SAND2008-1675C

Coulomb Blockade in Double Top Gated Si MOS Nano-Structures

APS March Meeting 2008

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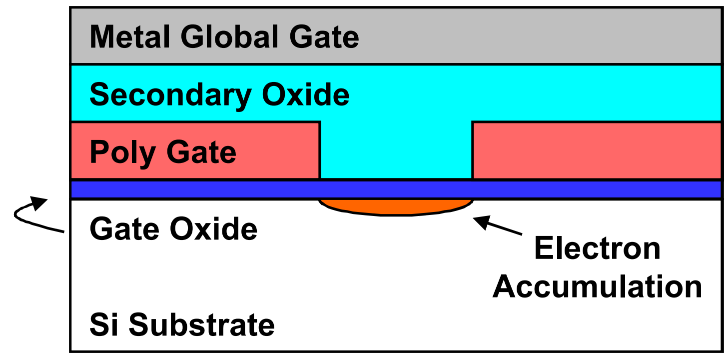
- Goal:
  - Coupled Few-Electron Quantum Dot in a Silicon/Silicon Dioxide Inversion Layer
- This Talk:
  - Nanostructure Fabrication
  - Nanostructure Characterization
  - Continuing Progress and Outlook

Two-Dimensional Electron Gas Formation in MOS Double Top Gate

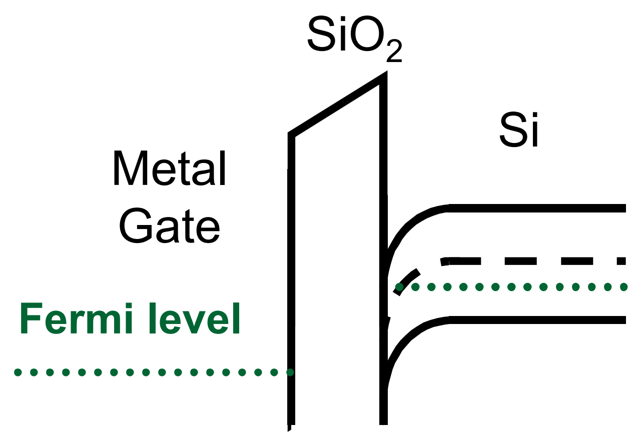


Advantages Si Quantum Dot Spin Qubits:

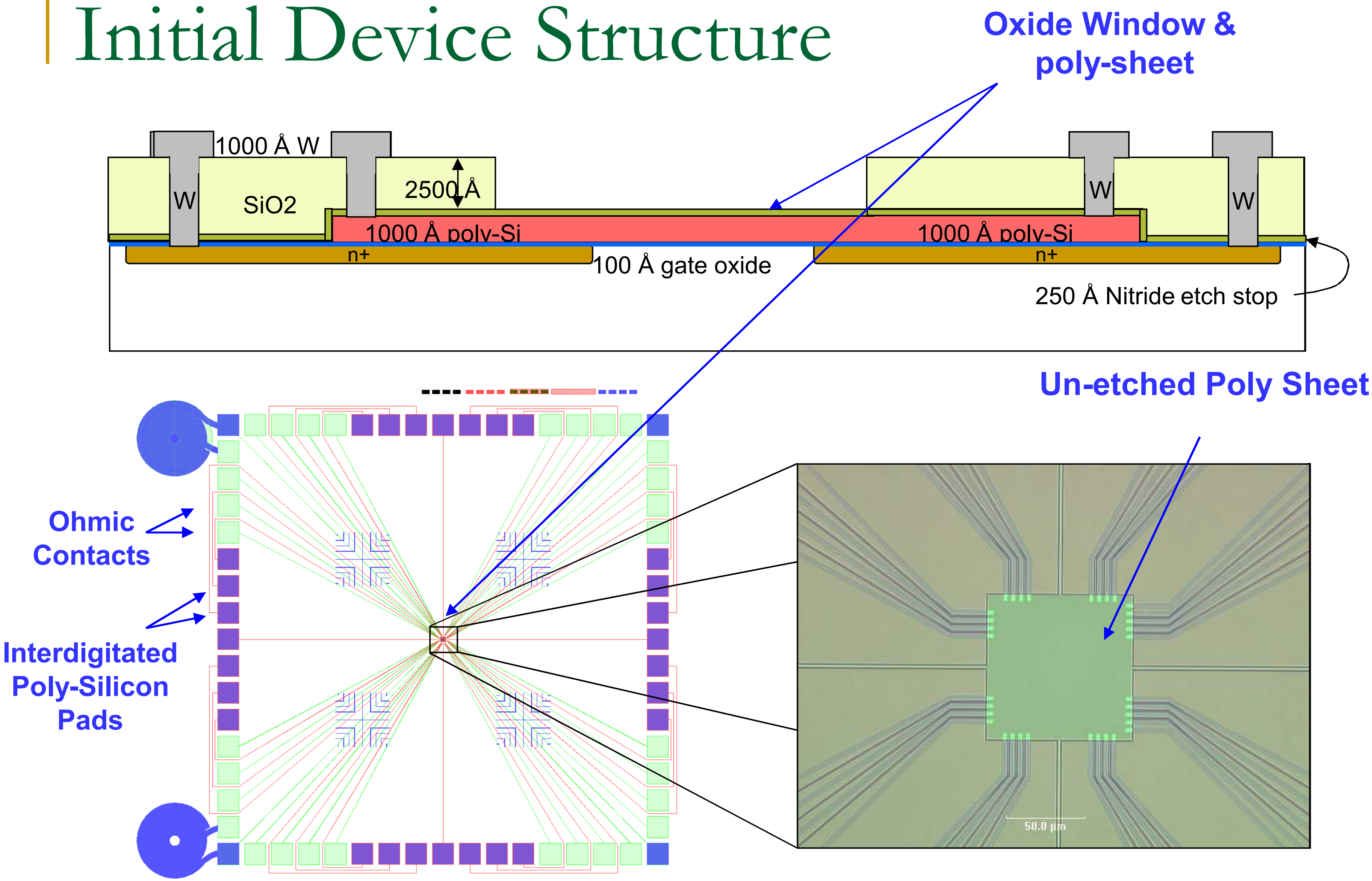
- Low spin-orbit coupling
- High percentage ^{28}Si reduces nuclear spin coupling

Advantages of the MOS System:

- No dopants required for transport
- Scaling advantage due to gate proximity to electrons
- Readily CMOS compatible

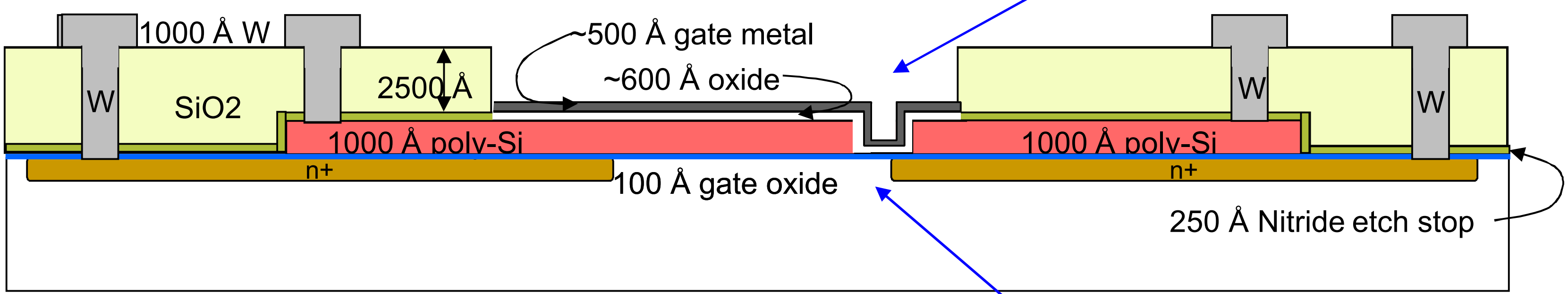


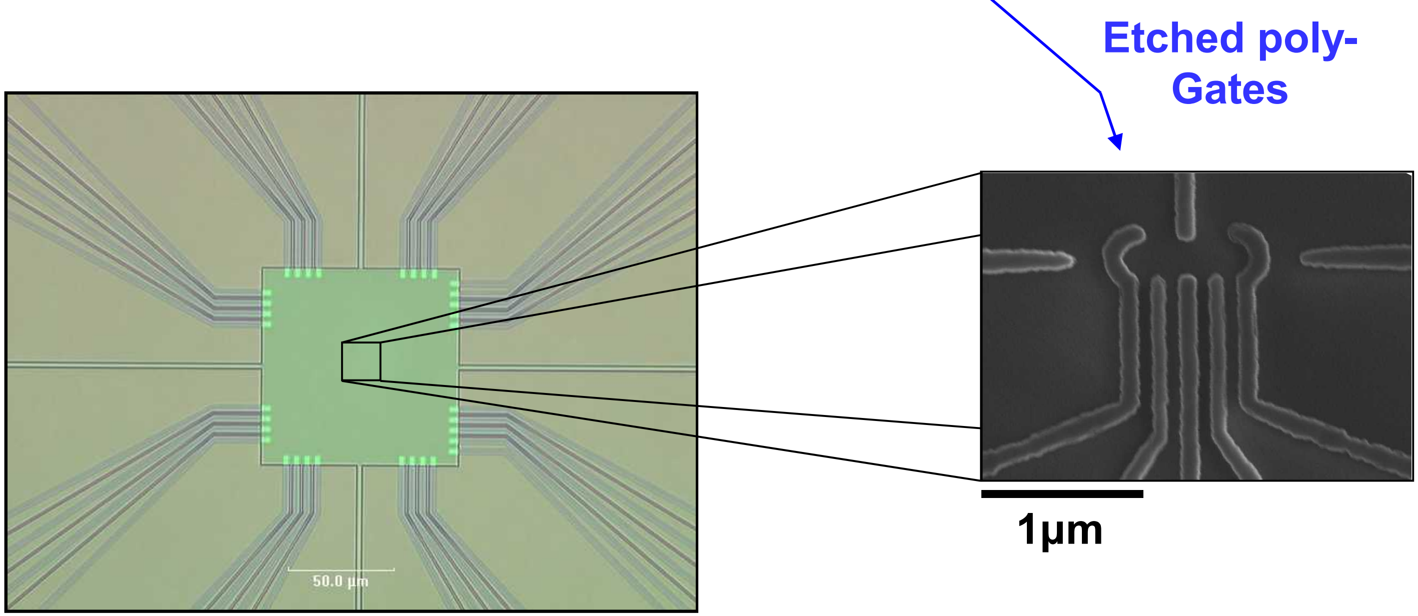
Initial Device Structure



Peak Mobilities ~ 15000 cm^2/Vs

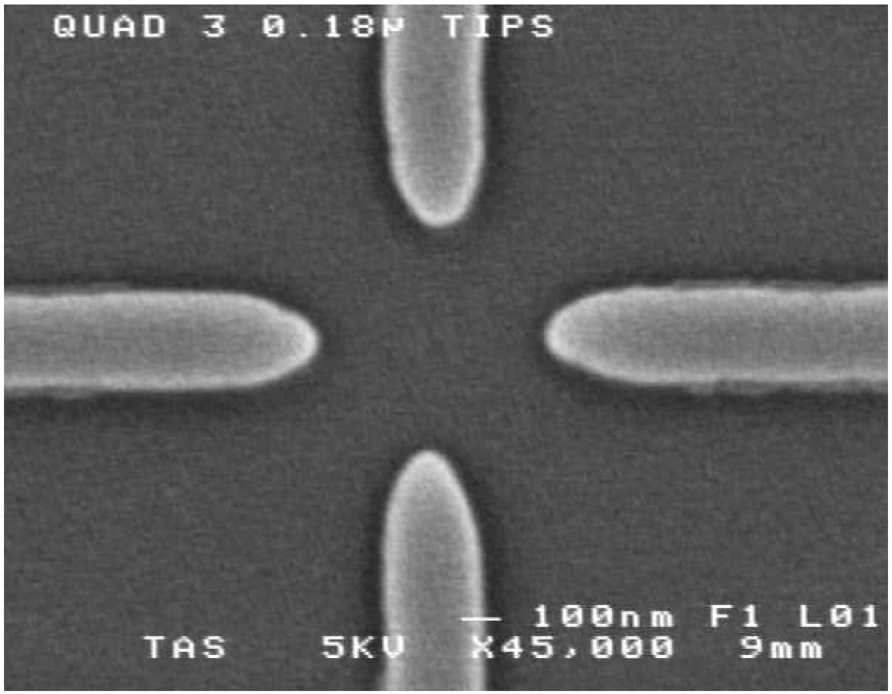
Final Device Structure

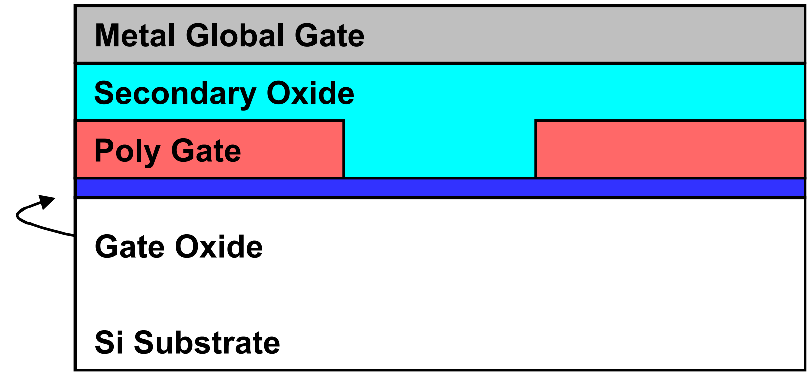




Peak Mobilities < 6000 cm²/Vs

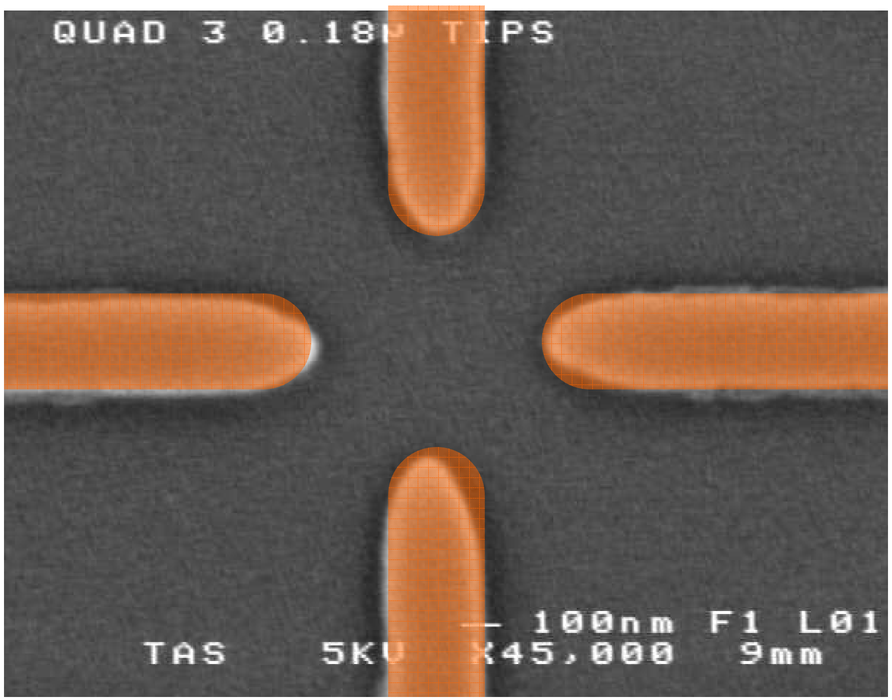
Device Operation



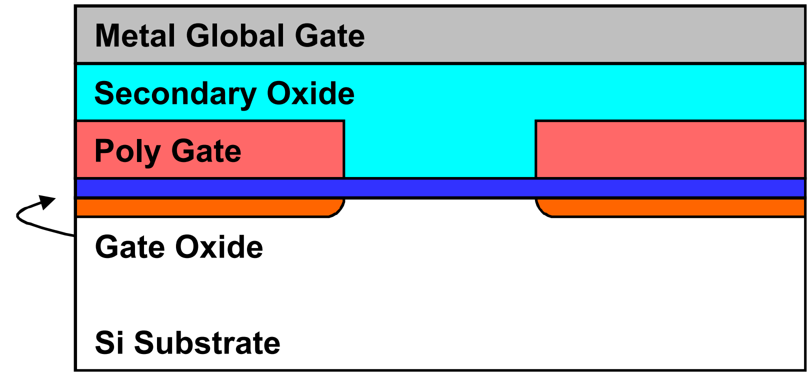


Polysilicon gates can be used for either accumulation or depletion in addition to the global accumulation gate

Device Operation



Polysilicon gates accumulating



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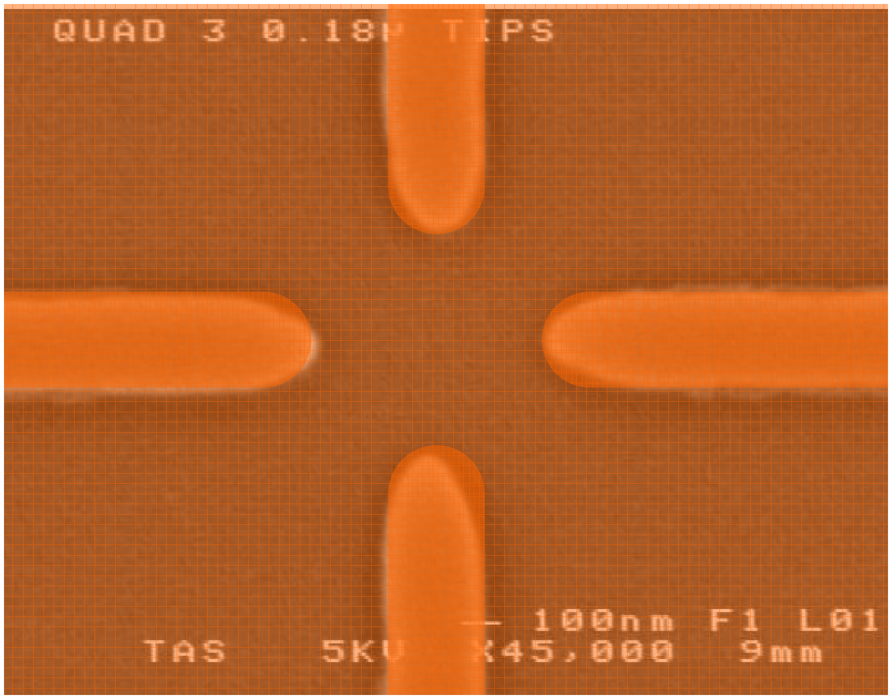
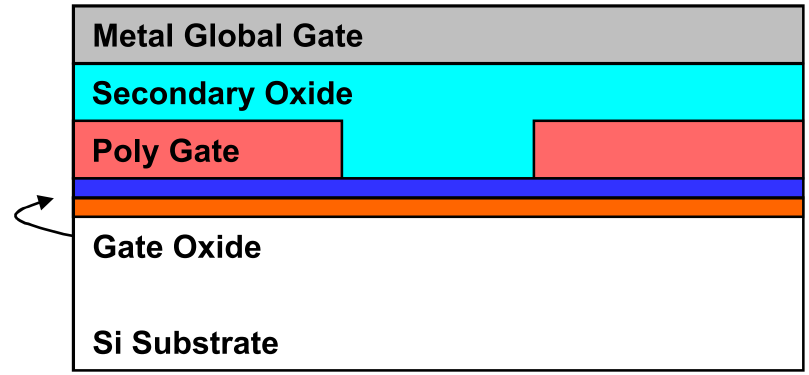


Both global top gate, and polysilicon gates accumulating



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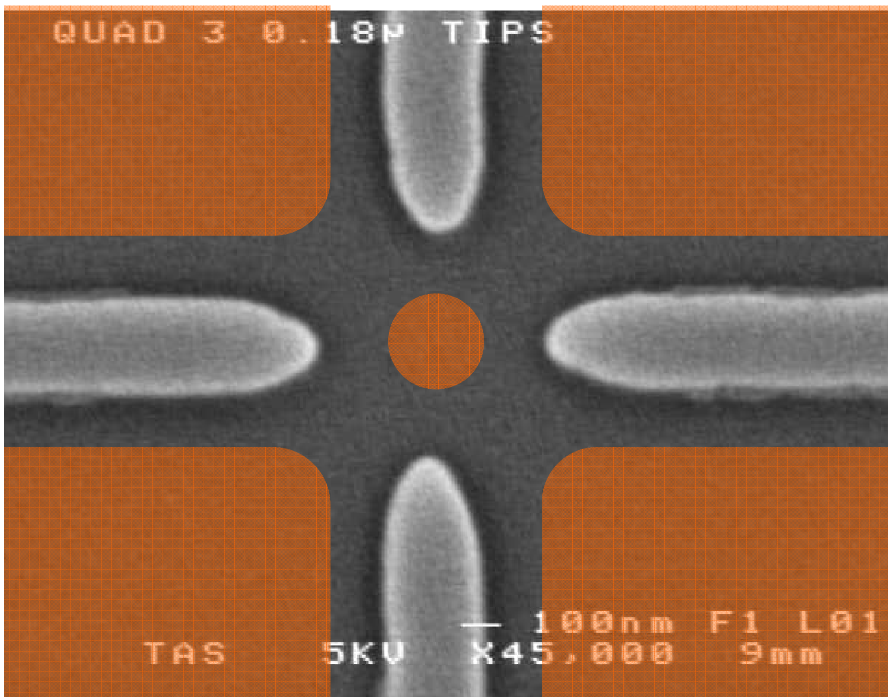
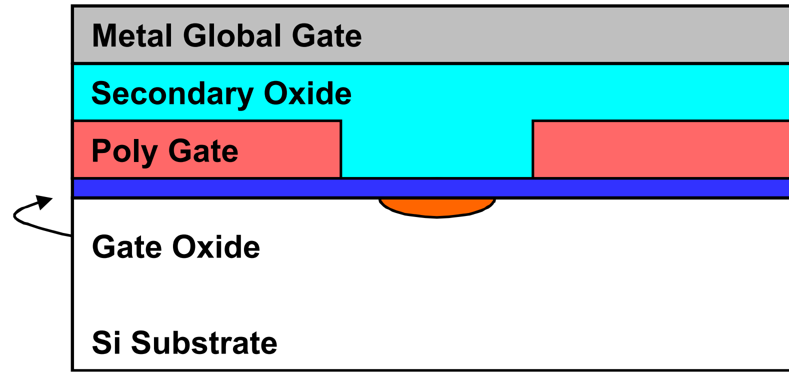


Global top gate accumulating, polysilicon gates depleting to form a quantum dot.



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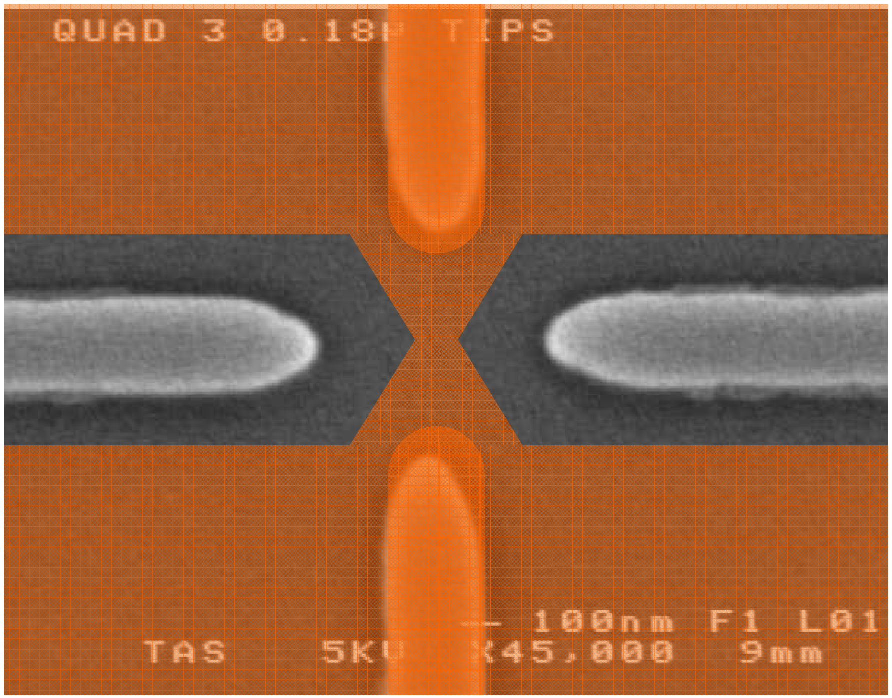
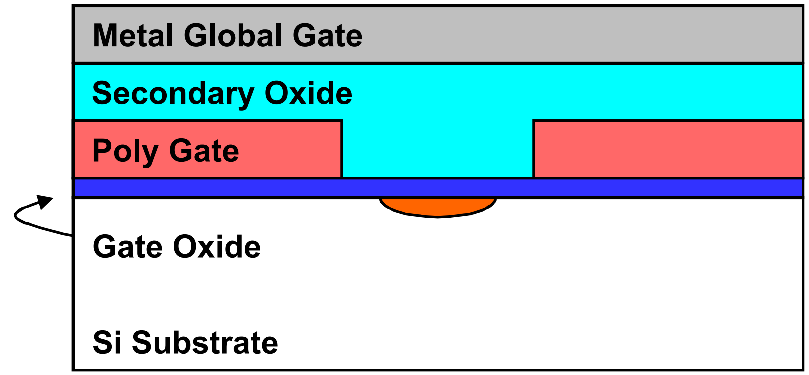
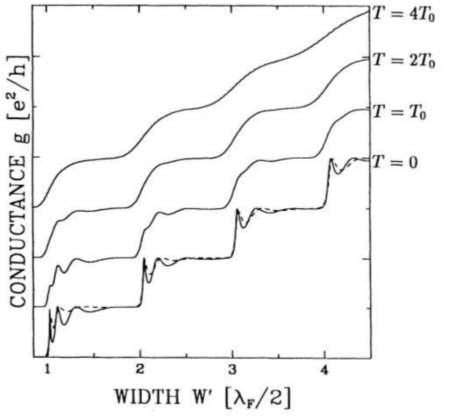


Global top gate accumulating, polysilicon gates depleting to form a 1D Channel



Polysilicon gates can be used for either accumulation or depletion in addition to the global accumulation gate

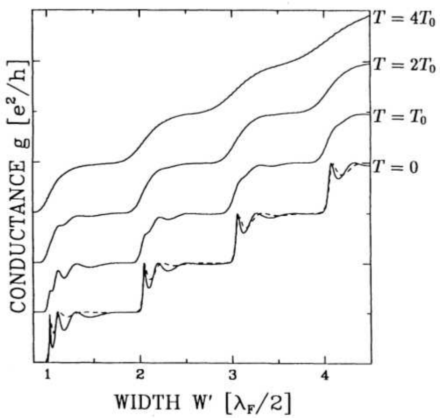
QPC Behavior

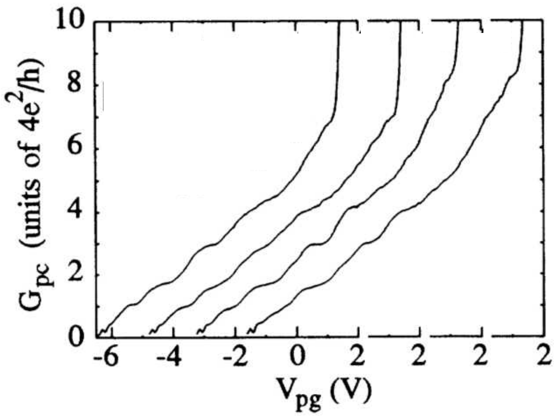


*A Szafer, et al. PRL **62**, 300 (1989)*

- In a perfect 1D channel, conduction is quantized in units of e^2/h

QPC Behavior

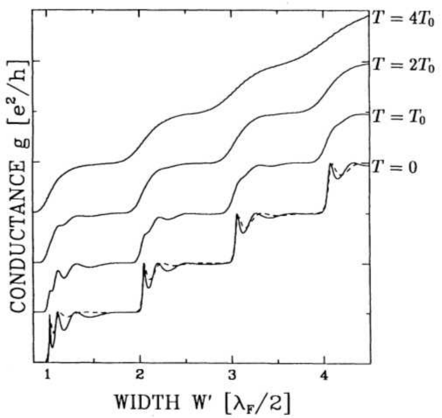




A Szafer, et al. PRL ***62****, 300 (1989)*   *S. L. Wang, et al. PRB* ***46****, 12873 (1992)*

- In a perfect 1D channel, conduction is quantized in units of e^2/h
- This can be demonstrated in a high mobility MOS constriction with varying degeneracies

QPC Behavior



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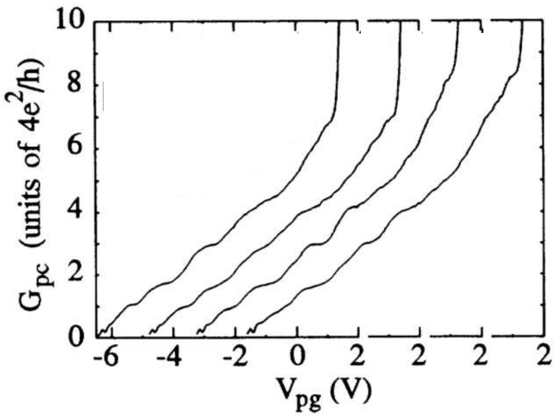

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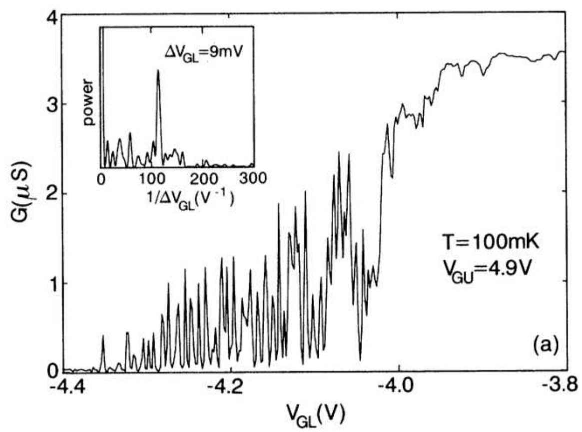
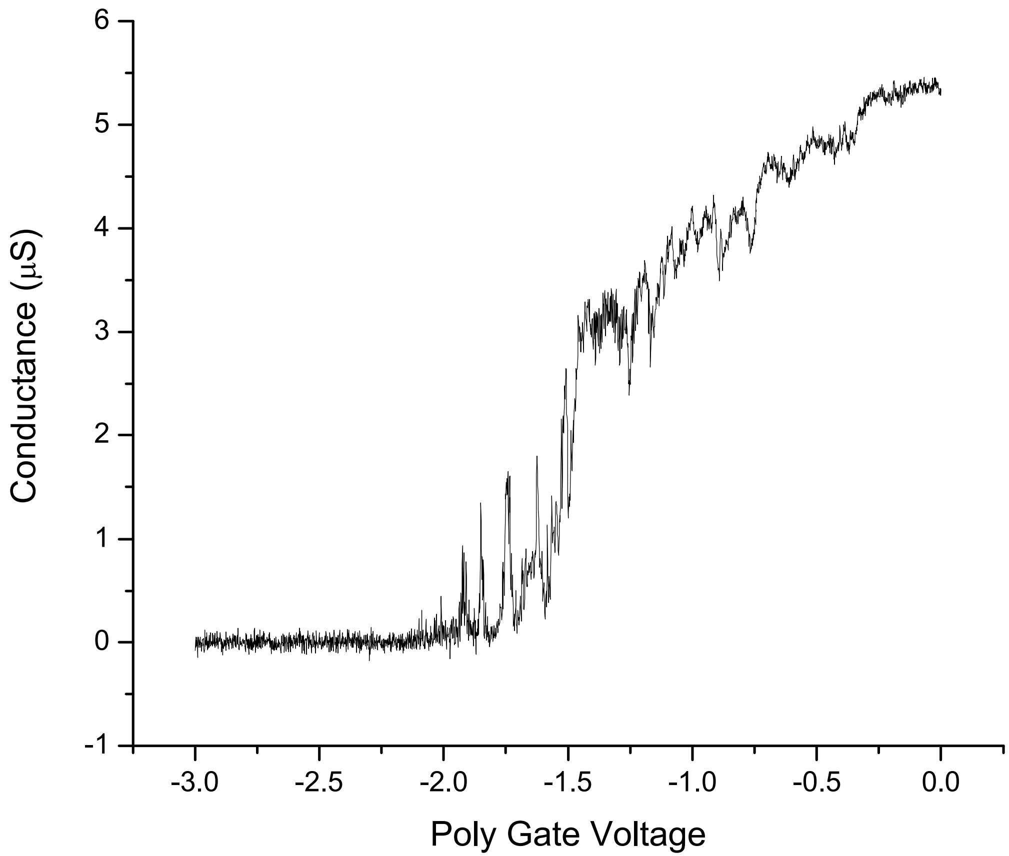
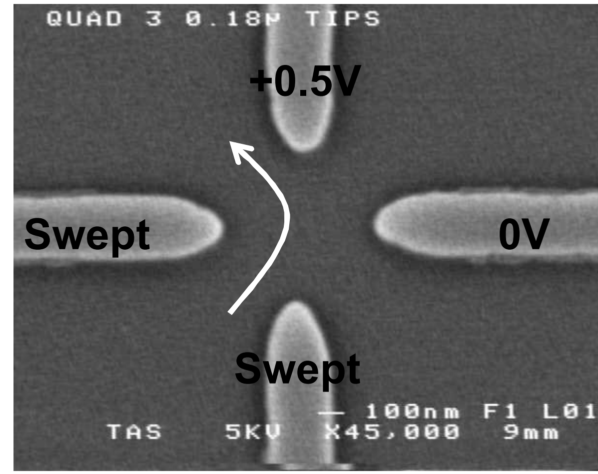


*C. De Graaf, et al. PRB **44**, 9072 (1991)*

- In a perfect 1D channel, conduction is quantized in units of e^2/h
- This can be demonstrated in a high mobility MOS constriction with varying degeneracies
- Lower mobility, disordered MOS constrictions show different behavior

Cross Structure

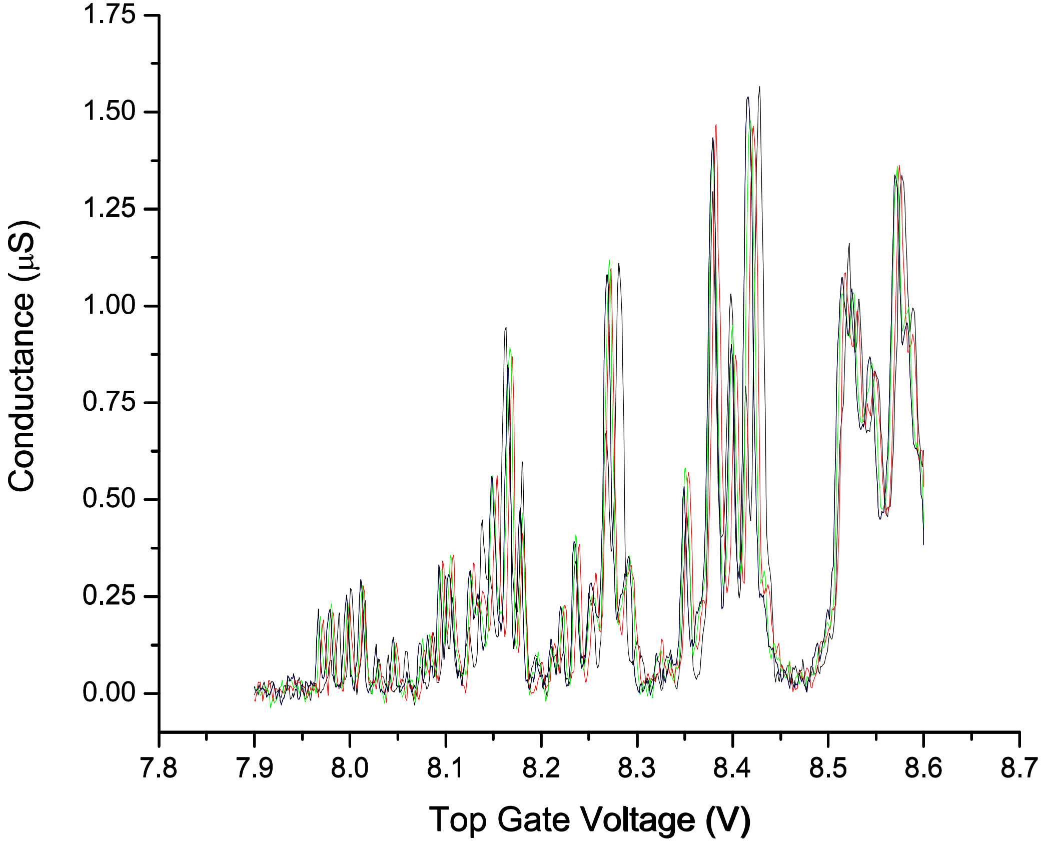


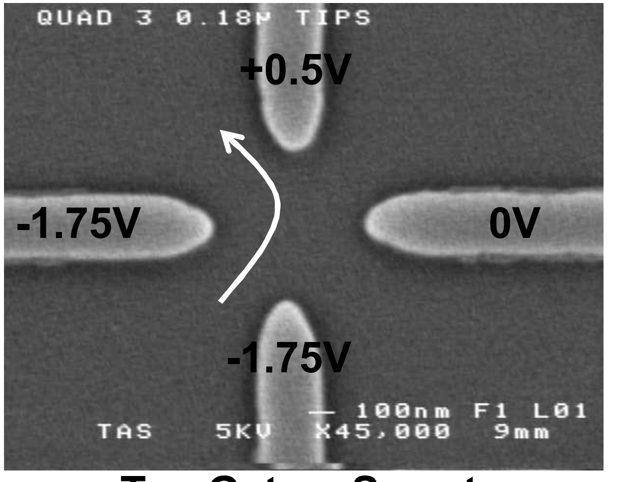


Top Gate = +8V

- No repeatable QPC steps
- Periodic, repeatable resonances near pinch-off

Cross Structure



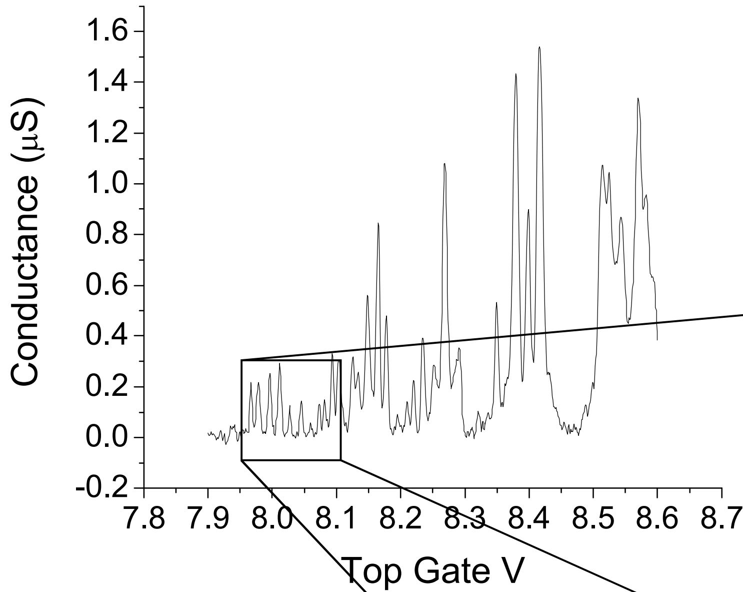


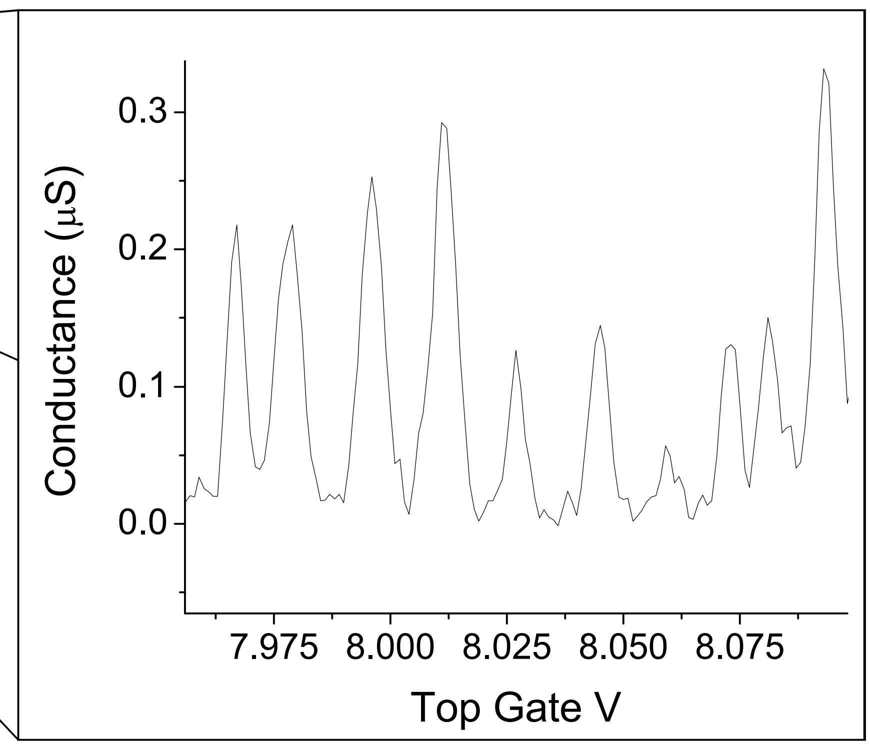
Top Gate = Swept

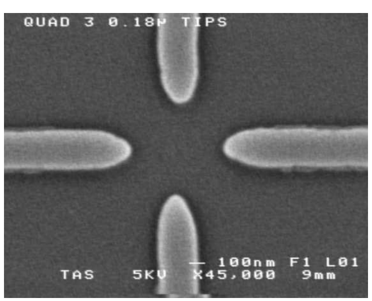
- No repeatable QPC steps
- Periodic, repeatable resonances near pinch-off

Cross Structure

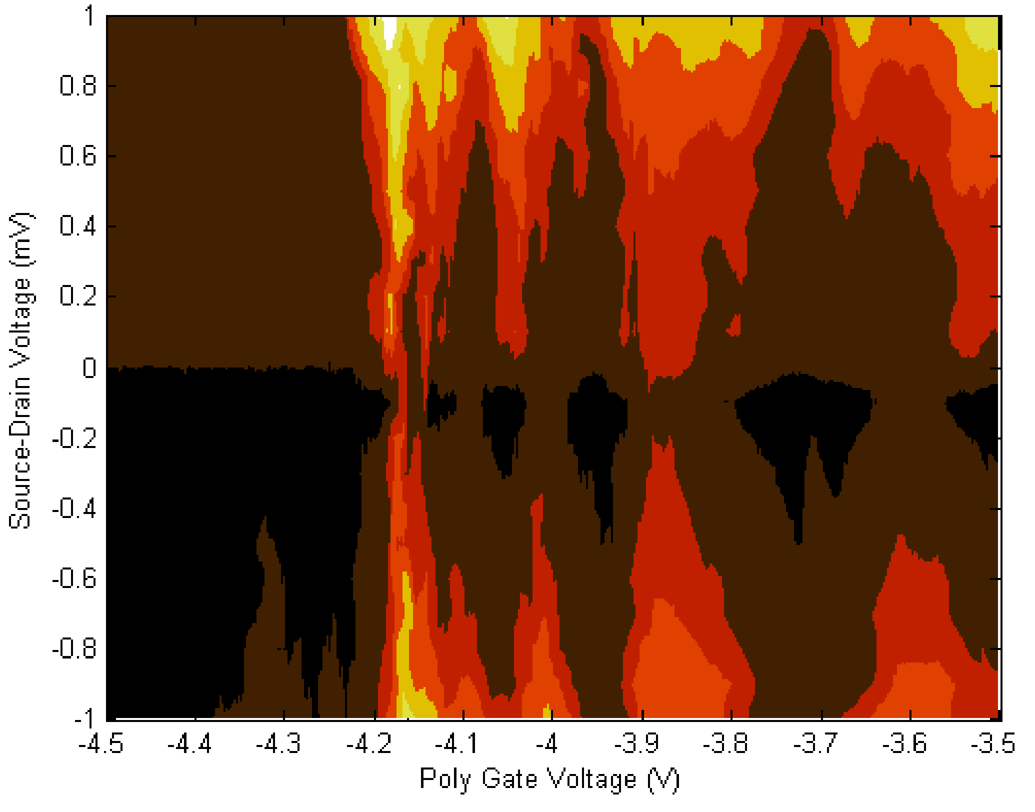
- Peak spacing corresponds to a dot diameter of ~65nm
- Longer period oscillations would correspond to a 25nm diameter







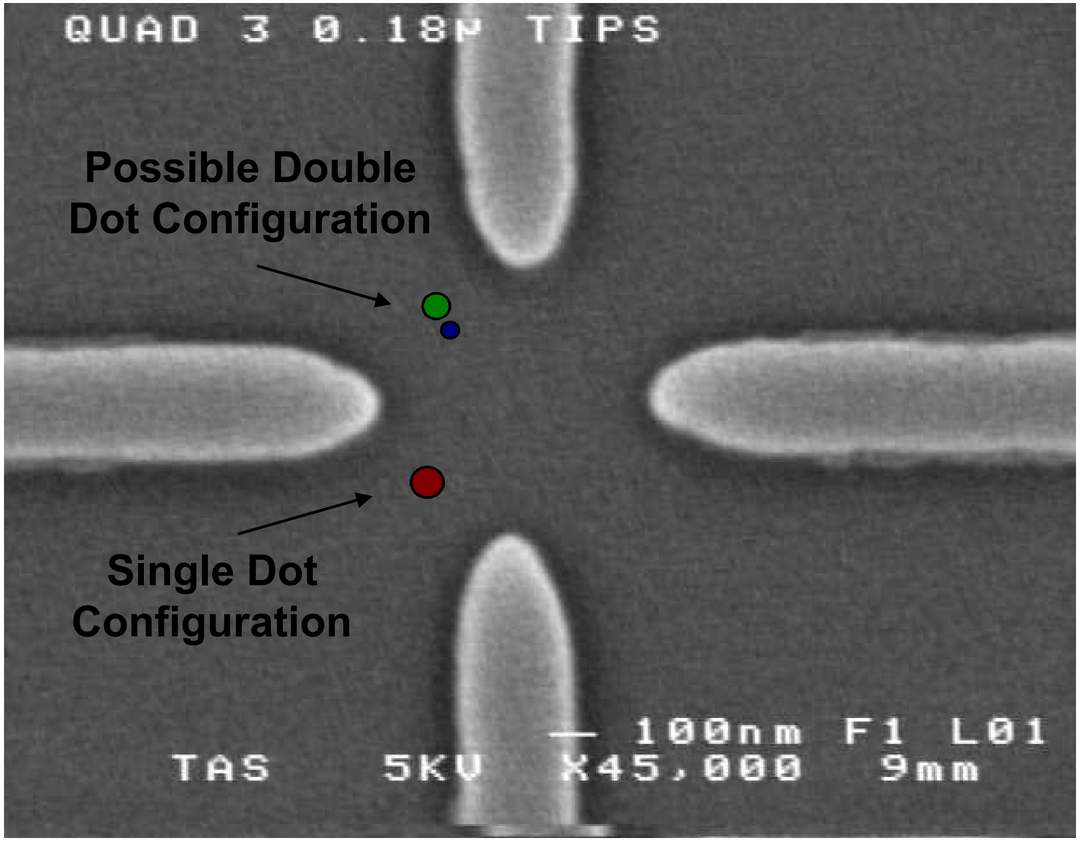
Coulomb Blockade



- Diamond structures suggest conductance resonances are Coulomb Blockade

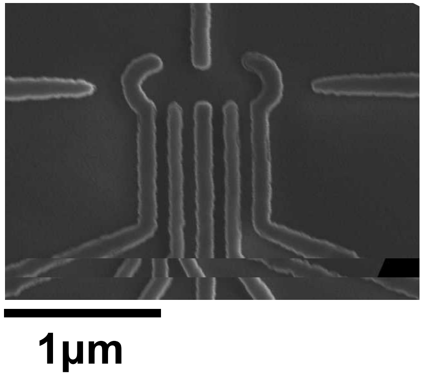
"Disorder" Dots

- Apparent dot sizes fit neatly between polysilicon gates
- Reducing feature size should reduce the probability of overlapping with a disorder site
- Process improvement can increase general sample "cleanliness"



Summary

- Double top gate MOS quantum confined structures produced with SNL Si fab facility and additional "back-end" processing
  - Stable Coulomb Blockade peaks observed
- Large lithographic features (~100's of nm) producing mesoscopic effects
  - Combination of less disorder (e.g., mobility, interface traps) and smaller dimensions suggested by literature for much "cleaner" results
- Future direction: Shrink size and reduce damage to increase post-process mobility



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