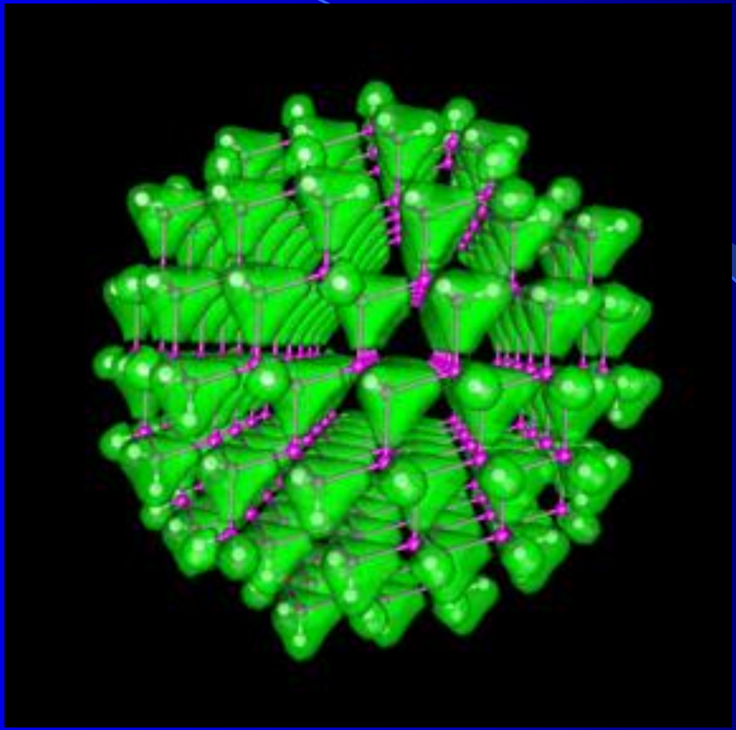
Quantum Confinement

William E. Buhro (2003)

When the size of the material becomes in the order of the de Broglie wavelength of an electron, then the charge carriers are confined within the small region. The state of the system is known as quantum confinement.

Particle confined in this way is similar to a particle in a box of infinite height. It has only quantized energy levels. It introduces new quantum effects at nanosize which are used to make new electronic devices in telecommunication and optoelectronics.

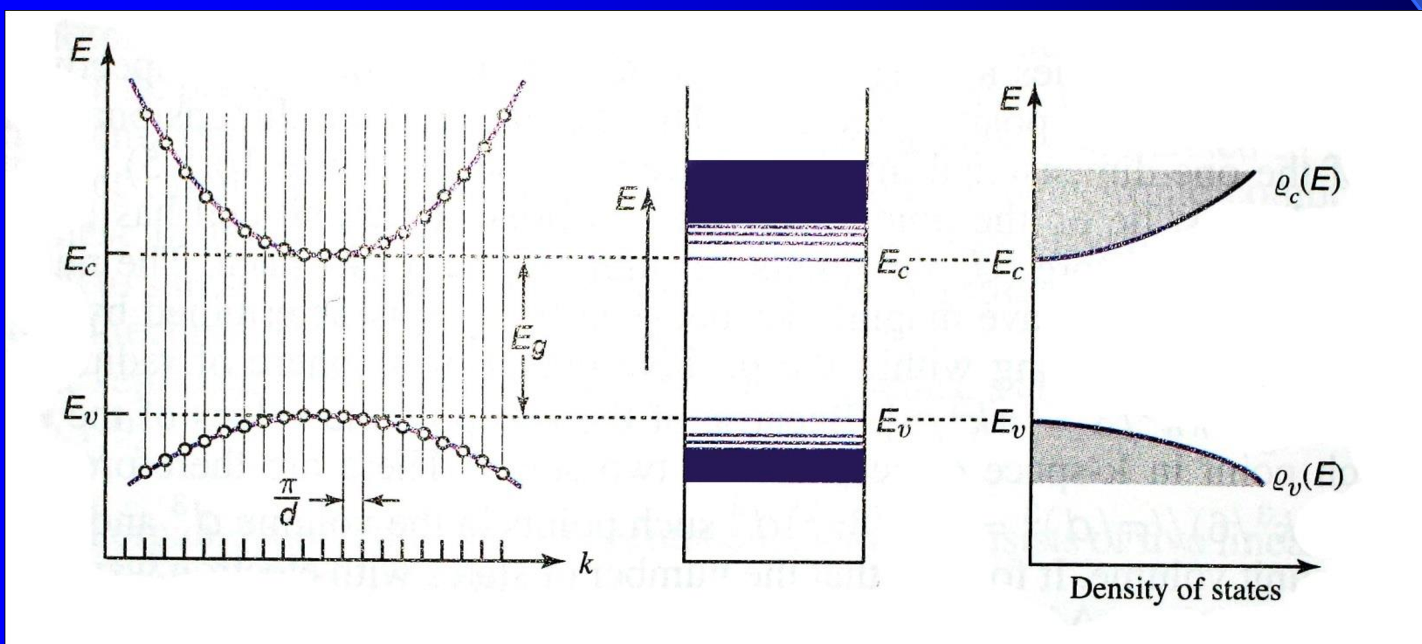
Quantum Well, wire and dot

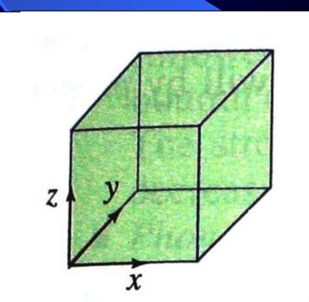


Quantum effect describes the phenomenon resulting from electrons and electron holes being squeezed into a dimension that approaches a critical quantum measurement, called the exciton Bohr radius. In current application, a quantum dot such as a small sphere confines in three dimensions, a quantum wire confines in two dimensions, and a quantum well confines only in one dimension. These are also known as zero-, one- and two-dimensional potential wells, respectively. In these cases they refer to the number of dimensions in which a confined particle can act as a free carrier.

Bulk Semiconductors

- Electrons in conduction band (and holes in the valence band) are free to move in all three dimensions of space.

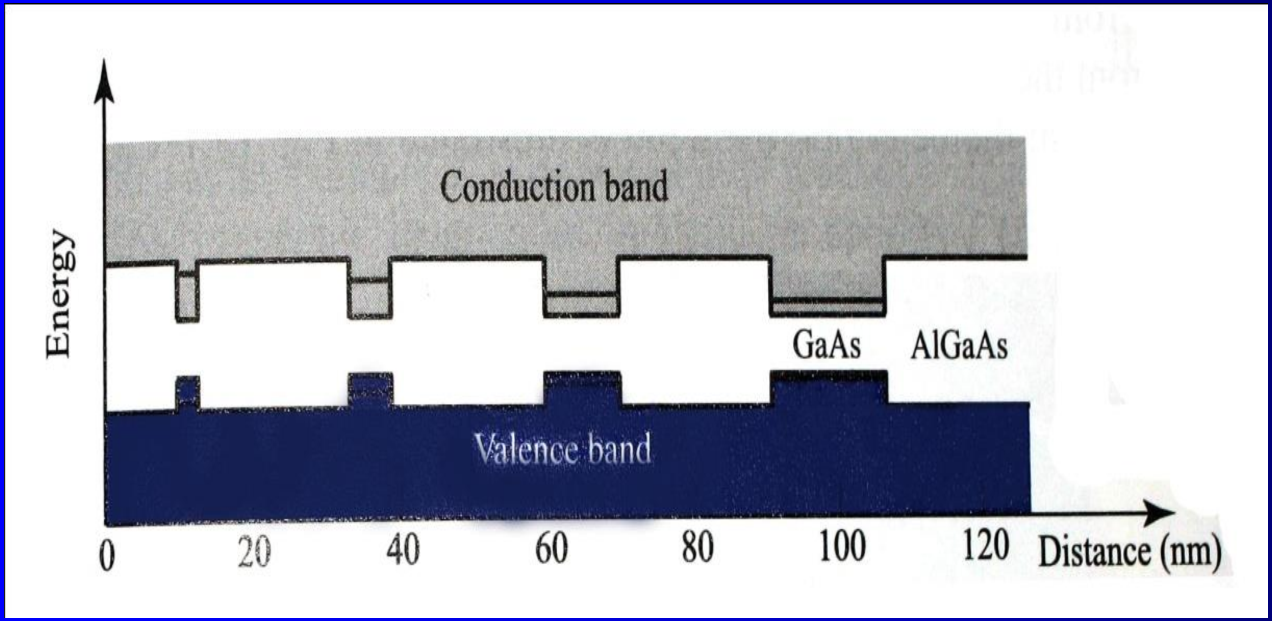


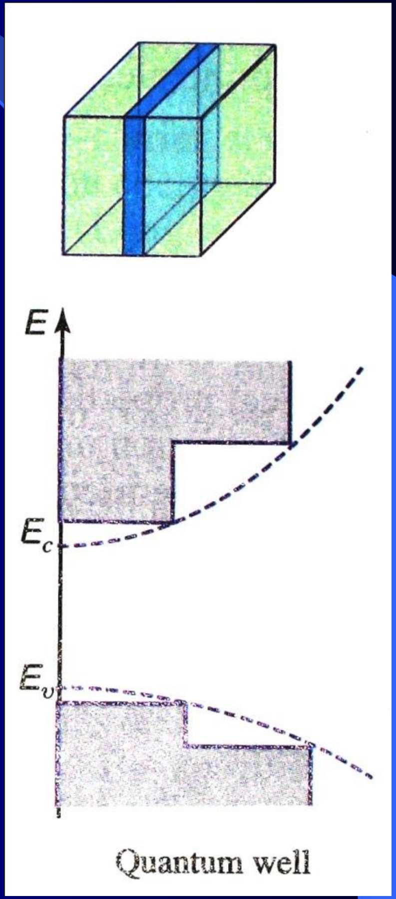


B.E.A. Saleh, M.C. Teich. Fundamentals of Photonics. fig. 16.1-10 and 16.1-29.

Thin Film Semiconductors

- Electrons in conduction band (and holes in the valence band) are free to move in two dimensions.
- Confined in one dimension by a potential well.
  - Potential well created due to a larger bandgap of the semiconductors on either side of the thin film.





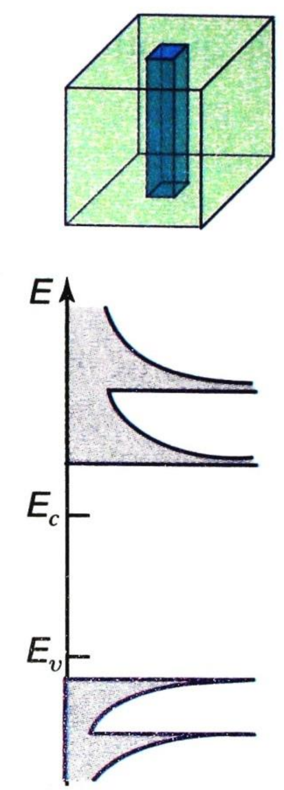
Electrons in quantum wells have a density of states as a function of energy that has distinct steps, versus a smooth square root dependence that is found in bulk materials.

The effective mass of holes in the valence band is changed to more closely match that of electrons in the conduction band.

Quantum wells are in wide use in diode lasers, including red lasers for DVDs and laser pointers, infra-red lasers in fiber optic transmitters, or in blue lasers. They are also used to make HEMTs (High Electron Mobility Transistors), which are used in low-noise electronics. Quantum well infrared photodetectors are also based on quantum wells, and are used for infrared imaging.

Quantum Wire

- Thin semiconductor wire surrounded by a material with a larger bandgap.
  - Surrounding material confines electrons and holes in two dimensions (carriers can only move in one dimension freely) due to its larger bandgap.
    - Quantum wire acts as a potential well.



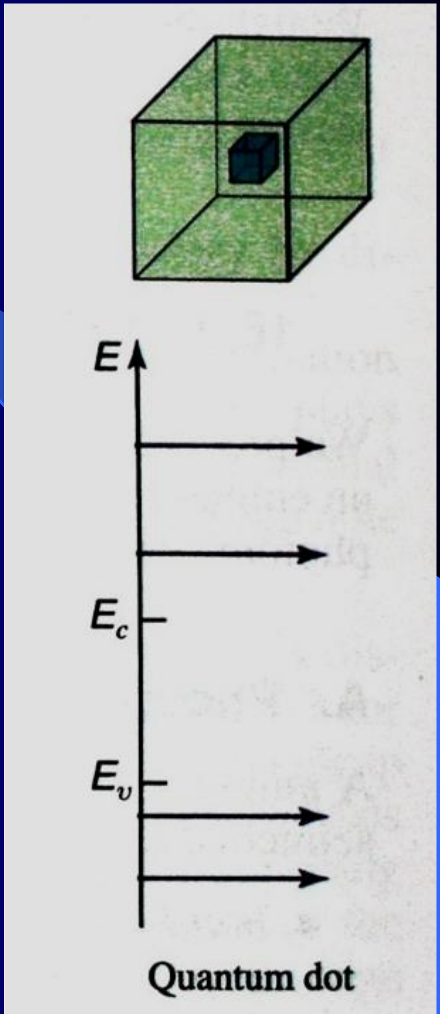
Quantum wire

The carbon nanotube is an example of a quantum wire. A metallic single-walled carbon nanotube that is sufficiently short to exhibit no internal scattering has a conductance that approaches two times
the conductance quantum $4e^2/h$

The factor of two arises because carbon nanotubes have two spatial channels

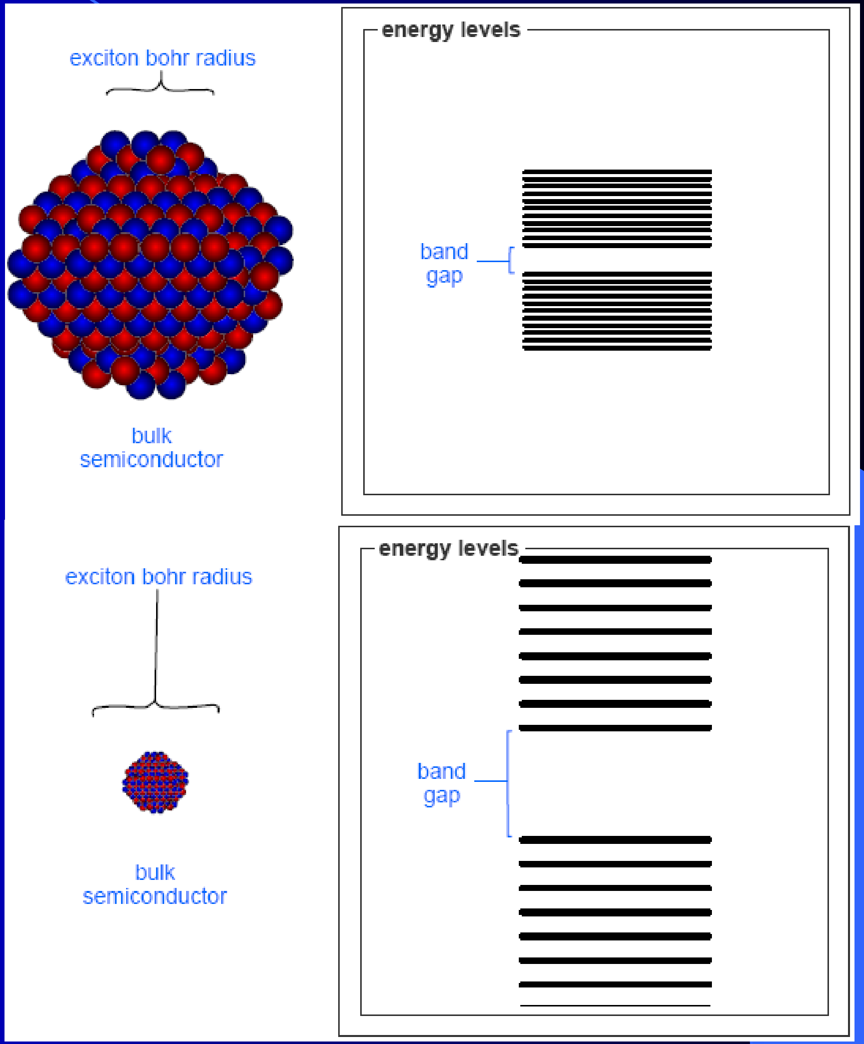
Quantum Dot

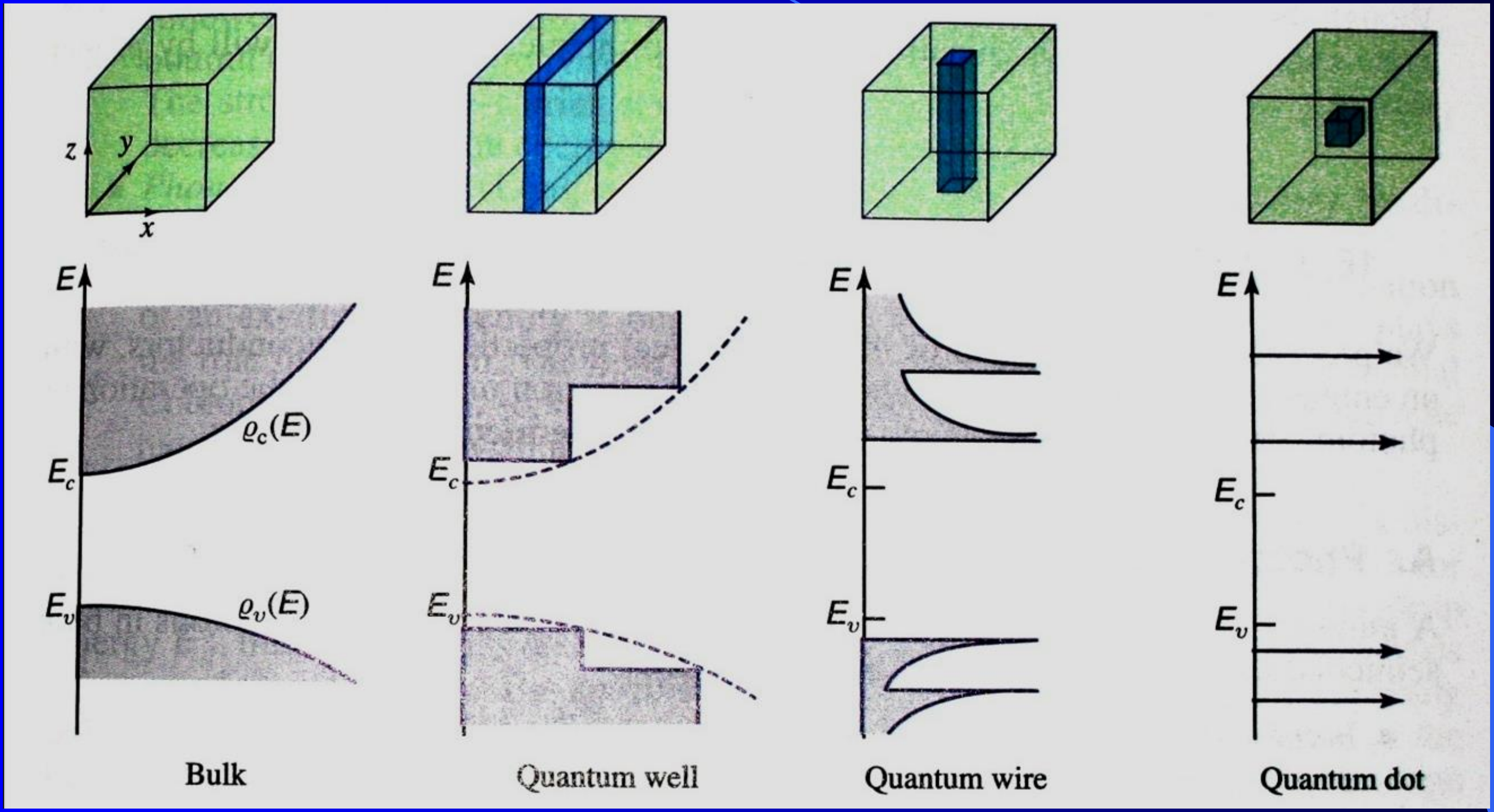
- Electrons and holes are confined in all three dimensions of space by a surrounding material with a larger band gap.
- Discrete energy levels (artificial atom).
- A quantum dot has a larger bandgap.
- Like bulk semiconductor, electrons tend to make transitions near the edges of the bandgap in quantum dots.



Discrete Energy Levels

- The energy levels depend on the size, and also the shape, of the quantum dot.
- Smaller quantum dot:
  - Higher energy required to confine excitons to a smaller volume.
    - Energy levels increase in energy and spread out more.
    - Higher band gap energy.





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