BEYOND CMOS

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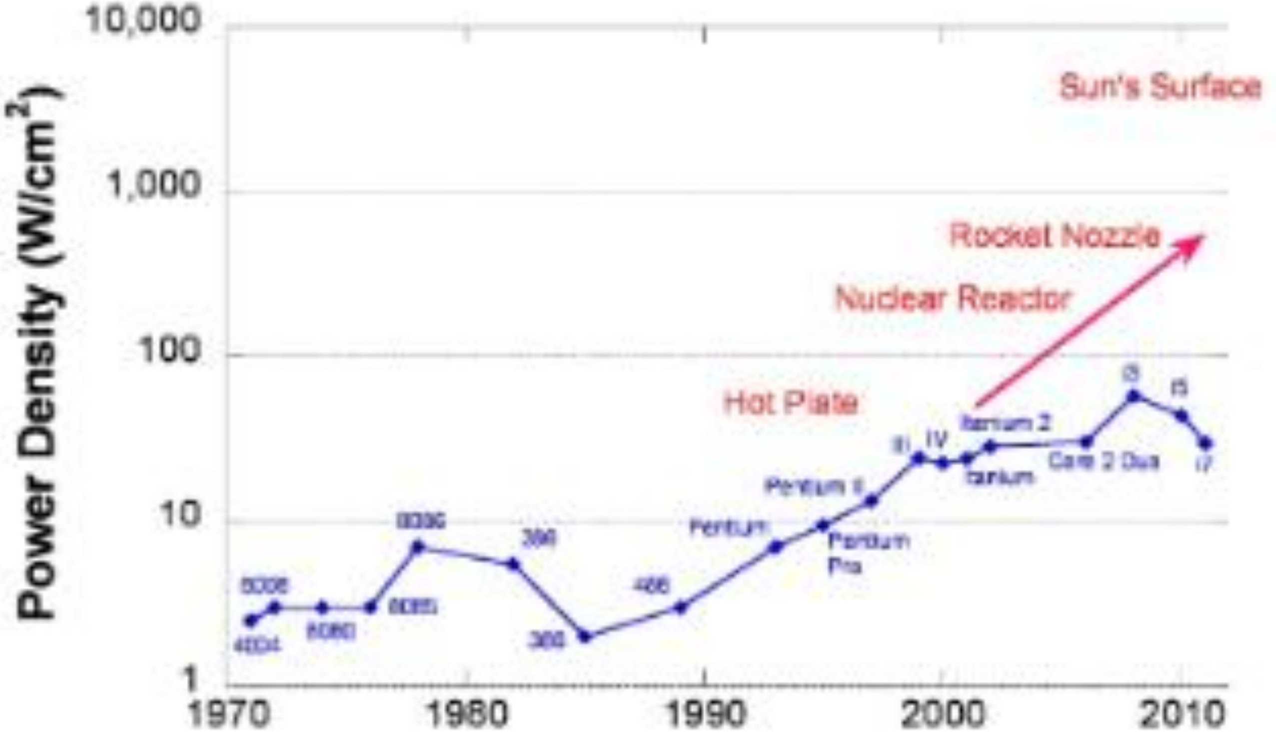
Limitation of CMOS



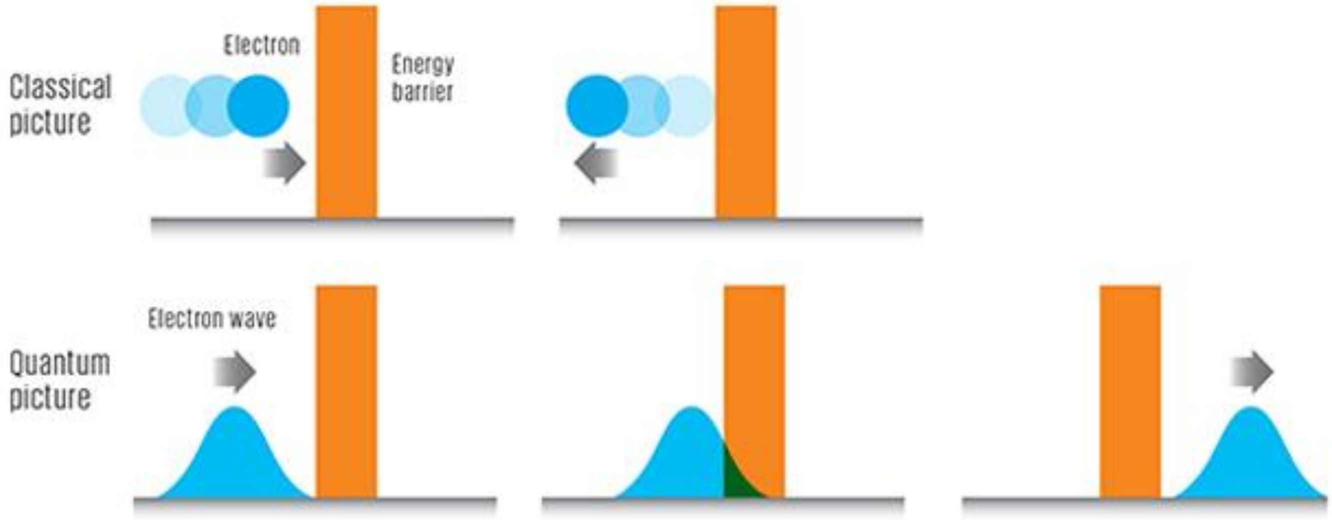
Nanotechnology

Beyond CMOS devices:

- Memory Devices:
  - ➢ Ferroelectric memory materials
  - ➢ Nano-electro-mechanical memory materials
  - ➢ Mott memory materials
  - ➢ Molecular memory materials
- Logic Devices:
  - ➢ Carbon nanotube FET
  - ➢ Graphene FET
  - ➢ Nanowire FET
  - ➢ p-III-V channel materials
  - ➢ Tunnel FET

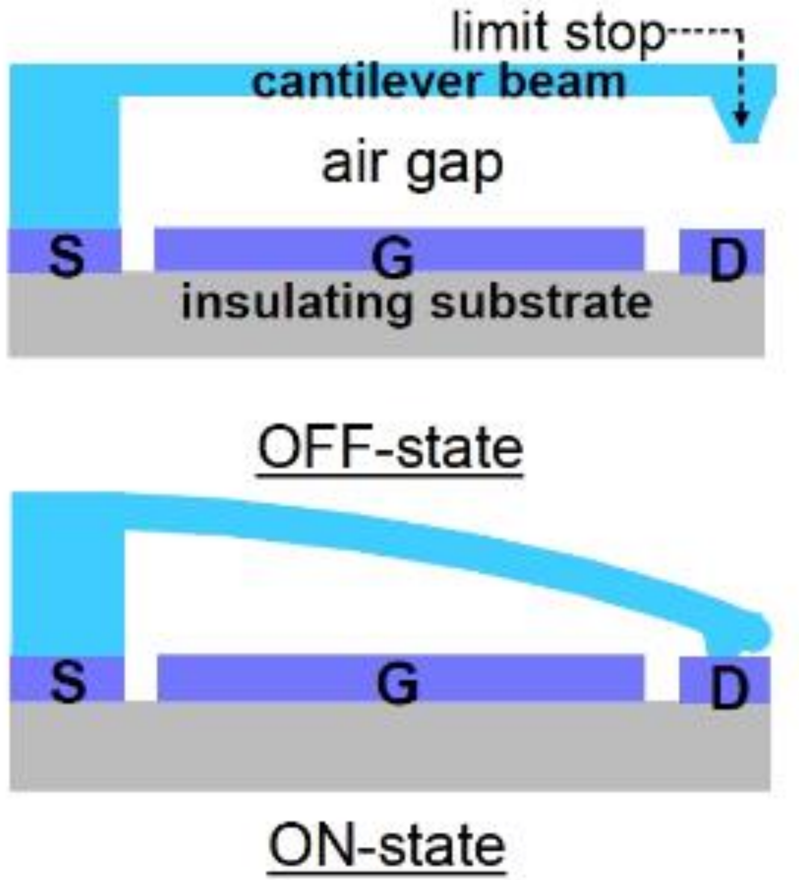
TFET

- Quantum, band-to-band tunneling mechanism
- Compatible with CMOS
- P-i-n diode
- Low saturation current, slow
- Pace the way



NEMS

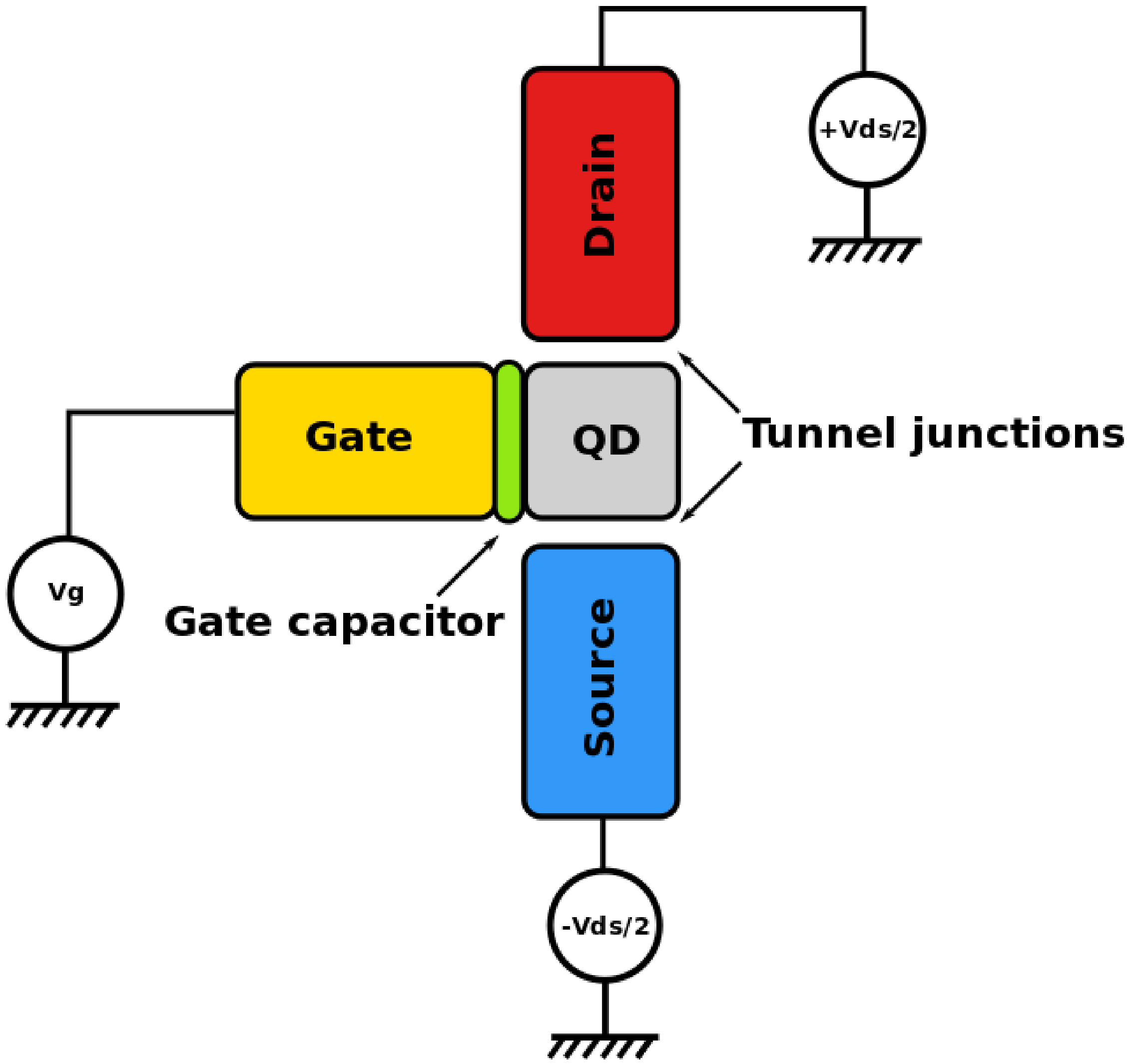
- Elastic forces Vs. electrostatic forces
- No leakage
- No sub-threshold current (in theory)
- Slow switching speed
- High pull-in voltage
- Sticky surface



Challenges

- Fabrication – compatible to CMOS
- Determining doping level
- Material

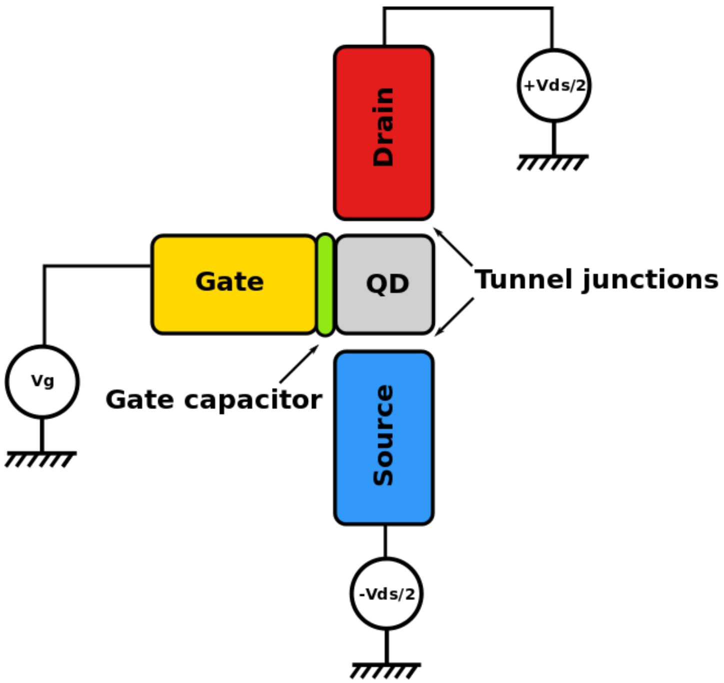
Single-Electron Transistor (SET)



http://en.wikipedia.org/wiki/File:Set_schematic.sv

Single-Electron Transistor (SET)

- Quantum dot: a semiconductor nanostructure that confines the motion of conduction band electrons, valence band holes, or excitons (bound pairs of conduction band electrons and valence band holes) in all three spatial directions (ScienceDaily.com).



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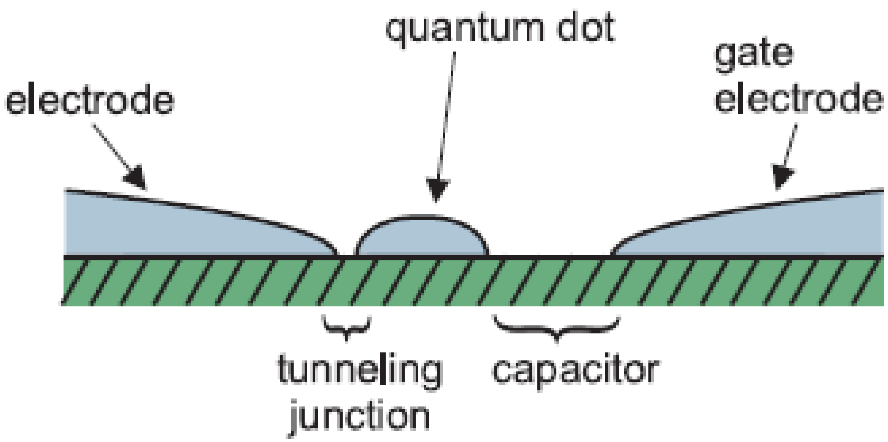
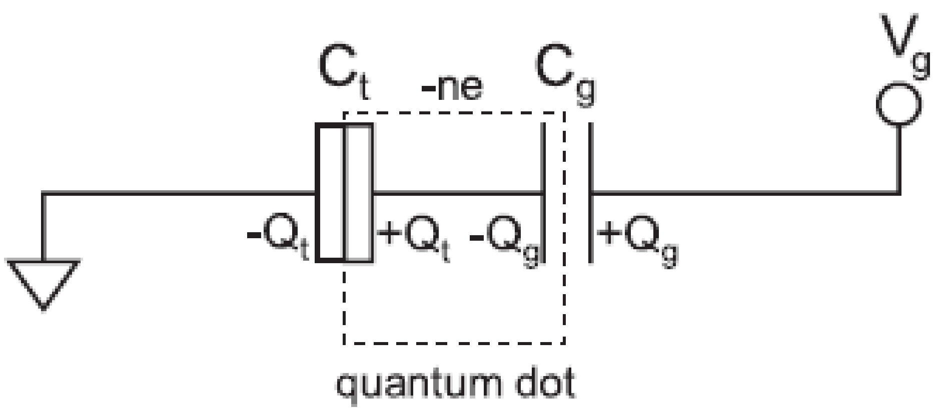
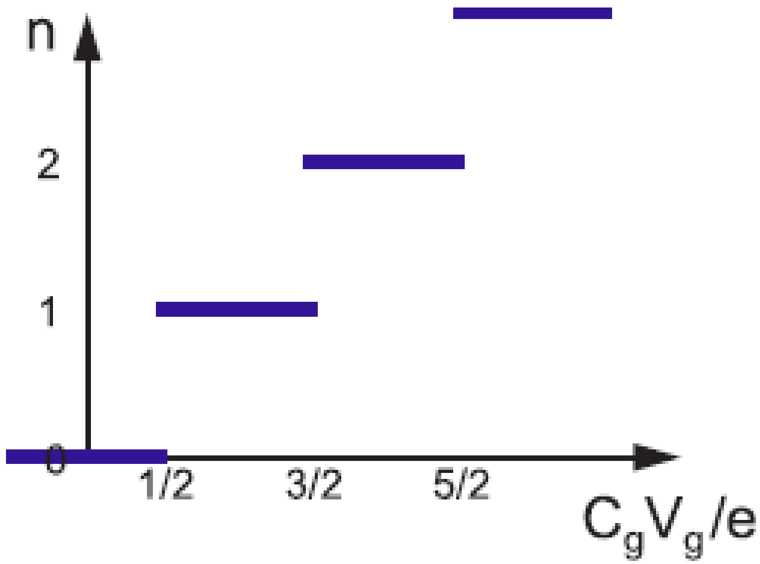
Single-Electron Box

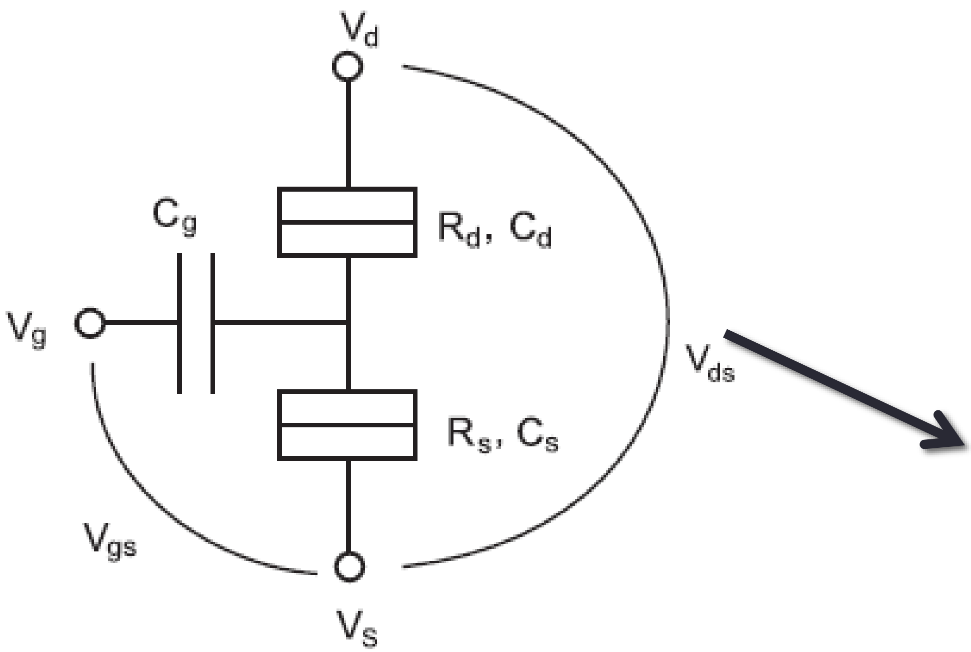


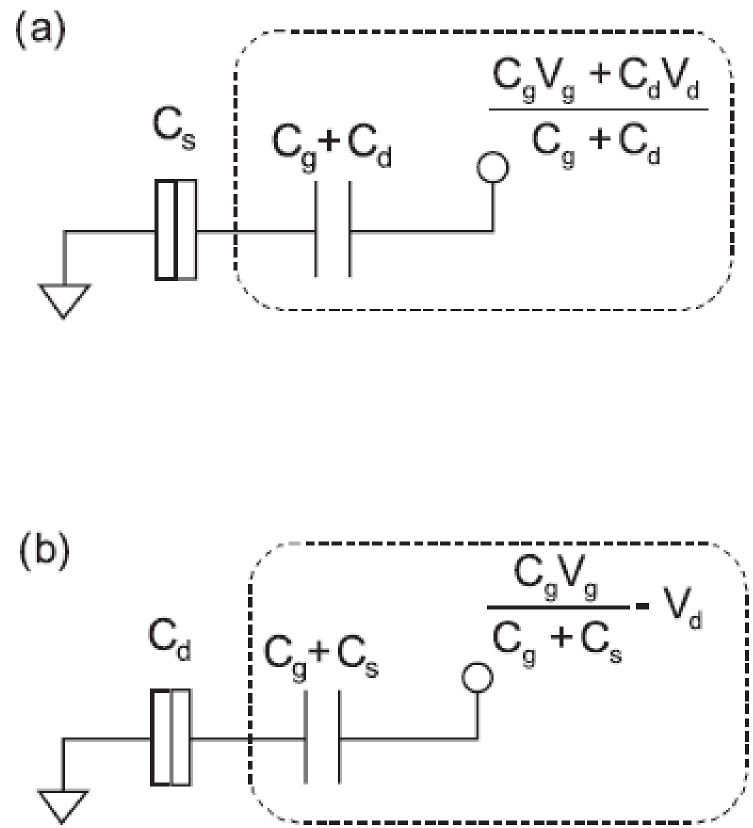




Coulomb Blockade Effect

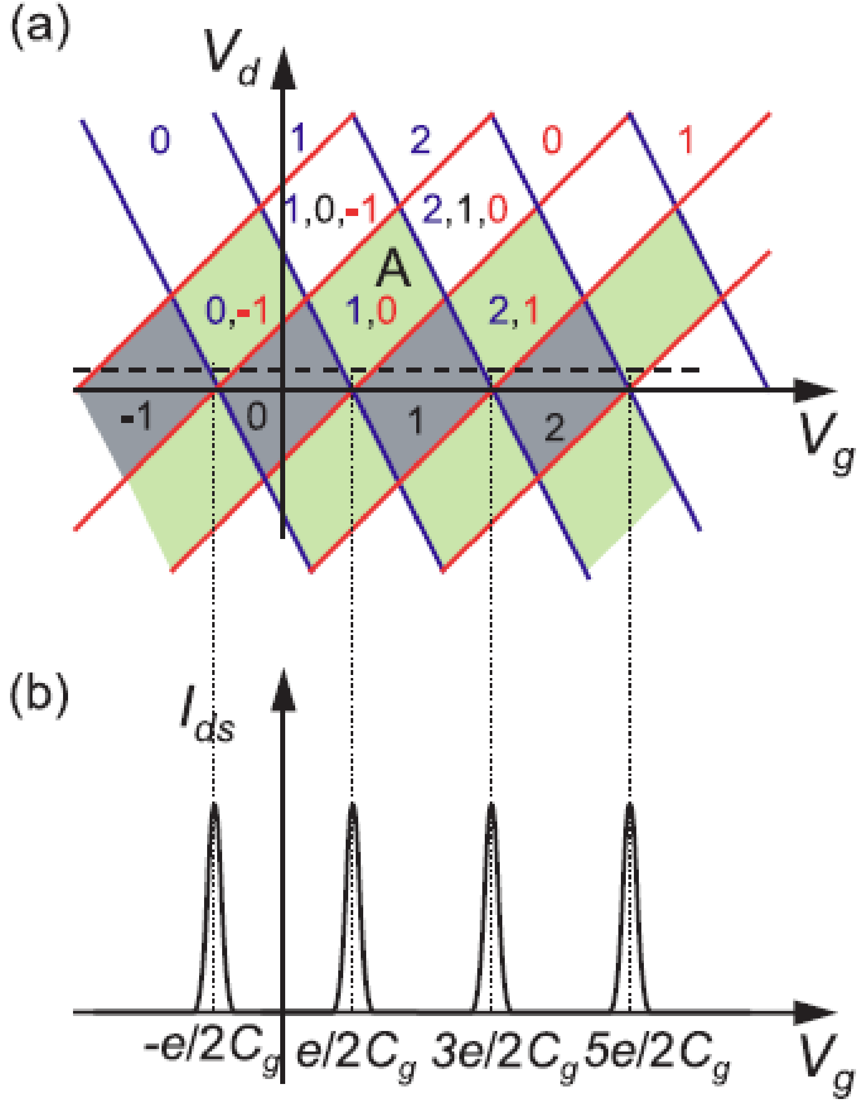
Single-Electron Transistor (SET)



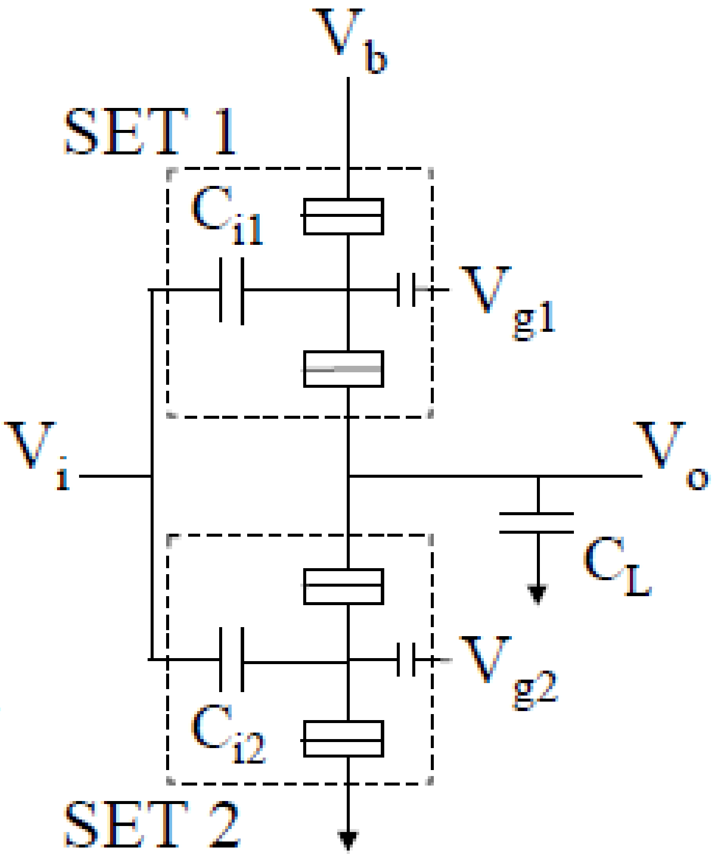


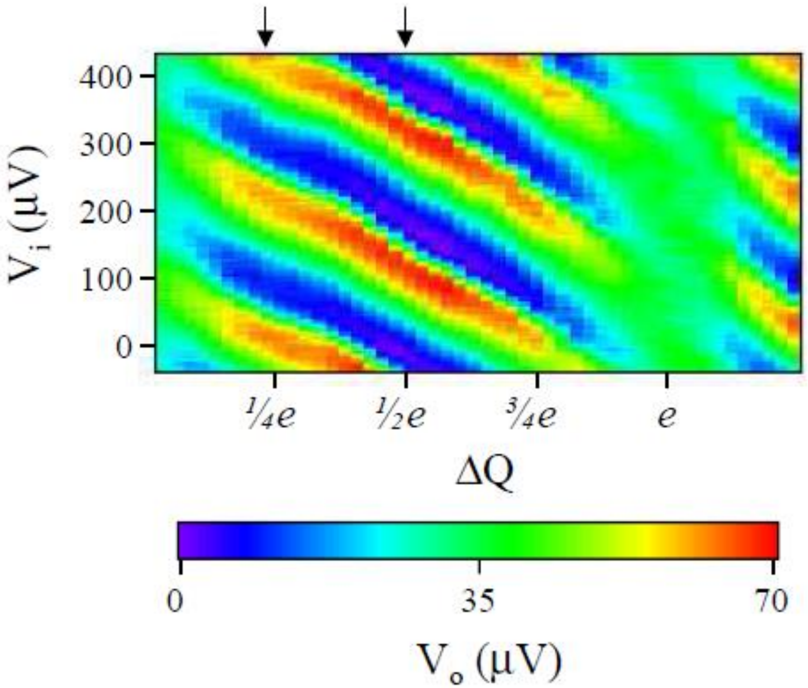
Thevenin’s Theorem

Single-Electron Transistor (SET)



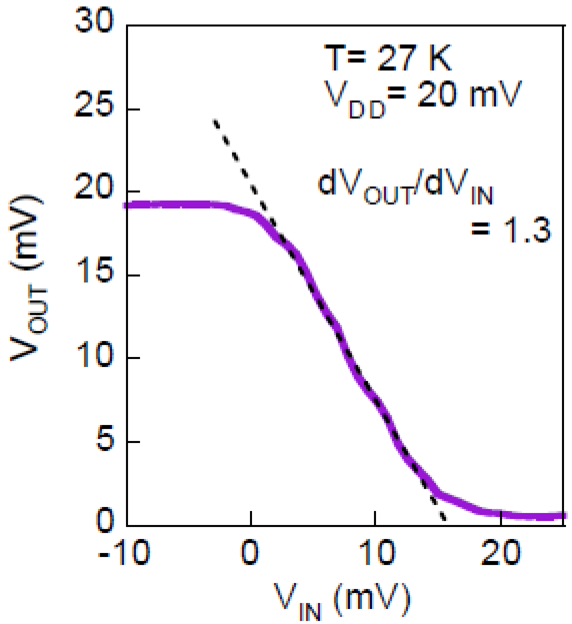
SET Inverter





Advantages and Challenges

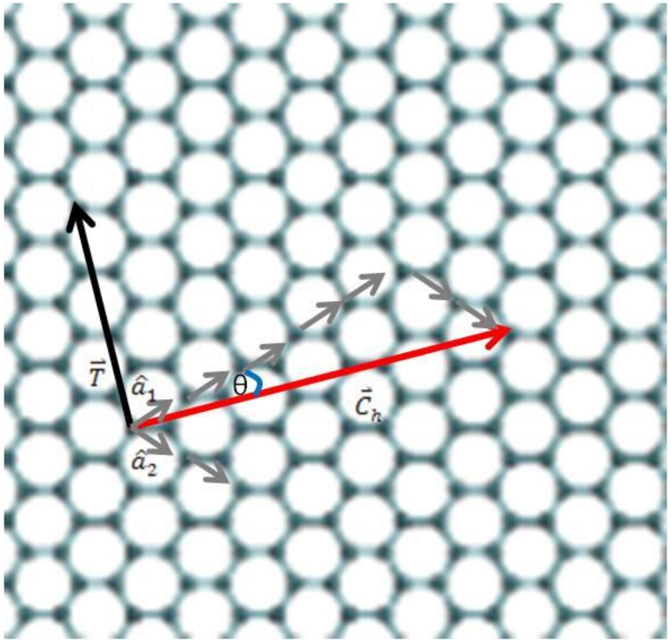
- Retain scalability even on an atomic level
- Extremely low power consumption



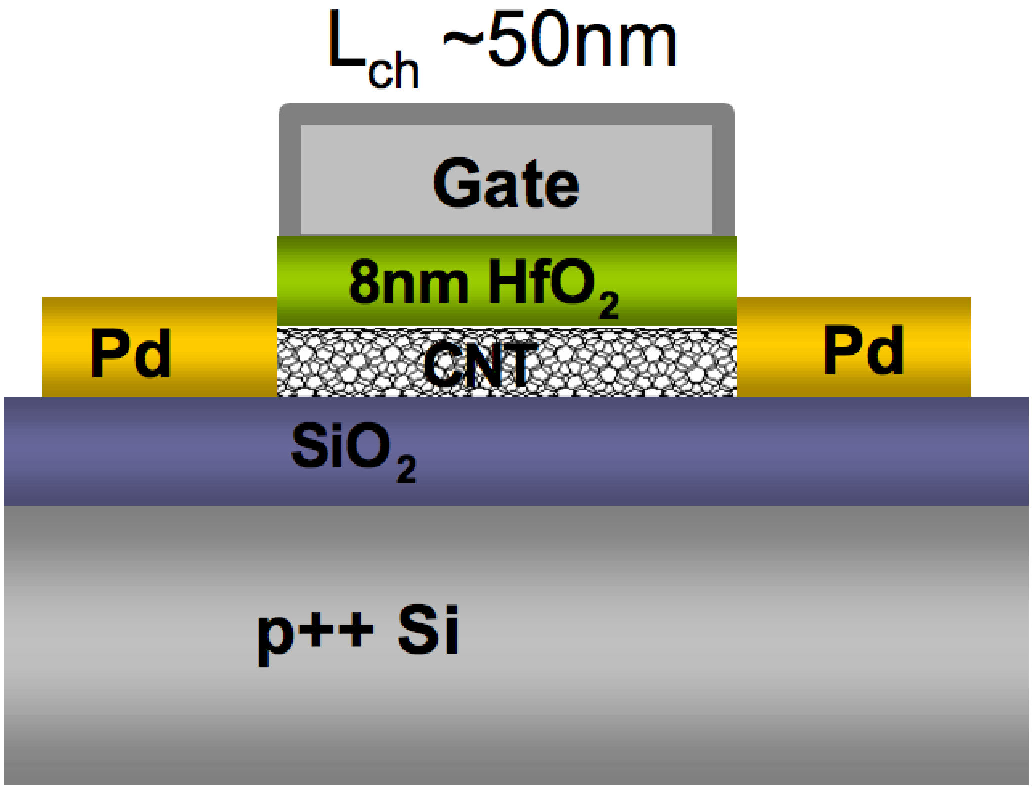
- Nanofabrication for SETs requires techniques well beyond the current state of the art.
- Background charge
- Low gain

Carbon Nanotube Transistor

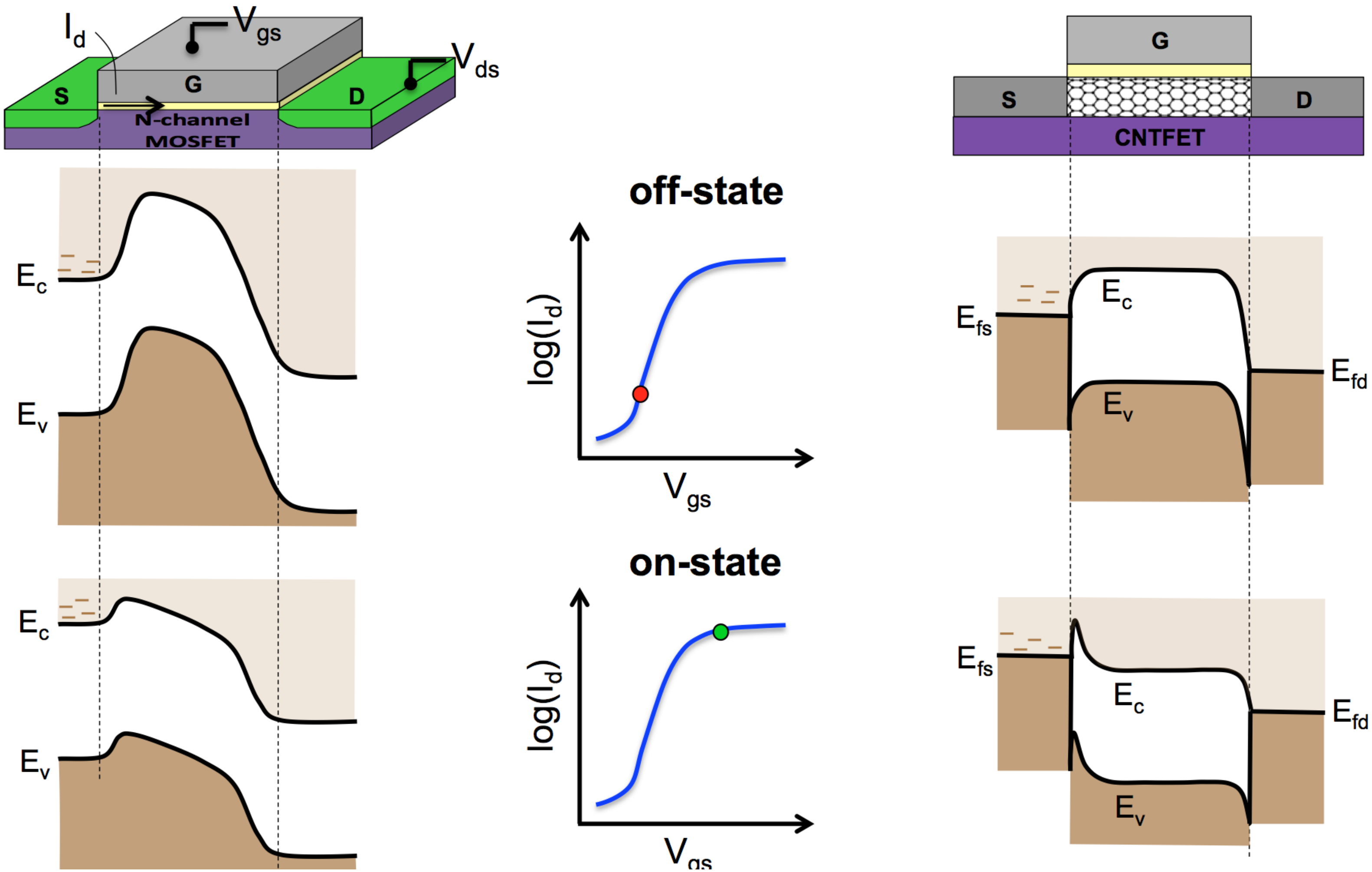
- Carbon nanotubes can be expressed by chiral vector
  - $$C_h = n\hat{a}_1 + m\hat{a}_2$$
- Different parameters causes different properties
  - $n = m$, metallic
  - $n - m = 3i$, semi-metallic
  - $n - m \neq 3i$, semi-conducting



Carbon Nanotube Transistor



Carbon Nanotube Transistor



Advantages over CMOS

- Better threshold voltage
  - Lower threshold voltage
- Better subthreshold performance
  - Steep subthreshold swing
- High electron mobility
  - $(100000cm^2/V \cdot S)\ VS\ (1000cm^2/V \cdot S) \quad Si$

Disadvantages over CMOS

- Lifetime (degradation)
  - Degrades in a few days when exposed to oxygen

- Reliability
  - Unreliable when operating under high electric field or temperature gradients

- Difficulties in mass production
  - No technology for mass production
  - High production cost

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