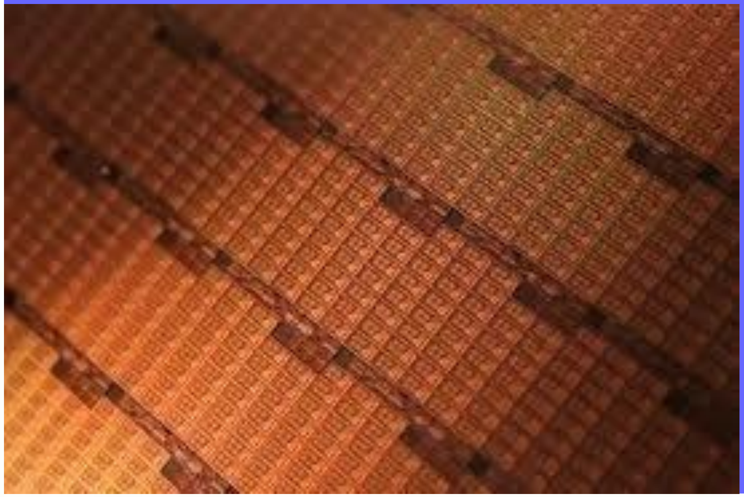
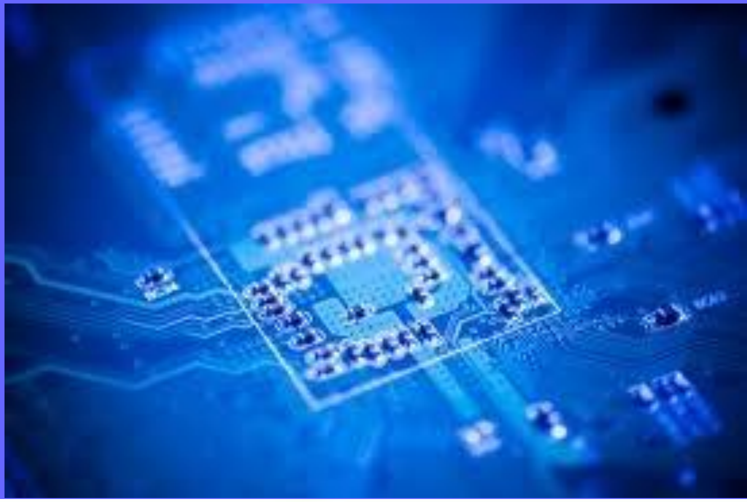
Chemistry 4631

Instrumental Analysis

Lecture 10





Components of Optical Instruments

UV to IR

Basic components of spectroscopic instruments:

- stable source of radiant energy
- transparent container to hold sample
- device to isolate selected region of the spectrum for measurement
- detector to convert radiant energy to a signal
- signal processor and readout

Components of Optical Instruments

Some sources and Detectors are based on Semiconductor Technology

Also Solar cells, some fuel cells, and many other technologies use semiconductor technology.

Semiconductors

Some sources and Detectors are based on Semiconductor Technology

Silicon is a semiconductor.

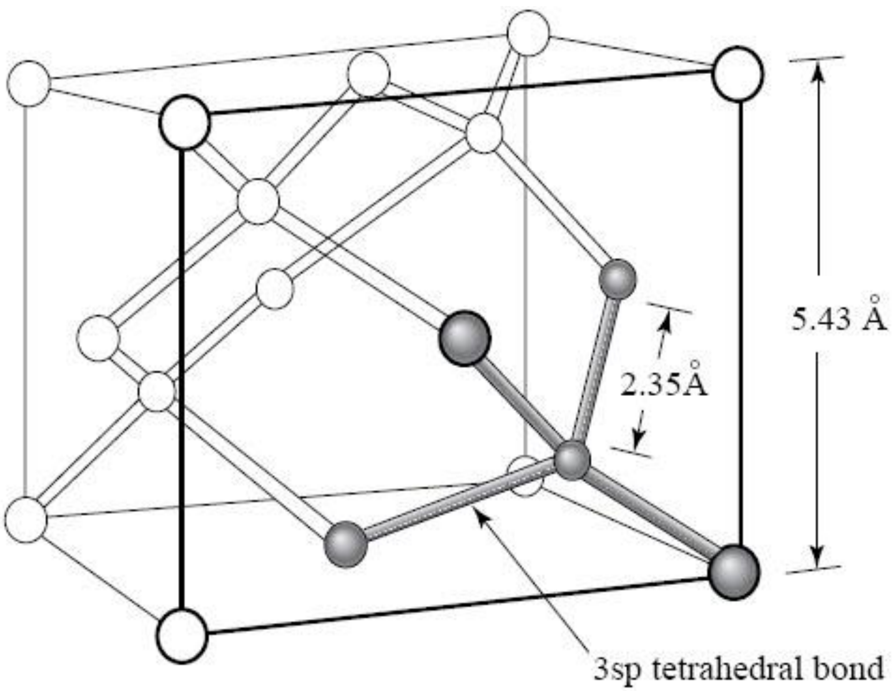
A silicon atom has the electronic configuration of **[Ne]$3s^2p^2$**

The 3s and 3p however form 4 hybrid orbitals so that silicon can form four bonds.

Semiconductors

Silicon is a semiconductor.

For a silicon crystal lattice the resulting structure is a tetrahedron arrangement.



Semiconductors

Silicon is a semiconductor.

Electronic properties for solids can be described in terms of the band model.

For a crystalline solid, atoms assemble into a lattice forming molecular orbitals.

Semiconductors

Silicon is a semiconductor.

The filled bonding orbitals form the valence band (VB) and the vacant antibonding orbitals form the conduction band (CB).

Since the CB is empty – an electron placed in the CB is free to move around.

These bands are separated by a band gap of energy, Eg (eV).

Semiconductors

Semiconductors

The electrical and optical properties of the solid are strongly influenced by the size of the band gap.

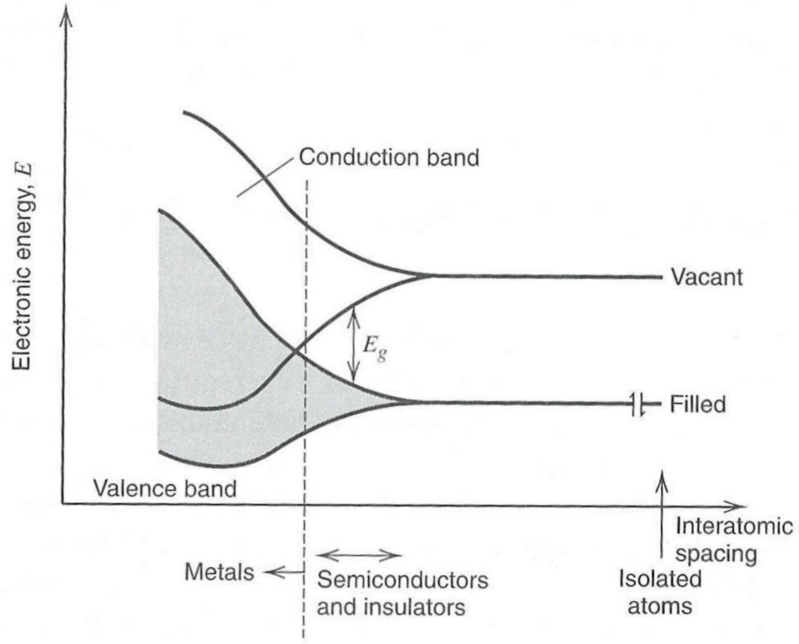


Figure 18.2.1 Formation of bands in solids (at left) by assembly of isolated atoms (characterized by orbitals at far right) into a lattice.

Semiconductors

Semiconductors

When the gap is very small ($E_g << kT$) or the conduction and valence bands overlap, the material is a good conductor.

For larger values of Eg (i.e. Si, 1.1 eV), valence band is almost filled and conduction band is almost vacant.

Semiconductors

Semiconductors

If Eg > 1.5 eV, thermal excitation does not produce enough carriers for conduction.

Example:	GaP	Eg = 2.2 eV
	TiO_2	Eg = 3.0 eV

Semiconductors

Semiconductors

Conduction occurs by thermal excitation of electrons from VB into the CB, producing electrons in CB and “holes” in VB.
The charge can then be carried by the electrons and holes.
This is called an intrinsic semiconductor.

Semiconductors

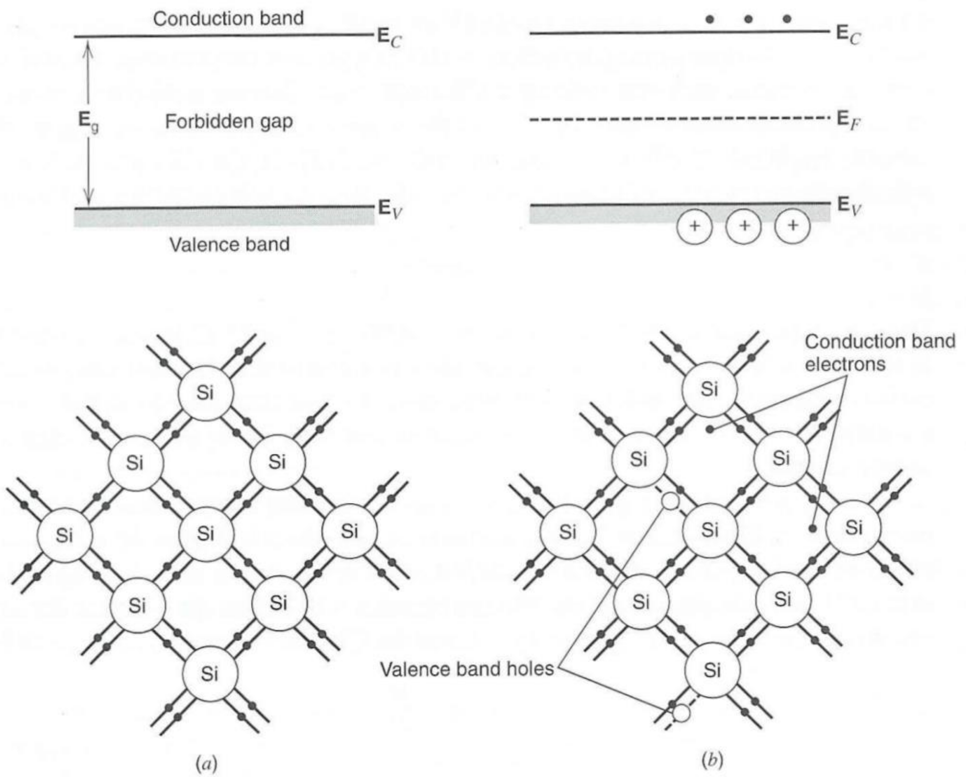


Figure 18.2.2 Energy bands and two-dimensional representation of an intrinsic semiconductor lattice. (*a*) At absolute zero (or $E_g >> kT$), assuming a perfect lattice; no holes or electrons exist. (*b*) At a temperature where some lattice bonds are broken, yielding electrons in the conduction band and holes in the valence band. E_F represents the Fermi level in this intrinsic semiconductor.

Semiconductors

Semiconductors

For an intrinsic semiconductor, the electrons and hole densities are equal.

n_i – density for CB electrons
p_i – density for VB holes
$n_i p_i = (constant)exp(-Eg/kT)$

Semiconductors

Semiconductors

$n_i = p_i = 2.5 \times 10^{19} \exp(-E_g/2kT) \mathrm{cm}^{-3}$ (near 25^oC)

The mobile carriers move in the semiconductor and have mobilities of
$u_n = 1350\ \mathrm{cm}^2\mathrm{V}^{-1}\mathrm{s}^{-1}$ and $u_p = 480\ \mathrm{cm}^2\mathrm{V}^{-1}\mathrm{s}^{-1}$

An intrinsic semiconductor is a pure semiconductor crystal in which the electron and hole concentrations are equal.

Semiconductors

Semiconductors

However , electrons in CB and holes in VB can be introduced by adding dopants into the semiconductor lattice to produce an extrinsic semiconductor.

This causes the concentration of one of the carriers to be in excess of the other.

Semiconductors

Semiconductors

Example: Add As atoms (Group V) which behave as electron donor for silicon (Group IV) and introduce an energy level, E_D just below the CB.

Thus at room temperature, the donor atoms are ionized and give a CB electron leaving a positive site.

Semiconductors

Semiconductors

Example: Add As atoms (Group V) which behave as electron donor for silicon (Group IV) and introduce an energy level, E_D just below the CB.

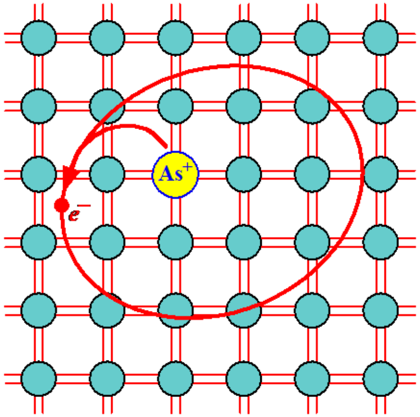


Fig. 5.9: Arsenic doped Si crystal. The four valence electrons of As allow it to bond just like Si but the fifth electron is left orbiting the As site. The energy required to release to free fifth-electron into the CB is very small.

Semiconductors

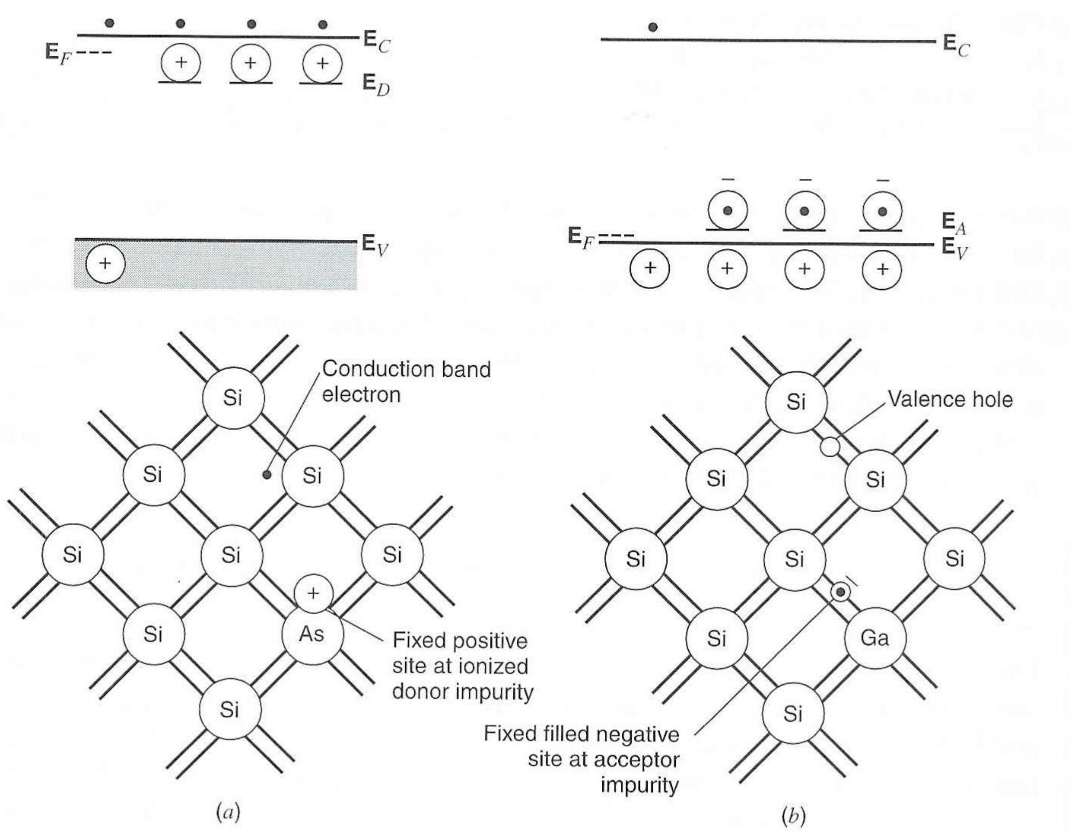


Figure 18.2.3 Energy bands and two-dimensional representation of extrinsic semiconductor lattices. (*a*) *n*-type. (*b*) *p*-type.

Semiconductors

Semiconductors

For 1 ppm of added dopant – the donor density is $N_D = 5x10^{16}$ cm^{-3} – making up most of the CB electron density, n.

$$p = n_i^2/N_D$$

In this case, the electrical conductivity is attributed to the CB electrons and are called the majority carriers.

Thus a material doped with a donor atom is called a n-type semiconductor.

Semiconductors

Semiconductors

Example: Add Ga atoms (Group III) which is an acceptor atom to silicon (Group IV) then introduce an energy level E_A just above VB.

Thus at room temperature, the electrons are thermally excited from the VB into the acceptor sites leaving mobile holes in the VB.

Semiconductors

Semiconductors

Example: Add Ga atoms (Group III) which is an acceptor atom to silicon (Group IV) then introduce an energy level E_A just above VB.

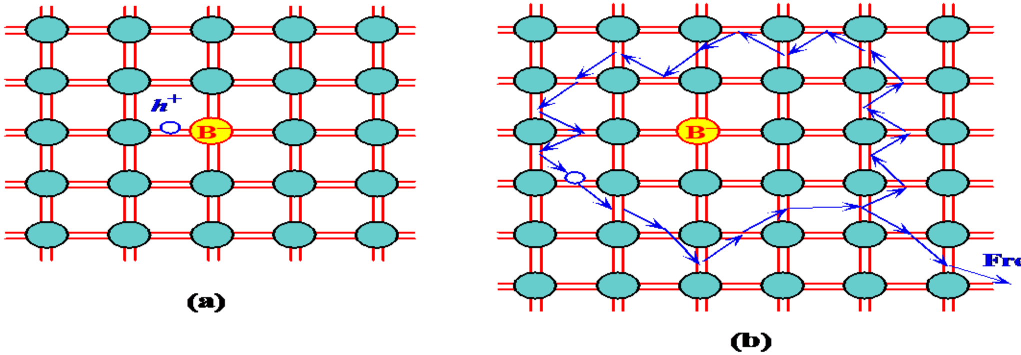


Fig. 5.11: Boron doped Si crystal. B has only three valence electrons. When it substitutes for a Si atom one of its bonds has an electron missing and therefore a hole as shown in (a). The hole orbits around the B— site by the tunneling of electrons from neighboring bonds as shown in (b). Eventually, thermally vibrating Si atoms provides enough energy to free the hole from the B— site into the VB as shown.

Semiconductors

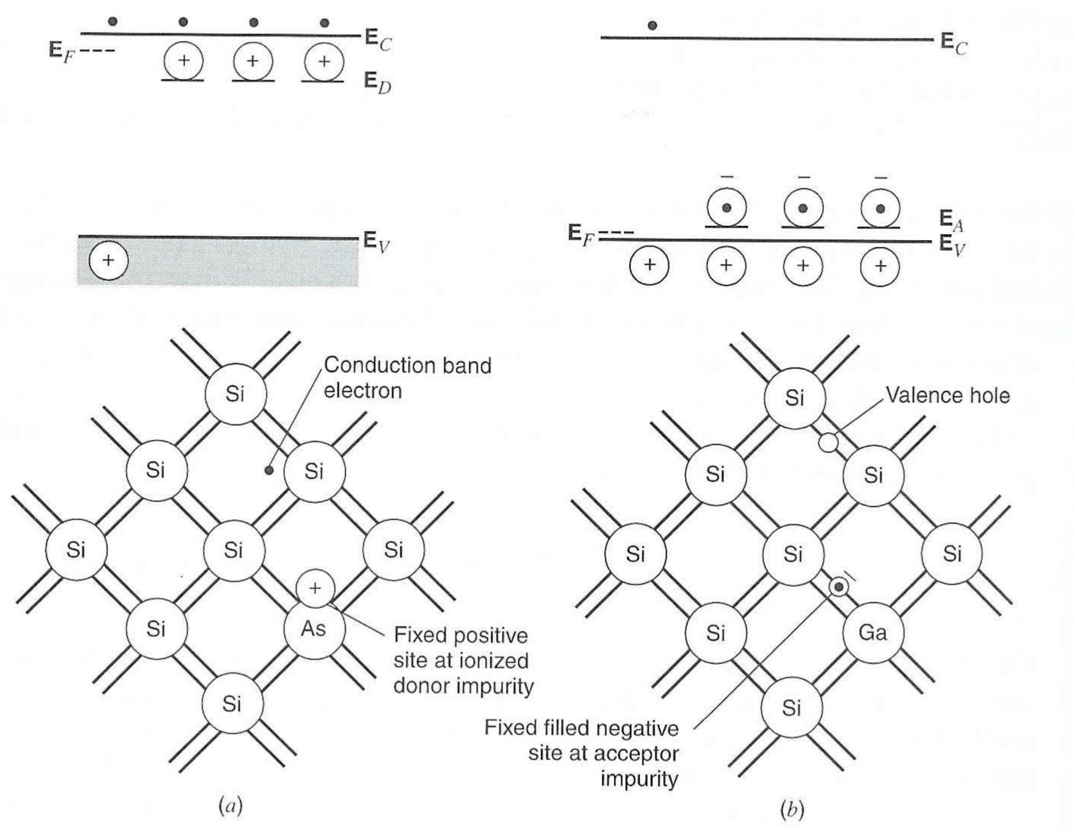


Figure 18.2.3 Energy bands and two-dimensional representation of extrinsic semiconductor lattices. (*a*) *n*-type. (*b*) *p*-type.

Semiconductors

Semiconductors

Acceptor density, N_A makes up most of the hole density, p.

$$n = p_i^2/N_A$$

In this case, the electrical conductivity is attributed to the holes as the majority carriers and the material is called a p-type semiconductor.

Semiconductors

Silicon semiconductor

The conductivity of silicon can be enhanced by doping the Si with As (Group V) or Ga (Group III).

As has 5 e's, with 4 forming bonds with silicon, leaving an extra electron to travel through the crystal. (n-type)

Ga has 3 e's leaving an excess of holes (+ charge) to act as mobile carriers in the crystal. (p-type)

Components of Optical Instruments

Semiconductors

Optical Absorption

When a photon of energy higher than Eg strikes a semiconductor, electrons are excited from the VB to the CB.

Components of Optical Instruments

Semiconductors

Optical Absorption

Beer-Lambert Law for the semiconductor:

$$I(x) = I_o \exp(-\alpha x)$$

where
I(x) – transmitted intensity
I_o – intensity of photons incident on semiconductor
α – absorption coefficient of the semiconductor
x – thickness

The distance over which 67 percent of the photons are absorbed is called the penetration depth.

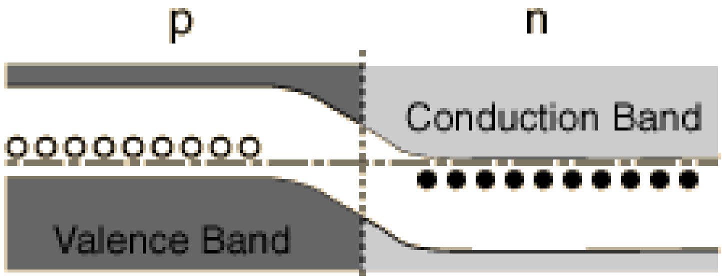
Components of Optical Instruments

Semiconductors
pn junctions

Formed by contact between a p-type and n-type semiconductor.

The junction formed has rectifying properties – current can flow in one direction easily but limited in the other direction.

p-n junction



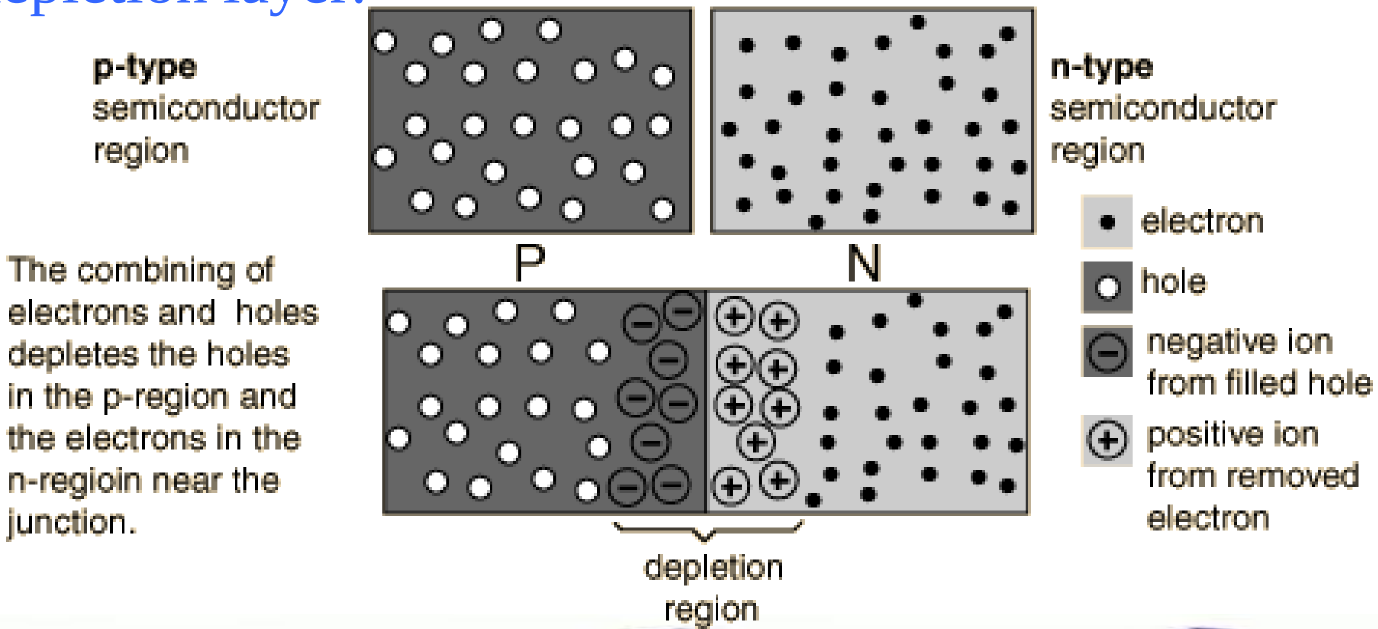
Energy bands at equilibrium

Components of Optical Instruments

Semiconductors

pn junctions

When the pn junction forms - some of the free electrons at the interface diffuse and combine with the holes creating a depletion layer.



Components of Optical Instruments

Semiconductors

pn junctions

When the electron and hole recombine this process is called recombination.

In some semiconductors, i.e. GaAs and InP this process results in an emission of a photon. This is a direct recombination mechanism and the excess energy of the electron is lost as a photon hv= E_g.

In other semiconductors, the energy is simply lost as lattice vibrations (heat).

Components of Optical Instruments

Semiconductors

pn junctions

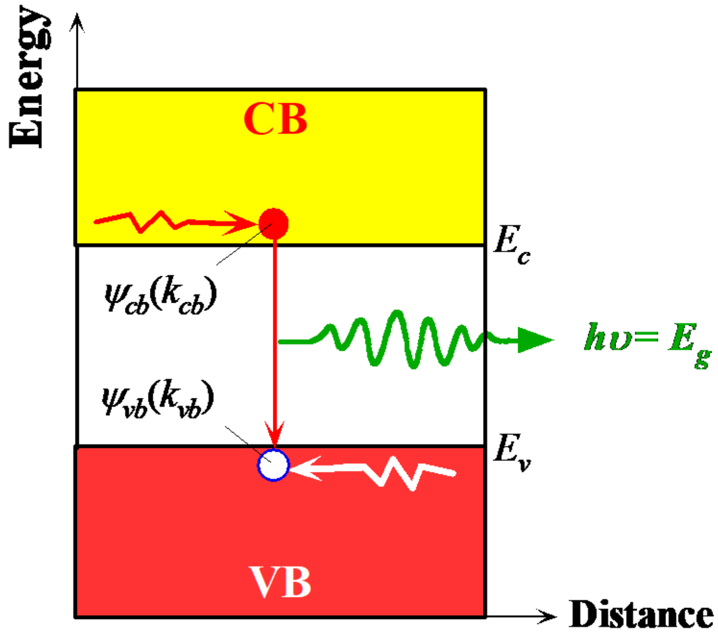


Fig.5.22: Direct recombination in GaAs. $k_{cb} = k_{vb}$ so that momentum conservation is satisfied

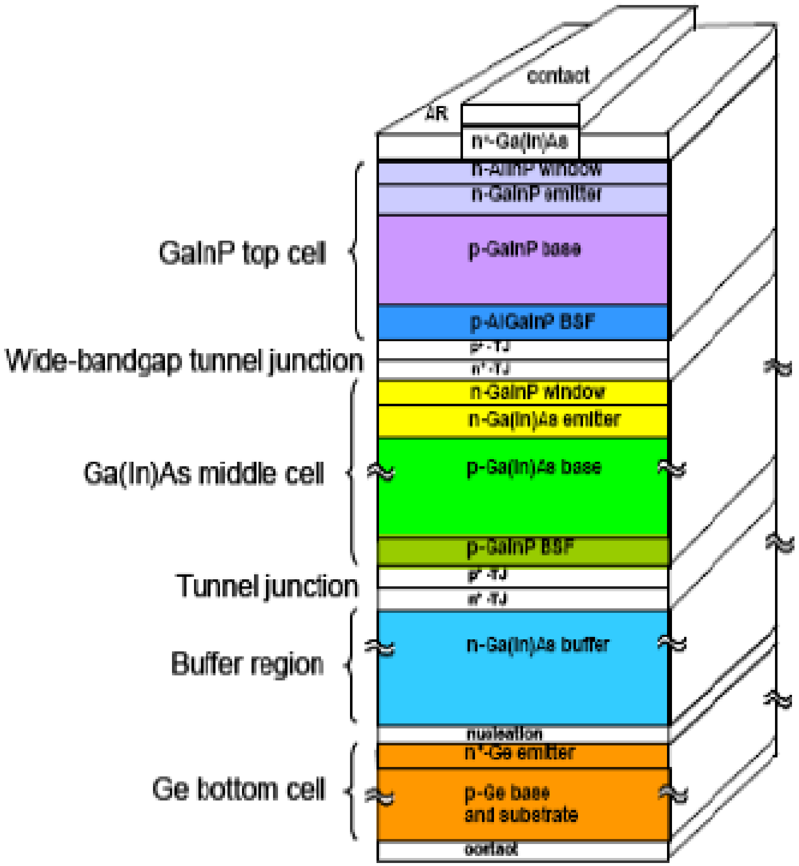
Semiconductors

Semiconductors

pn junctions

Solar Cells

High Efficiency Device
GaInP/GaInAs/Ge by Spectrolab
(A Boeing Company)
achieved 40.7% efficiency in 2007.
44.7% (2013). 46% (2014)
Top cell – 1.8 eV = 689 nm
Middle cell – 1.4 eV = 866 nm
Bottom cell – 0.67 eV = 1850 nm



Semiconductors

Semiconductors

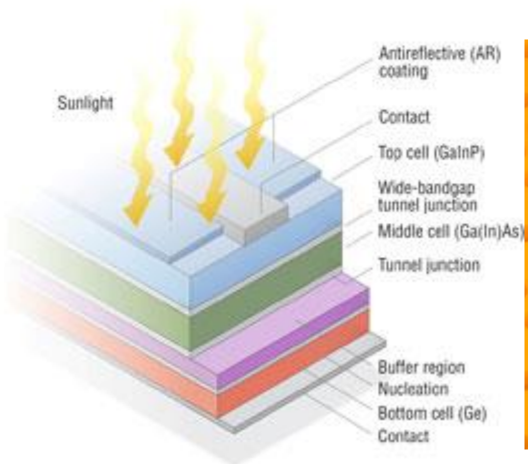
pn junctions

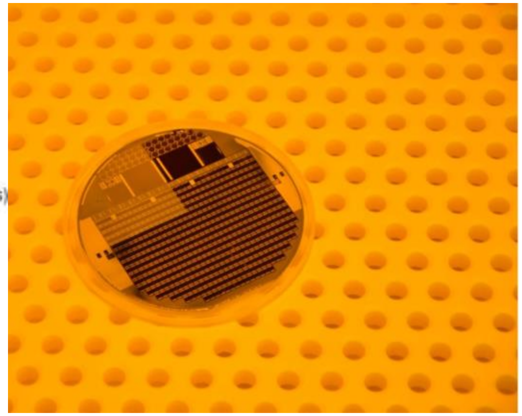
Solar Cells

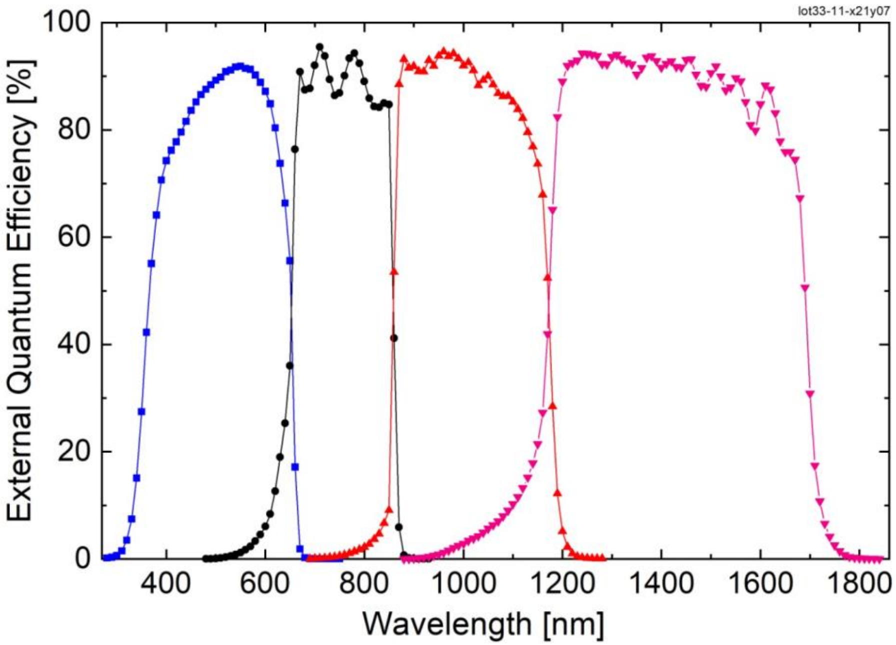
High Efficiency Device

III-V four-junction CPV cell by Fraunhofer ISE achieved 47.6% (2022).

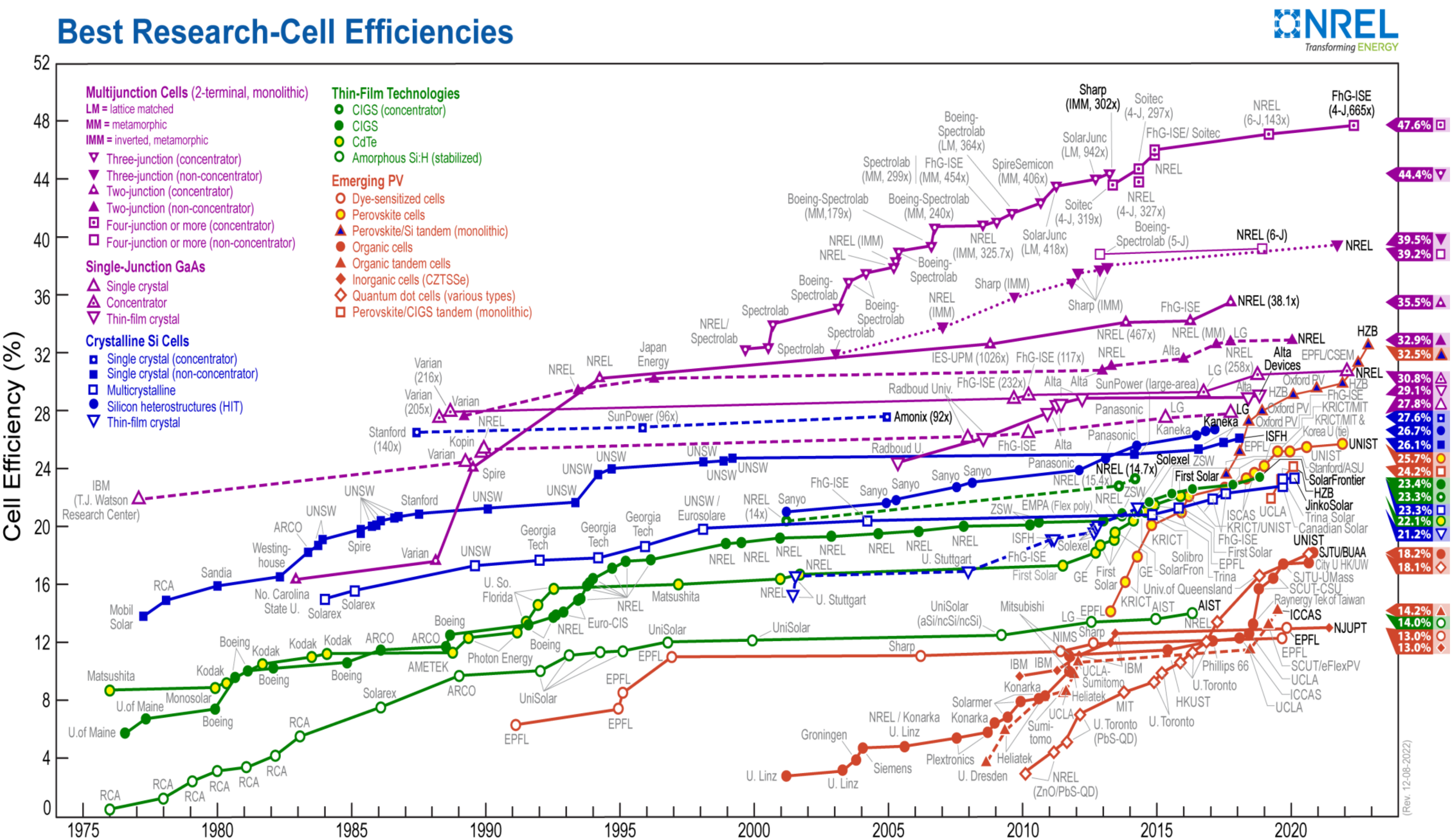
In real-world conditions held by NREL, who developed triple junction cells with a tested efficiency of 39.5%.







Solar Cells



Best Research-Cell Efficiencies
NREL
Transforming ENERGY
Multijunction Cells (2-terminal, monolithic)
LM = lattice matched
MM = metamorphic
IMM = inverted, metamorphic
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Two-junction (non-concentrator)
Four-junction or more (concentrator)
Four-junction or more (non-concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal (concentrator)
Single crystal (non-concentrator)
Multicrystalline
Silicon heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
CIGS (concentrator)
CIGS
CdTe
Amorphous Si:H (stabilized)
Emerging PV
Dye-sensitized cells
Perovskite cells
Perovskite/Si tandem (monolithic)
Organic cells
Organic tandem cells
Inorganic cells (CZTSSe)
Quantum dot cells (various types)
Perovskite/CIGS tandem (monolithic)
Cell Efficiency (%)
52
48
44
40
36
32
28
24
20
16
12
8
4
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
47.6%
44.4%
39.5%
39.2%
35.5%
32.9%
32.5%
30.8%
29.1%
27.8%
27.6%
26.7%
26.1%
25.7%
24.2%
23.4%
23.3%
23.3%
22.1%
21.2%
18.2%
18.1%
14.2%
14.0%
13.0%
13.0%
(Rev. 12-08-2022)

Semiconductors

Solar Cells

Here are the top five best solar panel manufacturers in 2024 ranked based on the highest efficiency solar panel they have to offer:

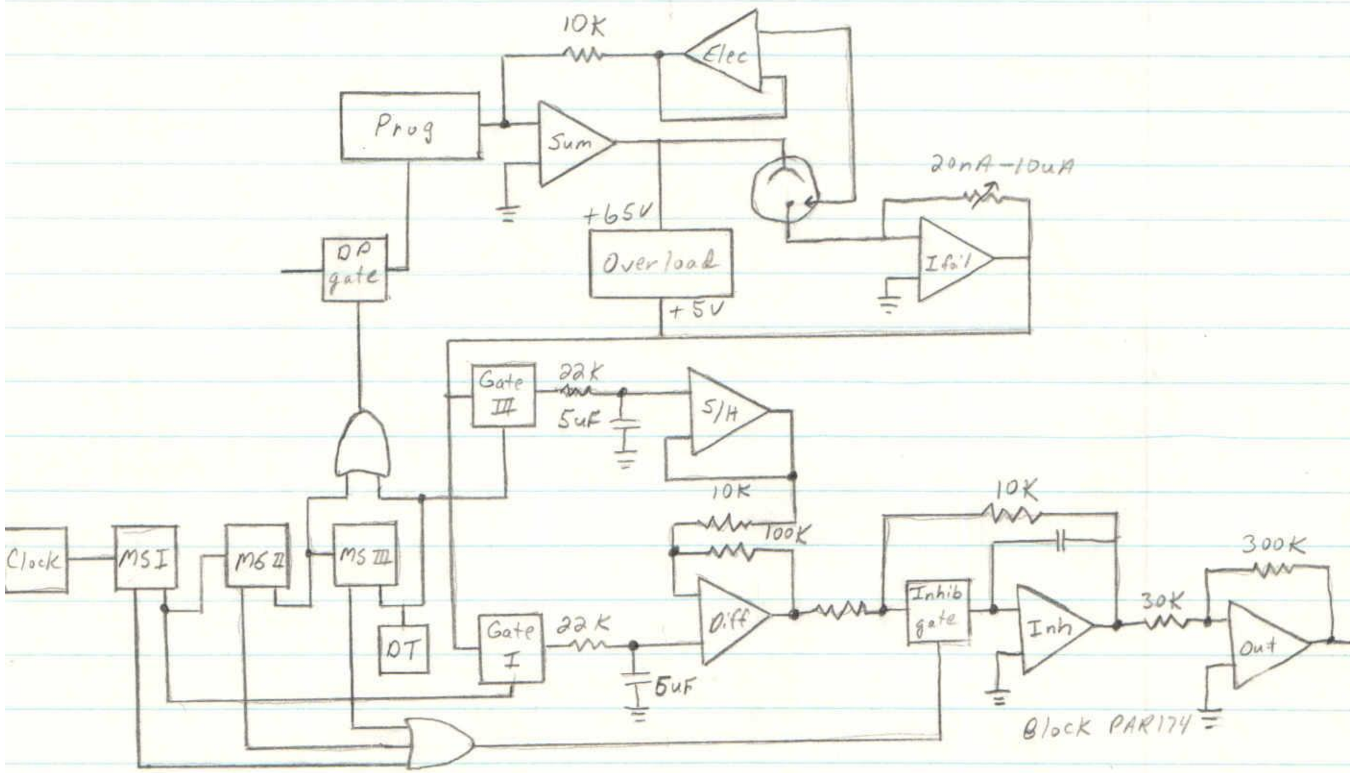
Brand	Type of Panel	Best Efficiency Rating
LG	Monocrystalline	22.30%
Maxeon	Monocrystalline	22.80%
Silfab	Monocrystalline	21.40%
Panasonic	Monocrystalline	21.70%
Q Cells	Monocrystalline	20.60%
REC	Monocrystalline	21.90%
Canadian Solar	Monocrystalline	22.00%
Trina Solar	Monocrystalline	21.60%

Assignment

- Read Chapters 7, 13, 15, 16, 17
- HW6 Chapter 13: 1, 2, 5-8, 12, 13, 16-19
- HW6 Chapter 13 Due 2-12 or 2-14

Instrument Lab

Block diagram of EG+G PARC Model 174A Polorographic Analyzer (Instrumental Method of Analysis, 6th Ed, Dean & Settle)



Instrument Lab

II. Instumentation

The Instrument used was a Spectrophotometer Beckman Double Beam #1401100834. And the light source was a Beckman Hydrogen Lamp Power Supply #337997.

Schematic drawing: Figure 1: Double Beam Spectrometer

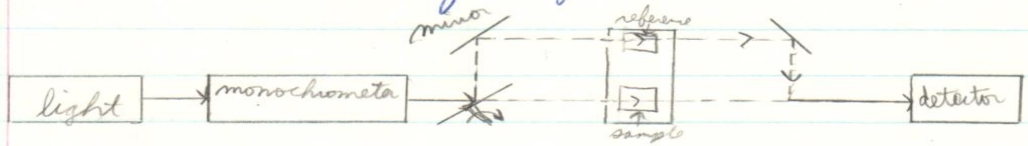


Figure 2: A scanning double-beam spectrometer with dual source, single grating.
pg. 57, Instrumental Analysis, Dean + Settle