Lateral Quantum Dot Charge Sensor in a Mesoscopic Electron Transport System

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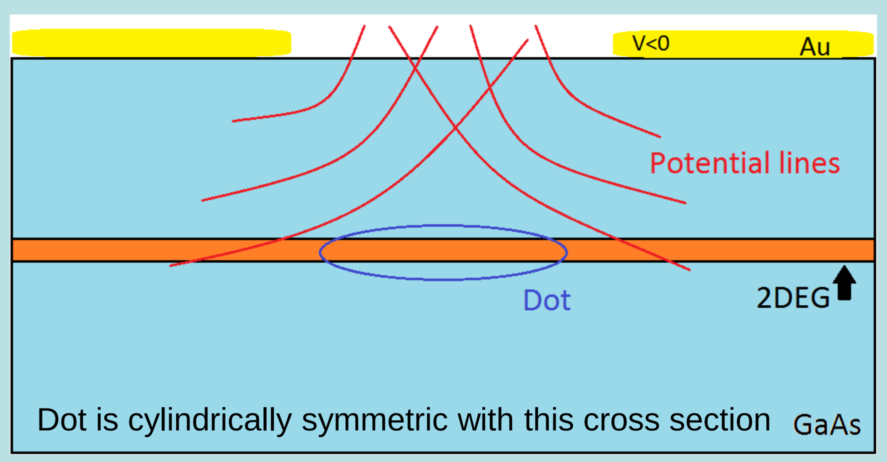
Theory

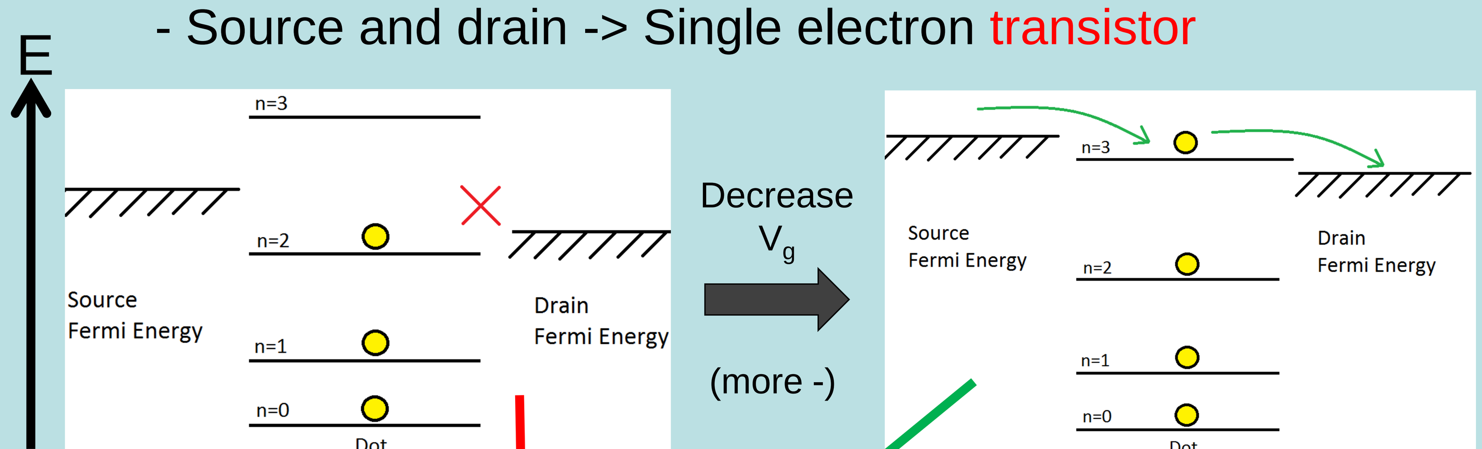
Quantum dot: The transport mechanism

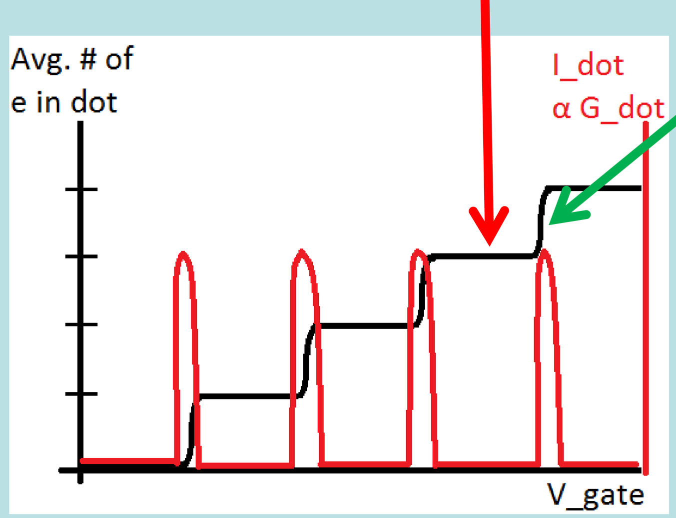


-Confinement of electrons in all three spatial directions

-Lateral dots confine a 2D electron "gas" layer electrically via metal surface gates

- Leads to discretized energy levels
  - Value and separation vary inversely on dot size
  - Controlled by varying voltage on a gate electrode
- Source and drain -> Single electron transistor





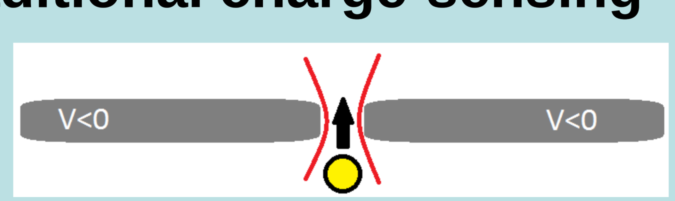
- Sweeping V_{gate} changes effective dot size -> shifts energy levels of dot

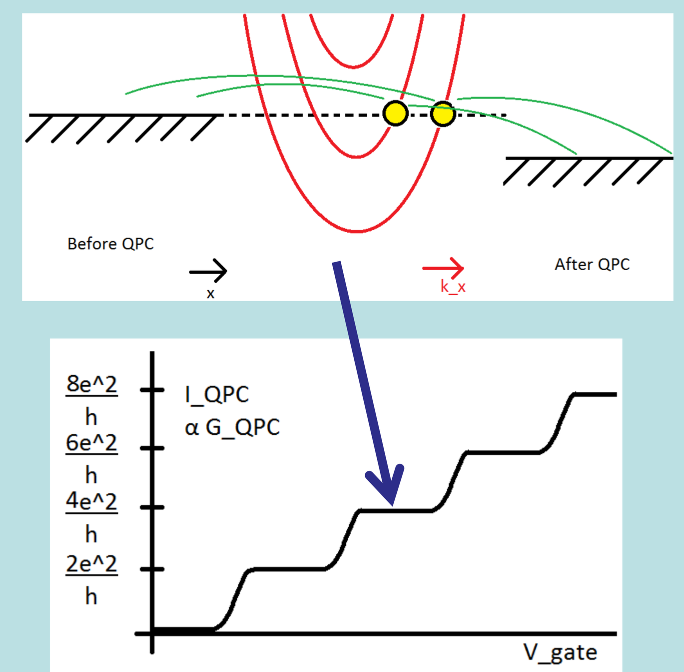
- Finite conductance when empty energy level is in window between S/D Fermi energies -> Coulomb oscillations

- Can place multiple dots in close proximity and analyze charge configurations
  - Electron vs. no electron, spin up vs. spin down
  - Charge state detection mechanism required
  - Quantum information processing applications

Quantum point contact: Traditional charge-sensing

- Narrow channel between two gates -> 2D of confinement



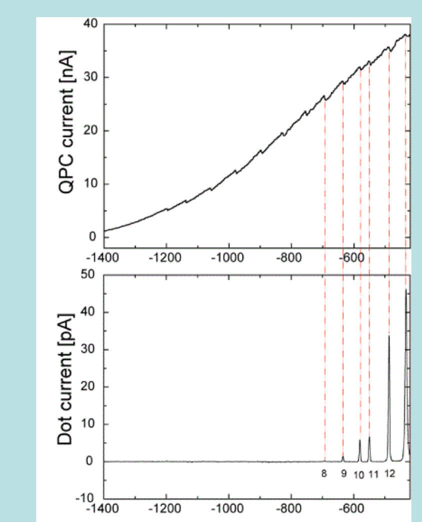


- Quantized conductance

- Parabolic shape from band structure, DC offset from gate-controlled confinement

- Each accessible "channel" adds 2e^2/h conductance

- Nearby charges also affect the confinement in a QPC
- **Bias QPC at G transition point-> movement of charge will induce a noticeable change in the QPC current**
- **Can be used as a charge-sensing signal**

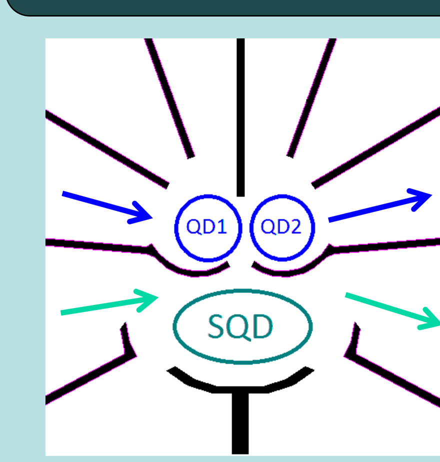


Goal

- Improve charge sensor signal-to-noise ratio and sensitivity
  - Typical QPC: Sensitivity = 10%, SNR = 10

- QD more sensitive to potential fluctuations at transition point
  - Use a Sensor QD with I_{SQD} as the signal
  - 30 times more sensitive, 3 times better SNR than QPC

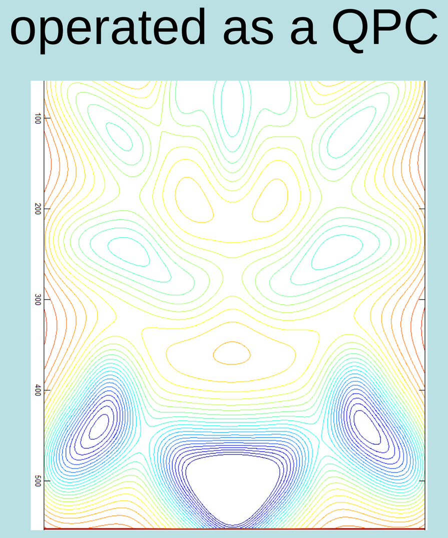
Design



- Double quantum dot transport system

- Sensor quantum dot directly underneath

- Any two gates can be operated as a QPC

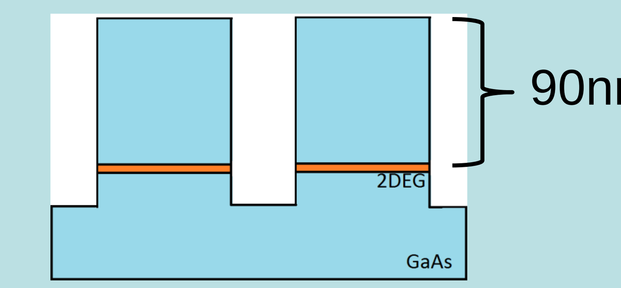


- Equipotential lines calculated for various gate positions and voltages

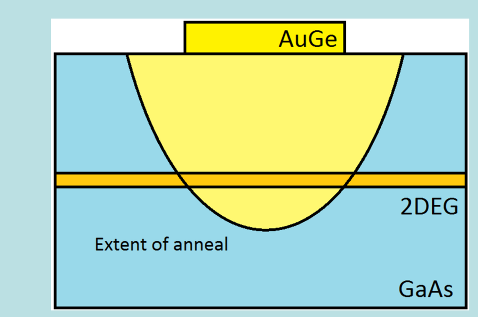
- Layout with strong coupling between dots, at least 200nm between gates, and ~ -1V operating point chosen for fabrication

Fabrication

1) MESA device and lead isolation structure patterned via UV photolithogrpahy

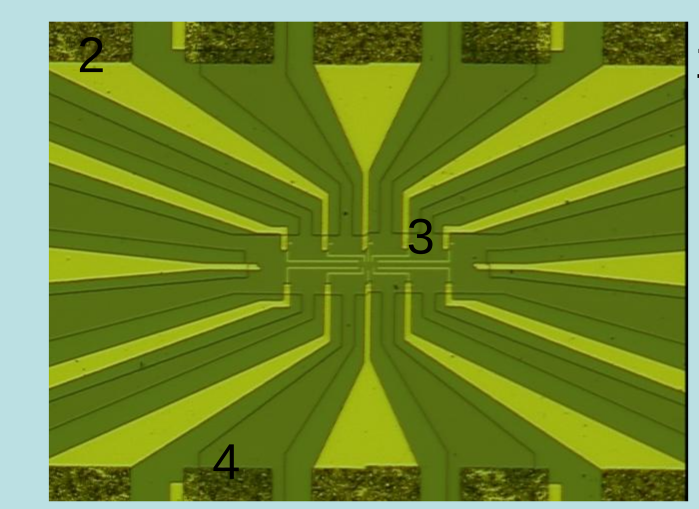


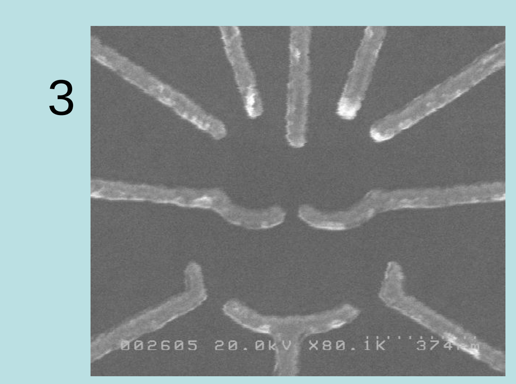
2) AuGe Ohmic substrate contacts patterned via UV photolithography, annealing drive-in

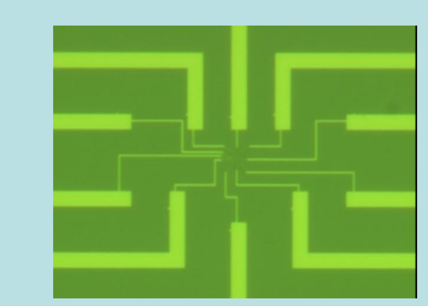


3) Ti/Au gate electrodes and leads patterned via EB lithography

4) Schottky gate contacts patterned via UV photolithography



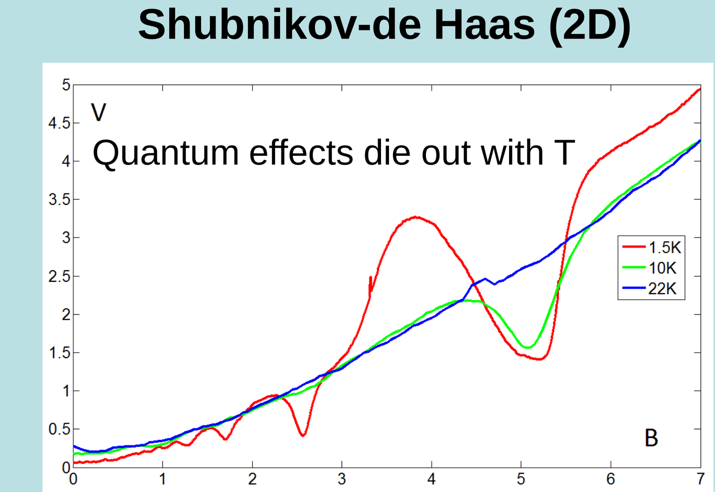




Results

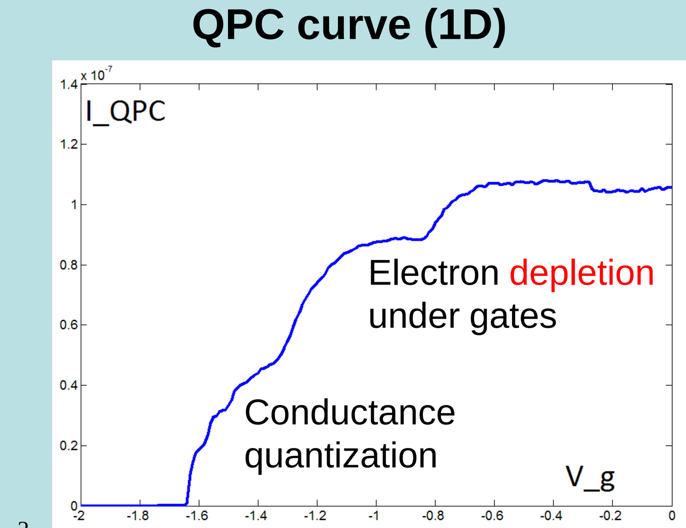
-Unable to form dots that demonstrate Coulomb oscillation in 1.5K fridge due to shortage of time and a series of mishaps

Shubnikov-de Haas (2D)



$$n = \frac{veB(v)}{h} = \frac{1 \cdot 1.6\times10^{-19} \times 5.18}{6.63\times10^{-34}} = 1.25\times10^{15}\, e/m^2$$

QPC curve (1D)



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This material is based upon work supported by the National Science Foundation under Grant No. OISE-0530220.