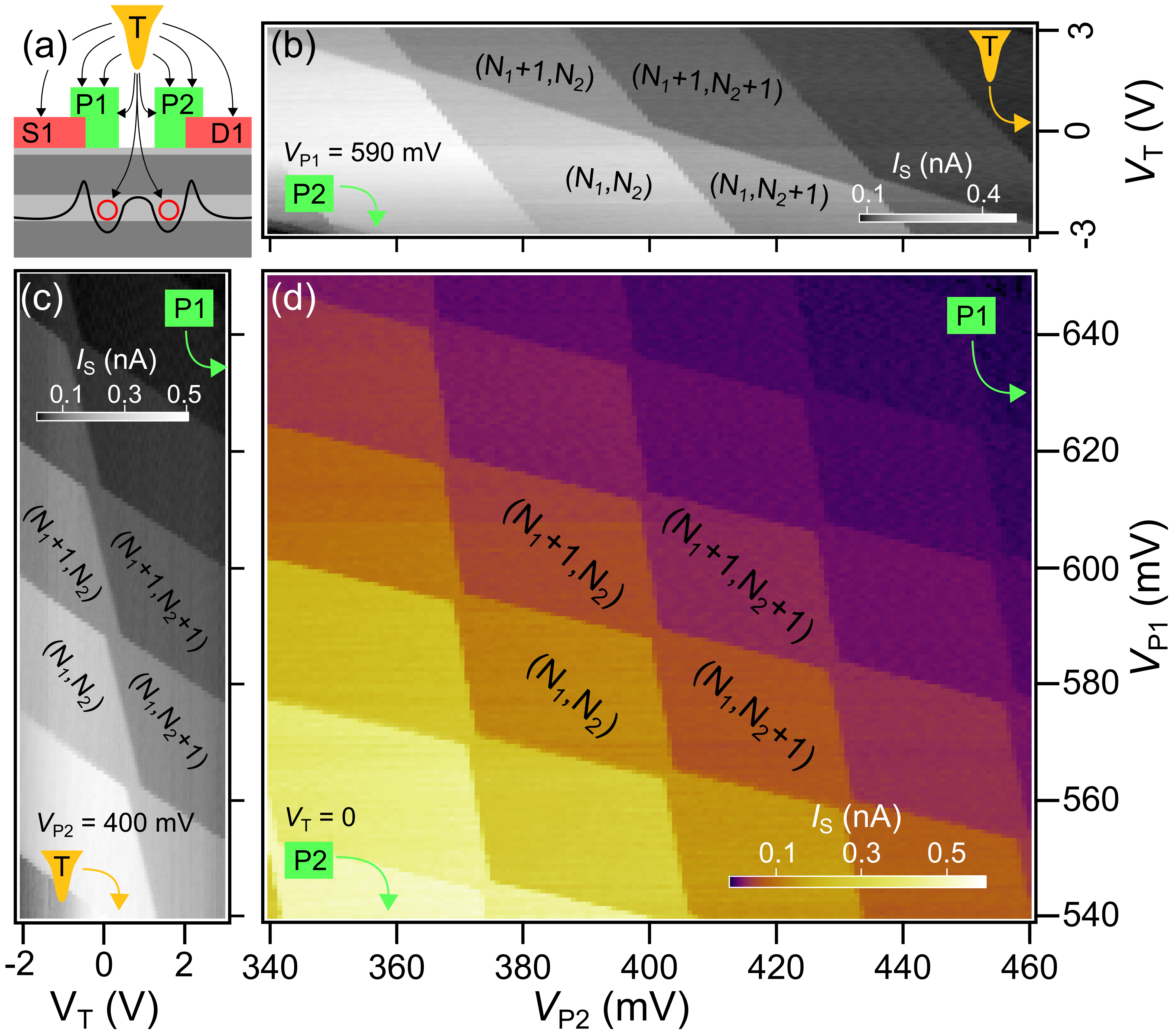
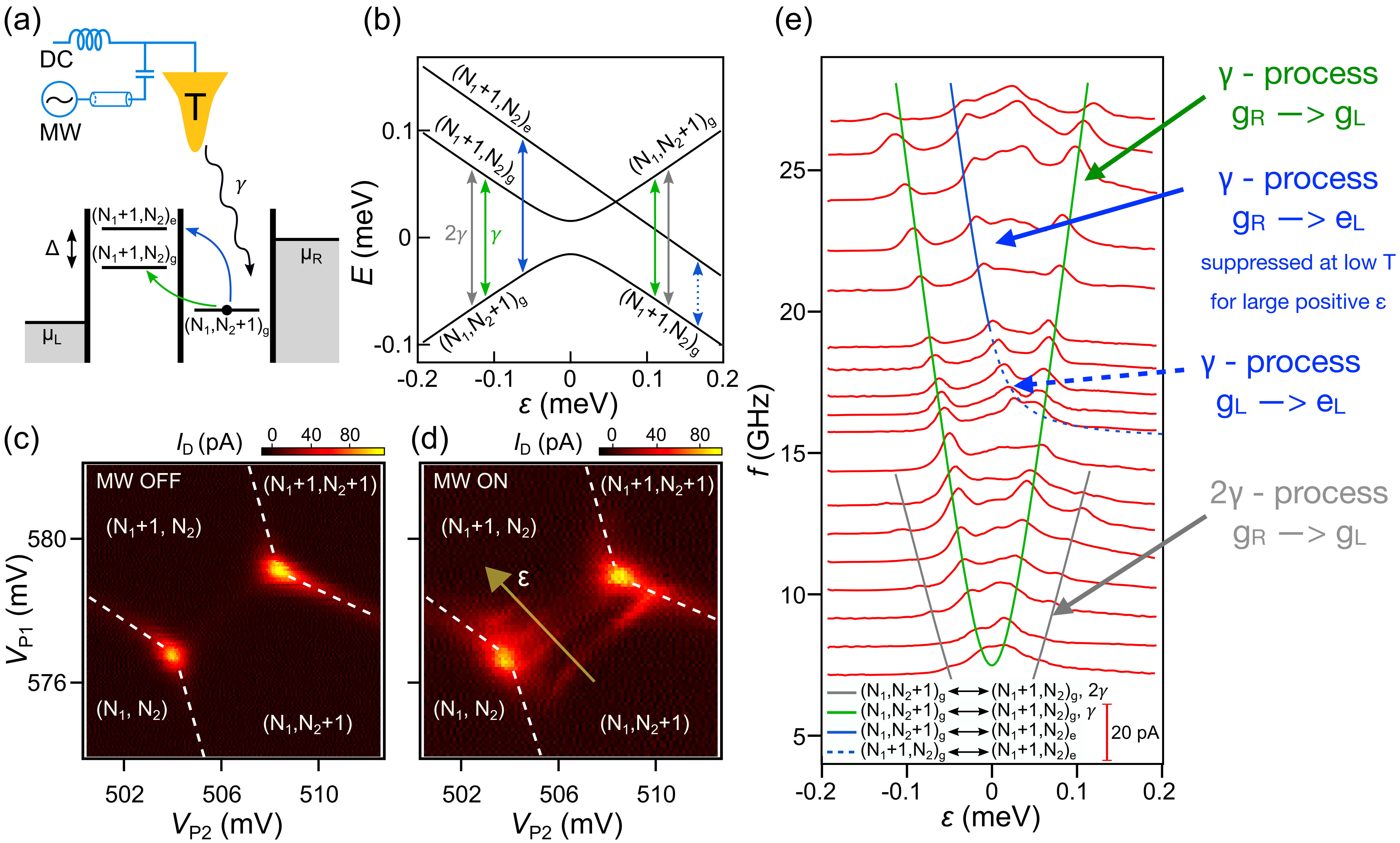



Fig. 3

# Photon Assisted Tunneling

- $V_{SD} = \mu_L - \mu_R = -80\ \mu V$
- $hf = \sqrt{\varepsilon^2 + 4t^2}$
- $t = 16\ \mu eV$ , $\Delta_{ex} = 64\ \mu eV$
  (Δ consistent with valley splittings)
- $(N_1 + 1, N_2)_g$ <—> $(N_1 + 1, N_2)_e$ for |ε| > 2t as it does not contribute to net current



# Conclusion

- Performed manipulation and imaging of single electrons inside DQD by means of transport and sensing measurements

- Characterise tip-device interactions

- Excited state spectroscopy with PAT scans and extracted tunnel rates