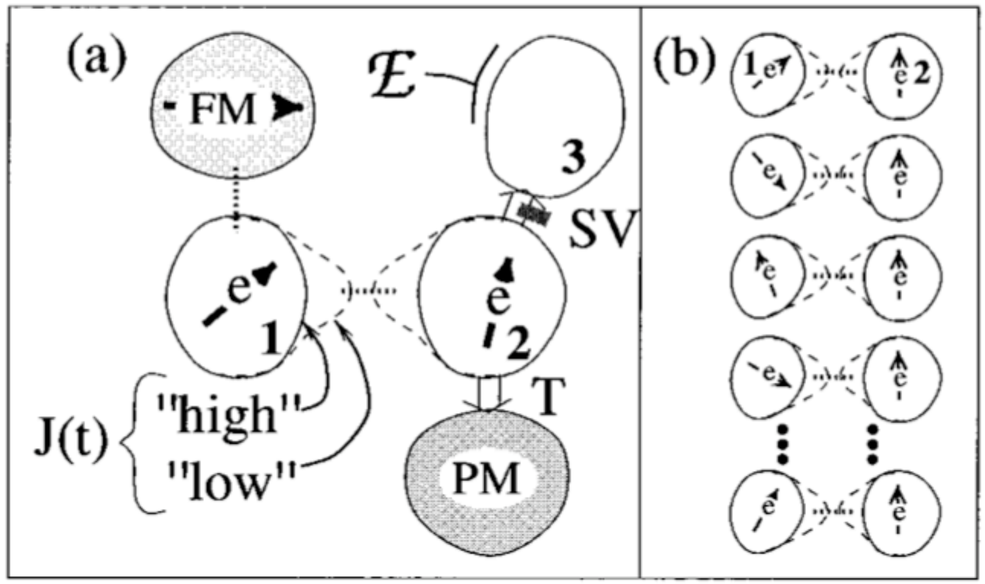
# Semiconductor nanocrystal-based quantum computation





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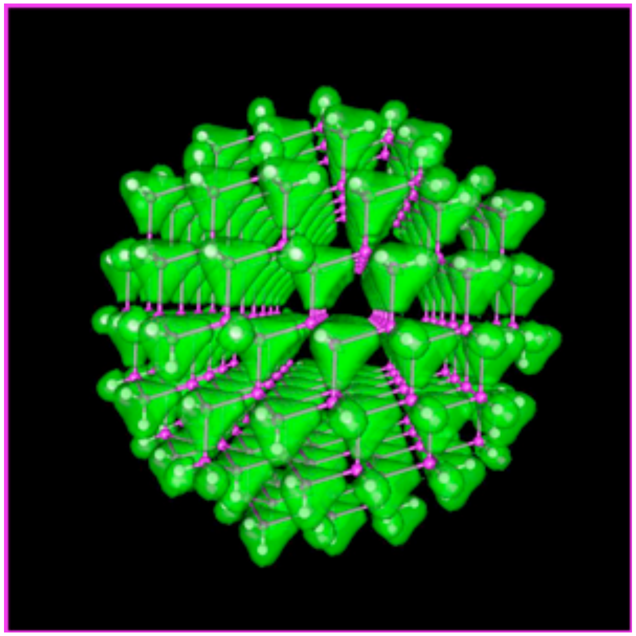
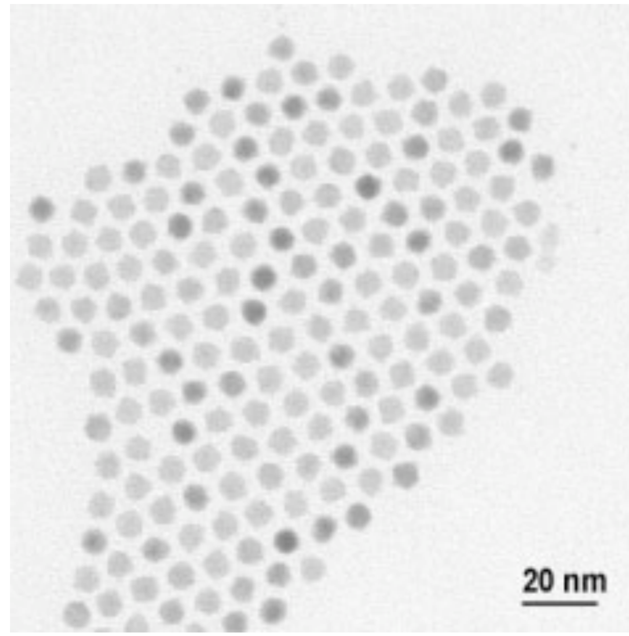
# Quantum Dots

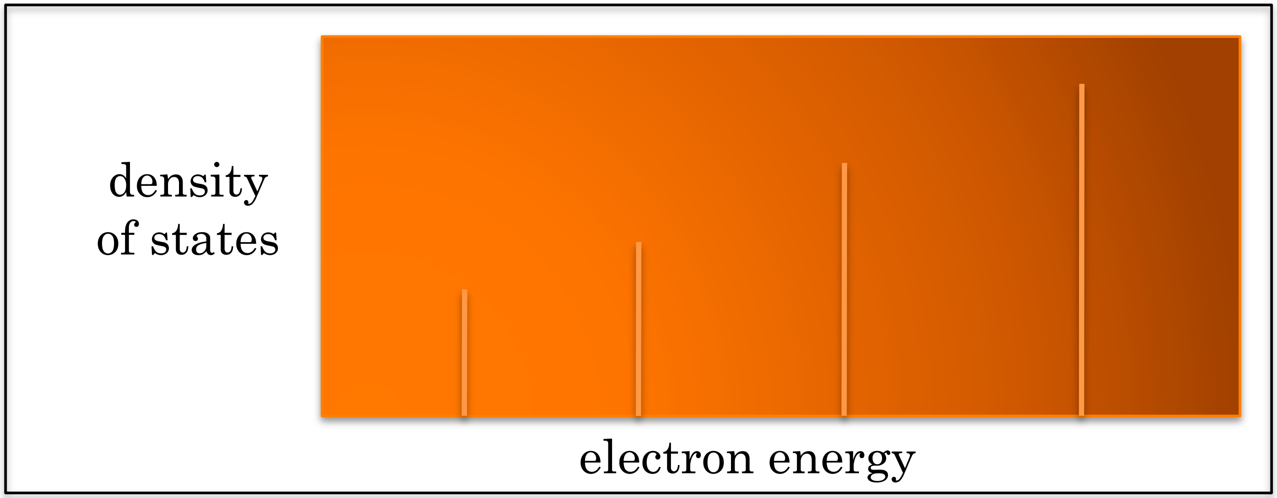





- **Semiconductor nanocrystals** with size in the range of 10 nanometers to one micrometer
- Constitutes a *well conducting region* surrounded in all directions by a *poor conducting region*
- Physics: excitons (electron-hole bound pairs) are bound in *three* directions

# Properties of Quantum Dots

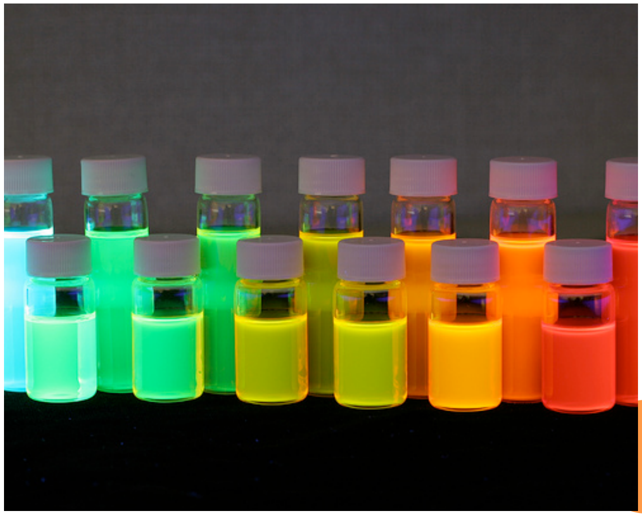
- Just like an atom, electronic energy levels are *quantized*




- Quantum dots contain a *countable number of electrons*
- **Addition of single electron** can drastically change the system's properties (Coulomb blockade)

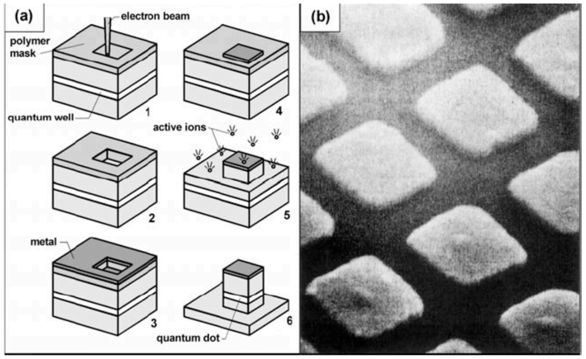
# Quantum Dot Advantages

- The wavelength at which they absorb or emit electromagnetic radiation can be adjusted
- They can be synthesized into a variety of different shapes and forms (e.g. pyramidal quantum dots)
- They can improve the efficiency of solar cells in two ways:
  - Extending band gap to absorb more light in spectrum
  - Generating more charges from single photon

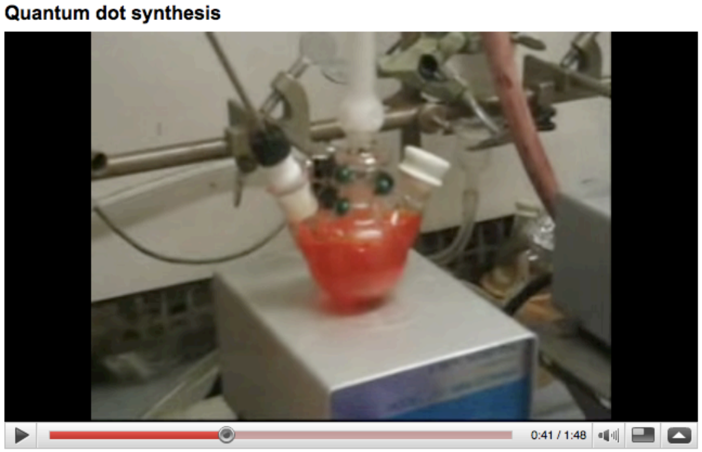


# Synthesis of Quantum Dots

- Photolithography creates a grid-like pattern, followed by selective growth




- Bottom-up approach: colloidal chemistry used to engineer reactions to precipitate quantum dots from polymer precursor, surface must be capped to ensure chemical stability



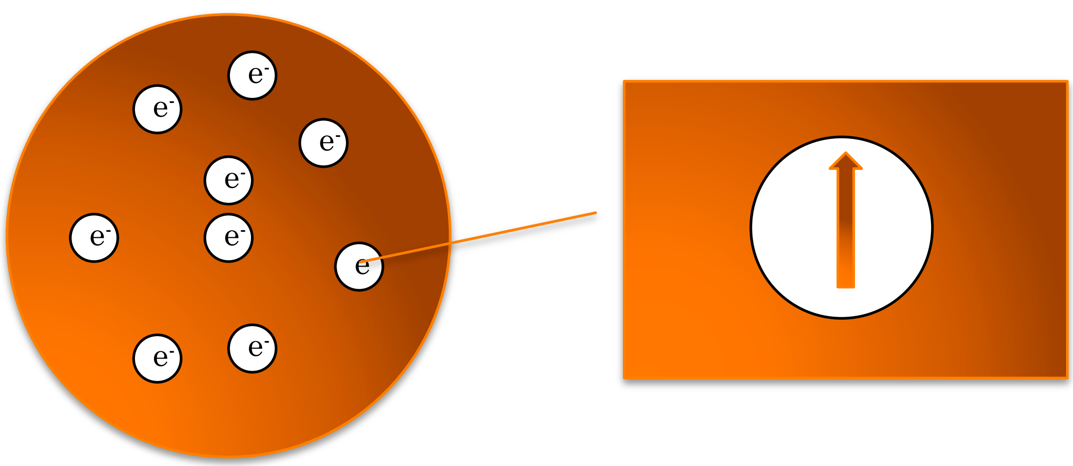

- Also molecular beam epitaxy (MBE)

# Classical versus Quantum

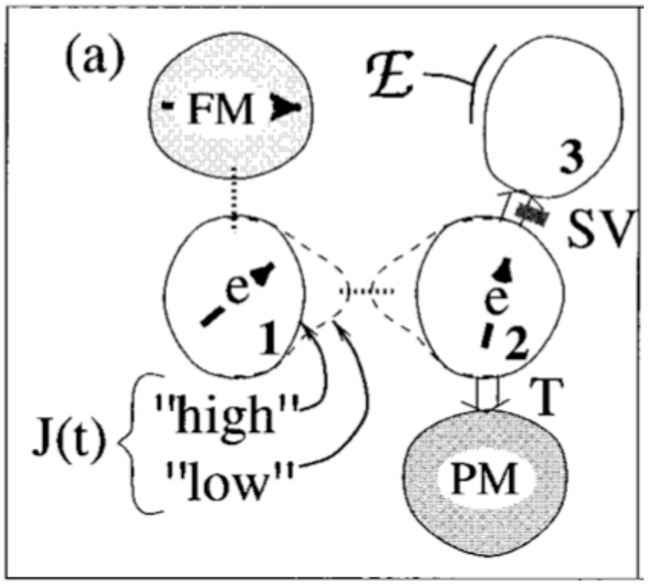
- While a transistor in a conventional computer is used to switch between on and off (the classical bit), a quantum computer takes advantage of quantum theory—the qubit can be simultaneously in both states, i.e. a superposition of the two. This enables the computer to work faster and to hold more memory.
- Conventional computer relies on electrical current. Quantum computer made from quantum dots relies on manipulation of spin.
- Size: approximately 180 nm. 1 grain of sand = 5000 quantum dots.

# Quantum Dot Qubits

- Size of quantum dots results in large Coulomb blockade, allowing precise control of # of electrons
- The dot has an excess electron in its outermost energy level. This electron can either be in the up spin or down spin (or as a superposition, of course). These two states are the basis of the qubit.

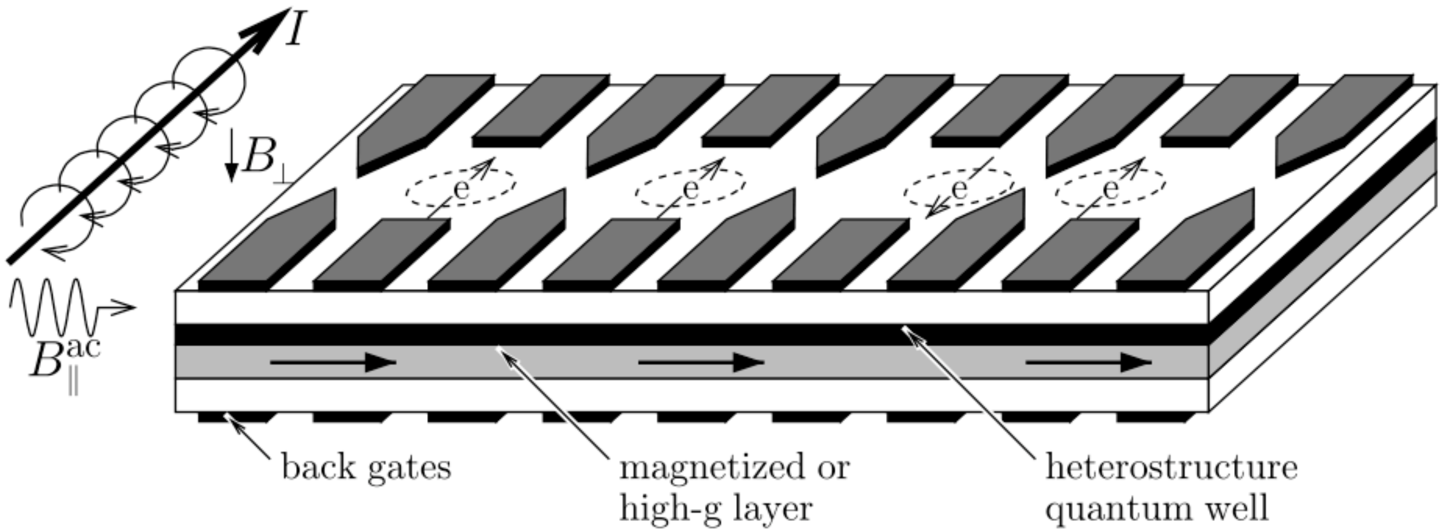


# Qubit interaction




- Electrical gating used to control interaction with other qubits
- High gate voltage prevents tunneling, low gate voltage results in time-dependent Hamiltonian $H_s(t) = J(t)\vec{S}_1 \cdot \vec{S}_2$, where J(t) is a function of the tunneling matrix
- Hopping to ferromagnetic quantum dot enables single-qubit operations
- Spin-dependent tunneling to 3 for measurement

# DESIGN




- Gate electrodes confine the electrons, changing voltage pushes electron wavefunction into mag. layer for Zeeman splitting (1-qubit gates), or current wires can be used for local magnetic field
- We use these fields to perform spin rotations, which are sufficient for one-qubit gates
- Pulsed in-plane magnetic field (in resonance w/ Zeeman splitting) also can address individual spins

Only electrical switching is required to control spin dynamics and quantum computation!

# DiVincenzo Criteria

- 1. Well characterized, scalable qubits? Spin of the excess electron is well-characterized, and arrays of quantum dots is feasible with best techniques for defining nanostructures in semiconductors
- 2. Ability to initiate state? Sure, large magnetic field can be used to relax quantum dot into thermal ground state
- 3. Decoherence time longer than operation time? Decoherence times in ms range, gate operation time in ns range
- 4. Universal set of gates? use local magnetic field for one-qubit gates, use interaction from tunneling for two-qubit gates

# DiVincenzo Criteria

- 5. Qubit readout? Idea is to transfer spin information into charge information. Charge distribution on a reference quantum dot (which is a function of spin-dependent tunneling from the dot of interest) can be used. Need electrometer.
- 6. Conversion of stationary and flying qubits?
- 7. Transmission of flying qubits?


Quantum
DOTS
Yep, They're
That small