

Optical Materials

CML102

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Units and conversions

- $h\nu$ in eV = $h\nu(\text{eV}) \times (1.6 \times 10^{-19}) \text{ J}$

- λ in nm $\equiv \frac{10^7}{\lambda(\text{nm})} \text{ cm}^{-1} \equiv$

$$\frac{10^9 \times hc}{\lambda(\text{nm})} \text{ J} \equiv \frac{10^9 \times hc}{(6.022 \times 10^{23}) \times (1.6 \times 10^{-19}) \times \lambda(\text{nm})} \text{ eV} = \frac{1242}{\lambda(\text{nm})}$$



Phosphors

- exhibit the phenomenon of luminescence
 - phosphorescent (slow), fluorescent (fast)
- transition metal or rare earth compounds
- Uses: CRTs, plasma screens, fluorescent lamps, sensors, LEDs
- incandescence: all atoms radiate
- luminescence: a fraction of atoms (luminescence centers) radiate
 - hosts and dopants (activators)
 - electron-hole excitation (exciton)
 - decay
 - trap by impurities
 - phosphorescence
- Materials
 - hosts – typically oxides, nitrides and oxynitrides, sulfides, selenides, halides or silicates of zinc, cadmium, manganese, aluminium, silicon, or various rare-earth metals.
 - activators: Cu, Mn, Ag, lanthanides ...
 - ZnS:Cu, ZnS:Ag
- Preparation: low-temp, sol-gel, post annealing at ~ 1000 C



Phosphors in Fluorescent Lights

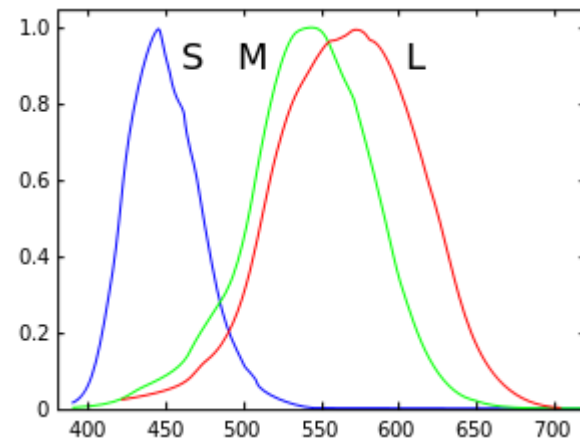
- Spontaneous emission
- CRT – e^- beams scintillate phosphors
- LCD – transistors excite phosphors
- Fluorescent tube
 - electric discharge through Hg vapors $\rightarrow$ 254 nm
 - white powder, e.g. $3\text{Ca}_3(\text{PO}_4)_2 \cdot \text{CaF}_2$, absorbs UV and emits visible radiation
 - blue phosphor – $\text{BaMgAl}_{10}\text{O}_{17}:\text{Eu}^{2+}$
 - green phosphor – $\text{CeMgAl}_{11}\text{O}_{19}:\text{Tb}$
 - red phosphor – $\text{Y}_2\text{O}_3:\text{Eu}$



Color

- human eye - three types of cone cells (LMS color space)

- S: short 420-440 nm peak
- M: middle 530-540 nm peak
- L: long 560-580 nm peak
- dim light only rod cells work – b/w vision
- LMS tri-stimulus – not a good measure

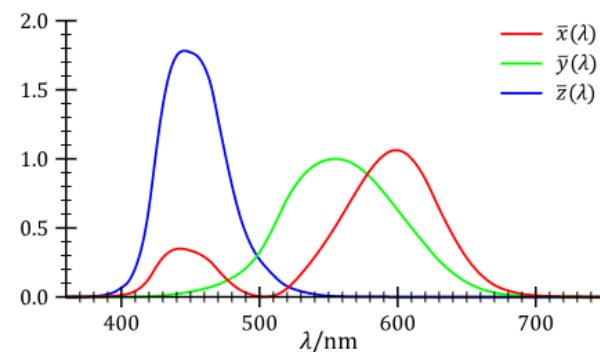
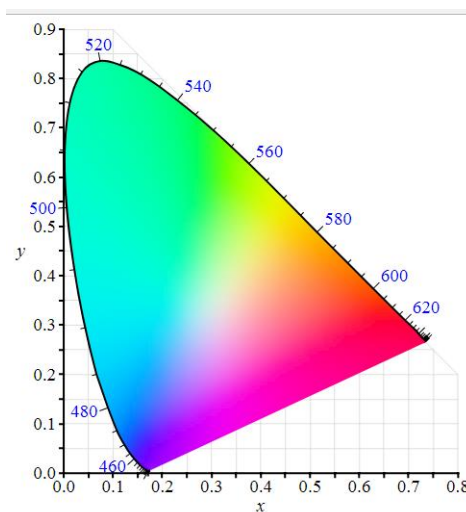


The normalized spectral sensitivity of human cone cells of short-, middle- and long-wavelength types.

- XYZ color space (CIE 1931)

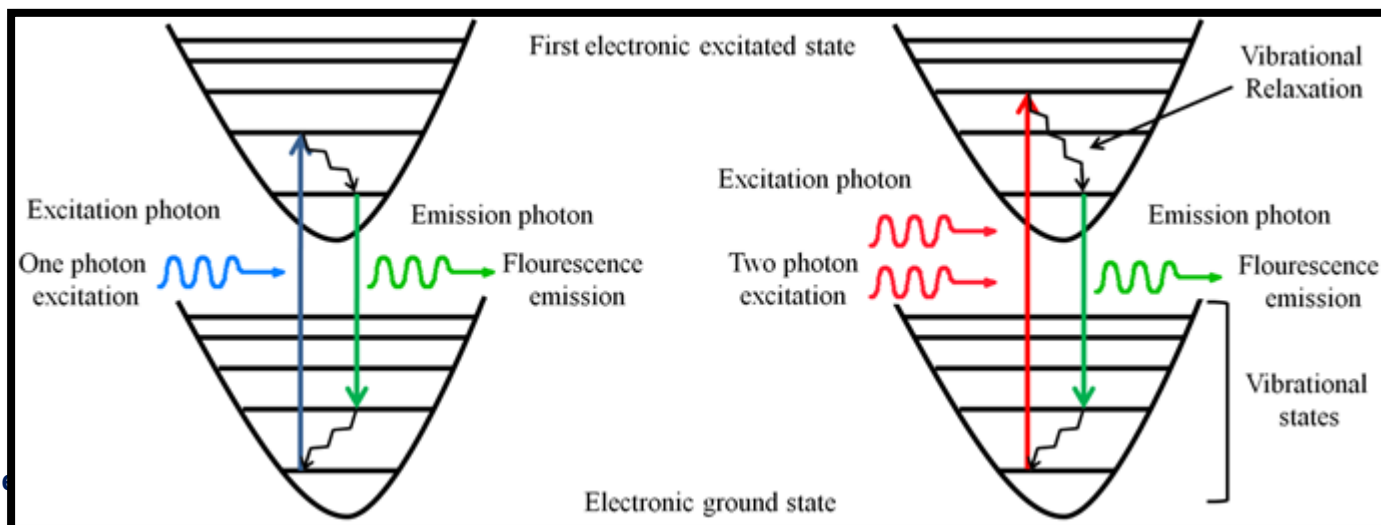
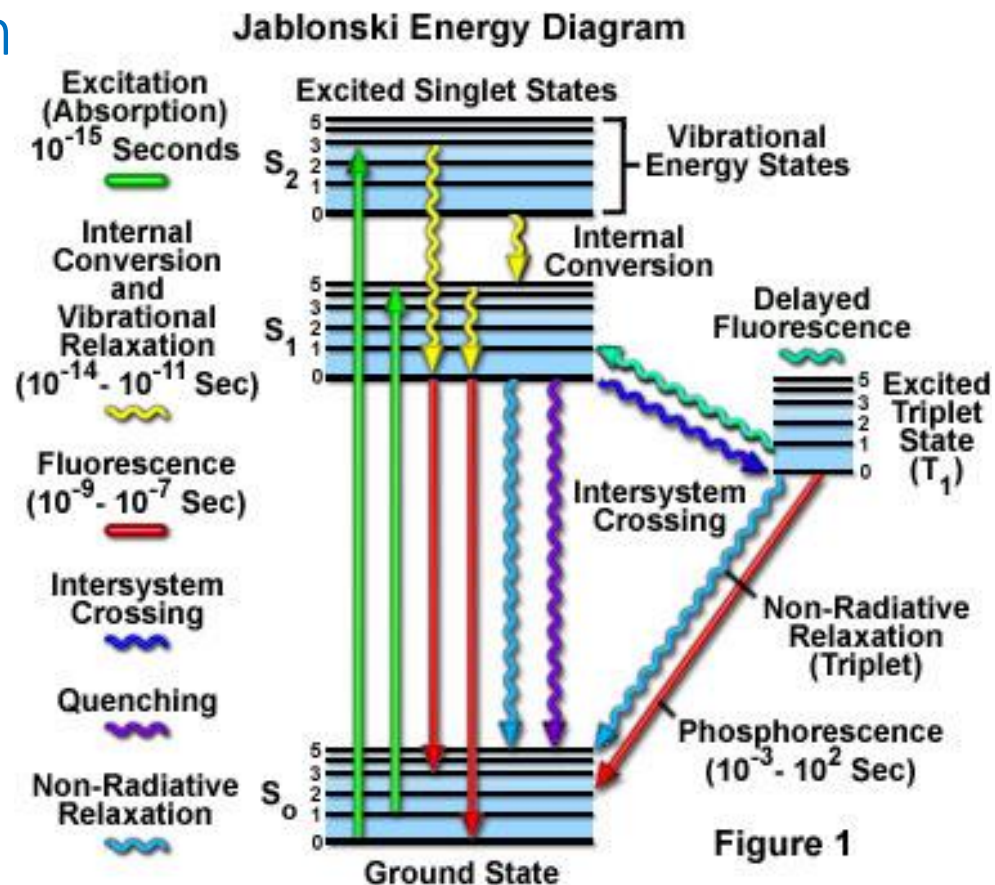
- 380 – 780 nm
- $X = \int_{\lambda} L(\lambda) \bar{x}(\lambda) d\lambda, Y = \dots Z = \dots$
- CIE xyz tristimulus

- $x = \frac{X}{X+Y+Z}$
- $y = \frac{Y}{X+Y+Z}$
- $z = 1 - x - y$

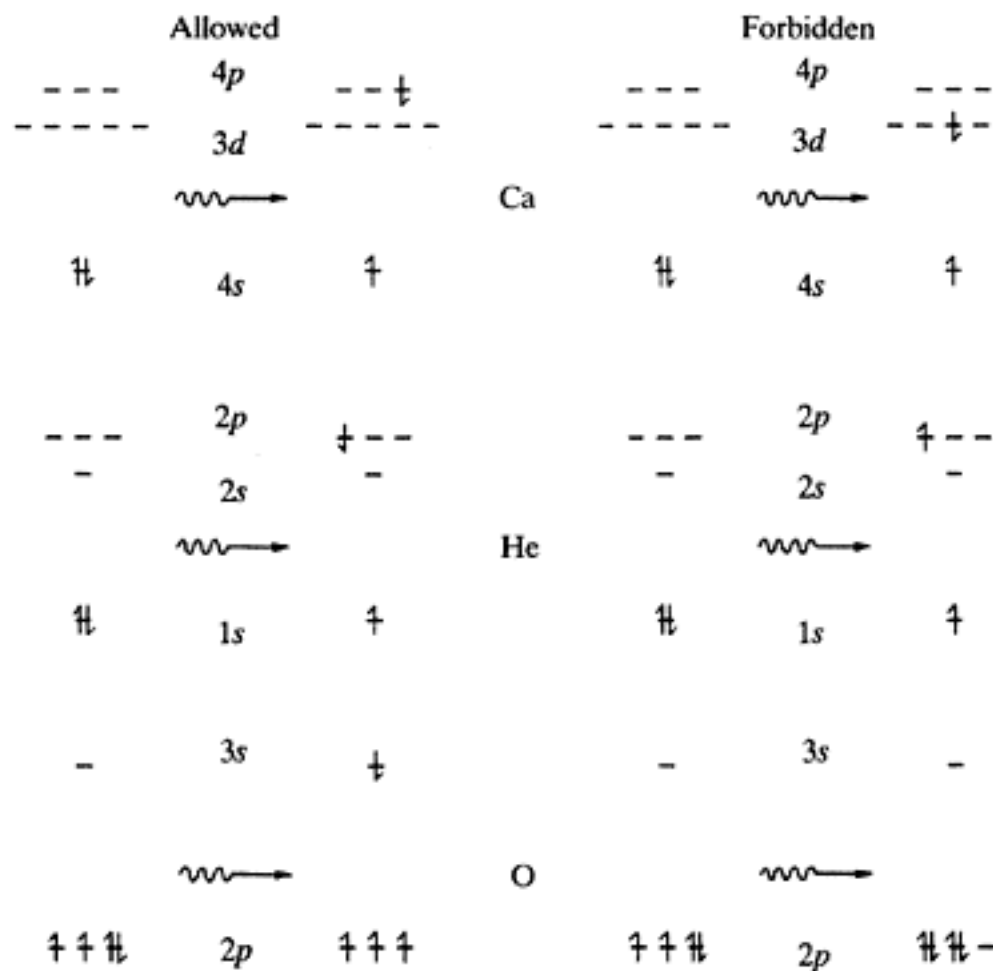


The CIE standard observer color matching functions

Jablonski diagram



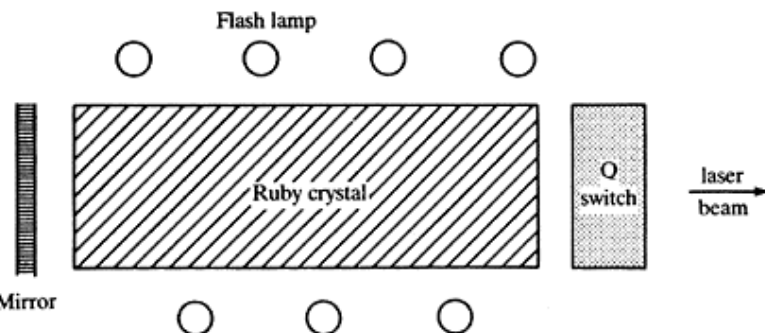
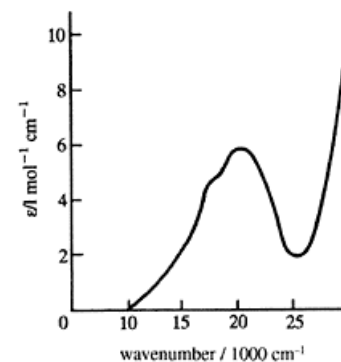
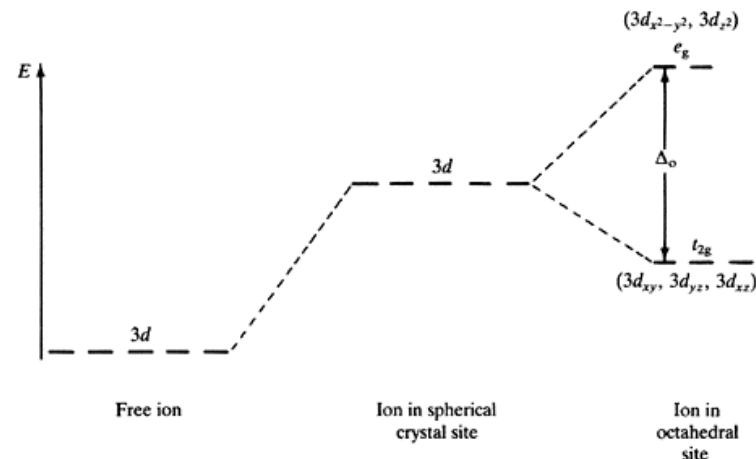
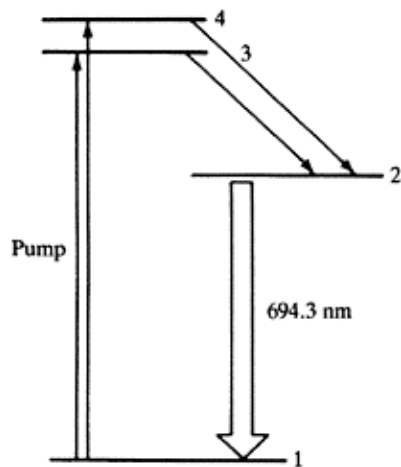
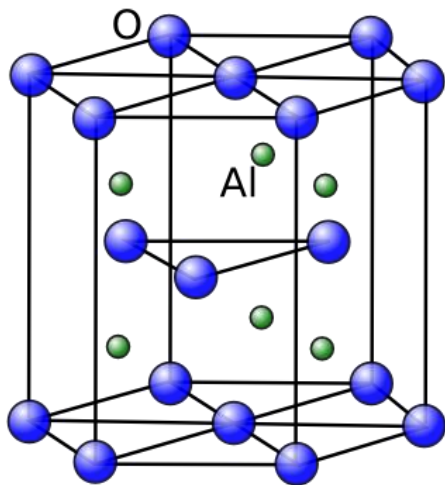
Allowed and Forbidden transitions



Ruby laser

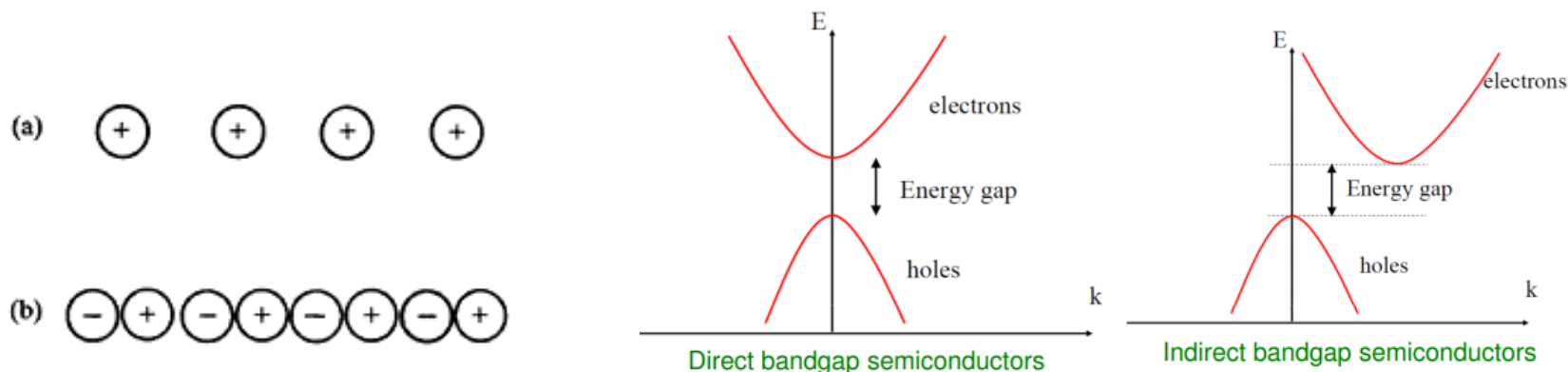
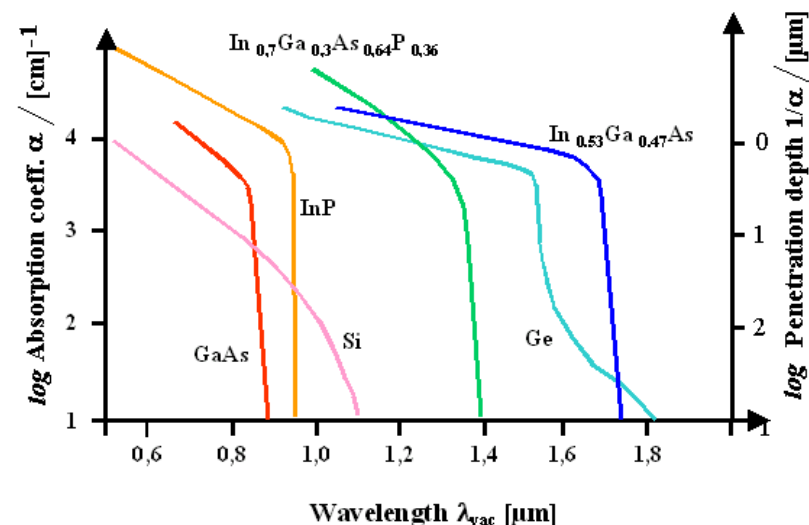
- Corundum (Al_2O_3) structure with 0.04% to 0.5% Cr^{3+} ions
 - 0 hcp lattice, Al in 2/3 Oh voids, Td voids are empty
 - 6 O atoms, 4 Al atoms
 - Cr^{3+} ions occupy the Oh sites (distorted sites)
 - Spontaneous and Stimulated emission

Ion	Host	Wavelength emitted (nm)
Nd^{3+}	Fluorite (CaF_2)	1046
Sm^{3+}	Fluorite	708.5
Ho^{3+}	Fluorite	2090
Nd^{3+}	Calcium tungstate (CaWO_4)	1060



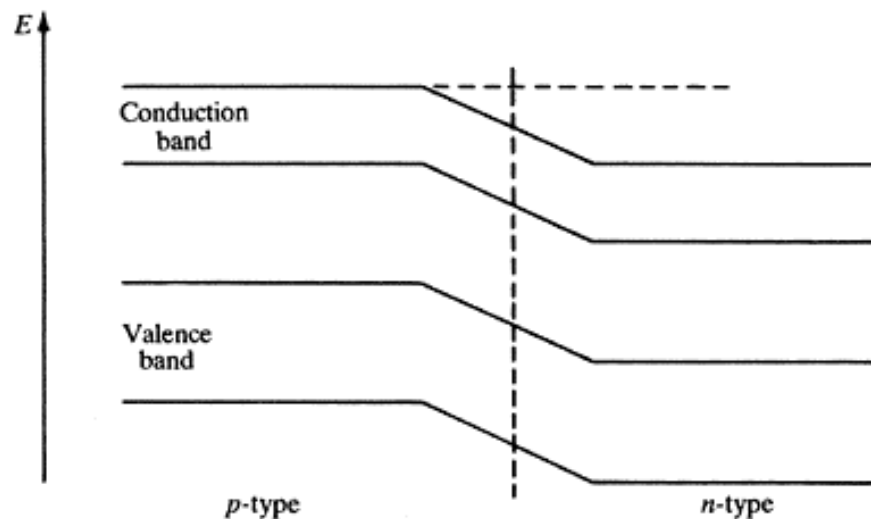
Absorption in semiconductors

- selection rules are a bit different
 - wavevector $\mathbf{k}$ is now restricted
 - momentum of $e^- = \mathbf{k}\hbar$
 - e^- cannot change its $\mathbf{k}$ – direct gap
 - indirect – phonon assisted
 - low recombination probability
- transition in solids
 - appearance of solids
 - multiple re-absorption and re-emissions in random directions
 - net effect = reflection of radiation $\rightarrow$ shiny appearance
 - complimentary of absorbed radiation



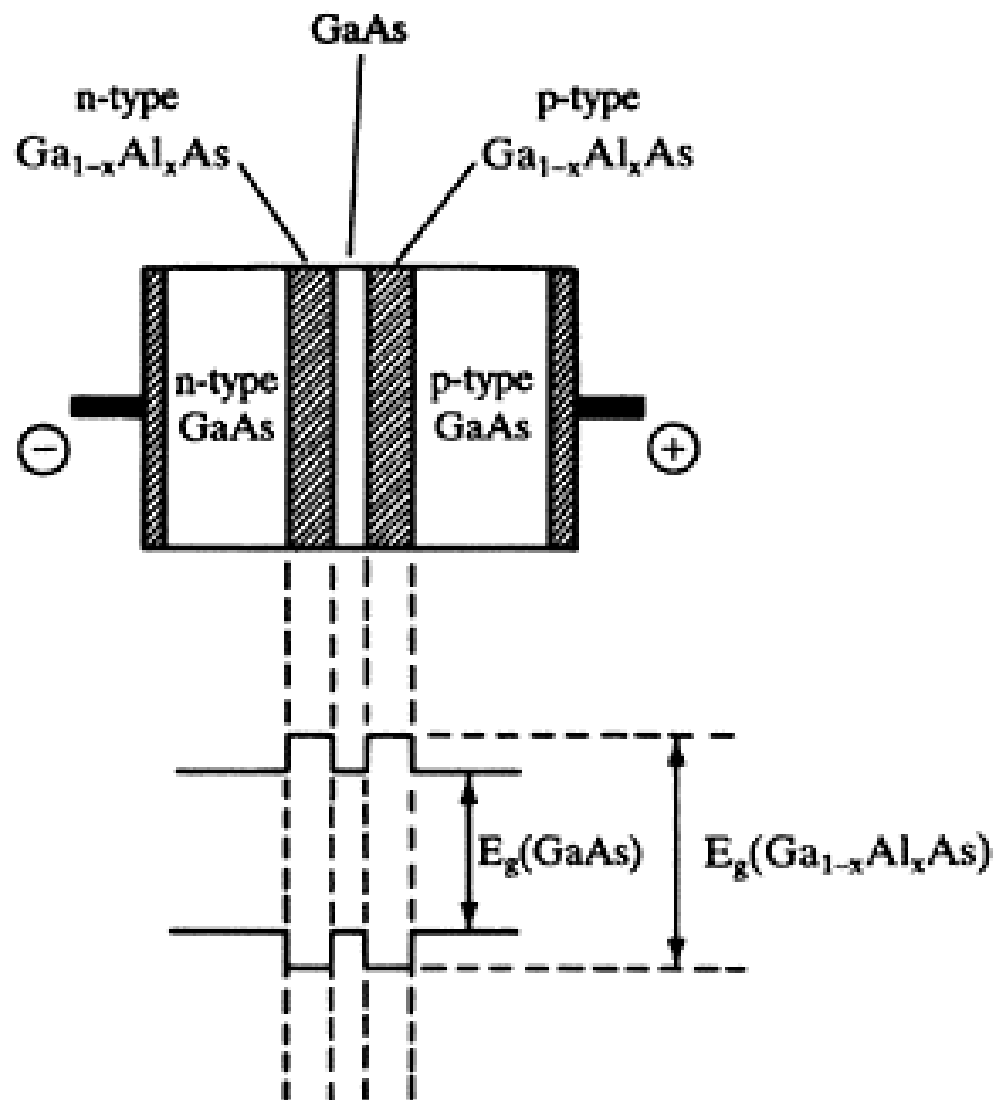
Light emitting diodes (LEDs)

- p - n junction
- GaAs, GaP (red), $\text{Ga}_{1-x}\text{Al}_x\text{P}$ (green/orange)
- apply negative to n and positive potential to p
- GaP, indirect gap – impurity mediated
- Si, indirect gap, not suitable as non-radiative states available to electrons in the BCB.



GaAs diode laser

- In, Ga, Al + As, P, Sb
- 400-1300 nm



Quantum wells – blue lasers

- GaN – 2014 Physics Nobel prize
- Isamu Akasaki, Hiroshi Amano, Shuji Nakamura
- *for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources*
- GaN, $\text{In}_x\text{Ga}_{1-x}\text{N}$ – quantum wells
 - excitation
 - electron goes to well
 - tunneling is faster than emission
 - population builds up in the excited state
 - active region is sandwiched between n and p doped GaN and $\text{Al}_y\text{Ga}_{1-y}\text{N}$

