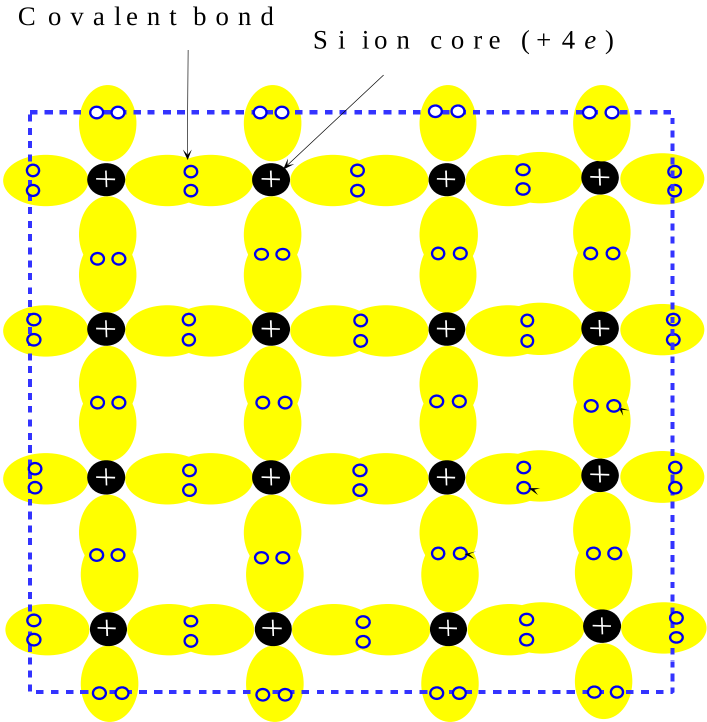
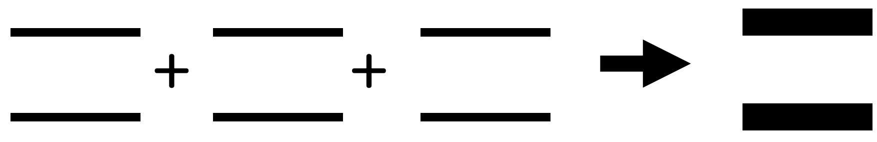
Lect. 21: Semiconductor

Electron energy levels in semiconductors



Electrons in each Si atom have discrete energy levels.

But in Si crystal, energy bands are formed.



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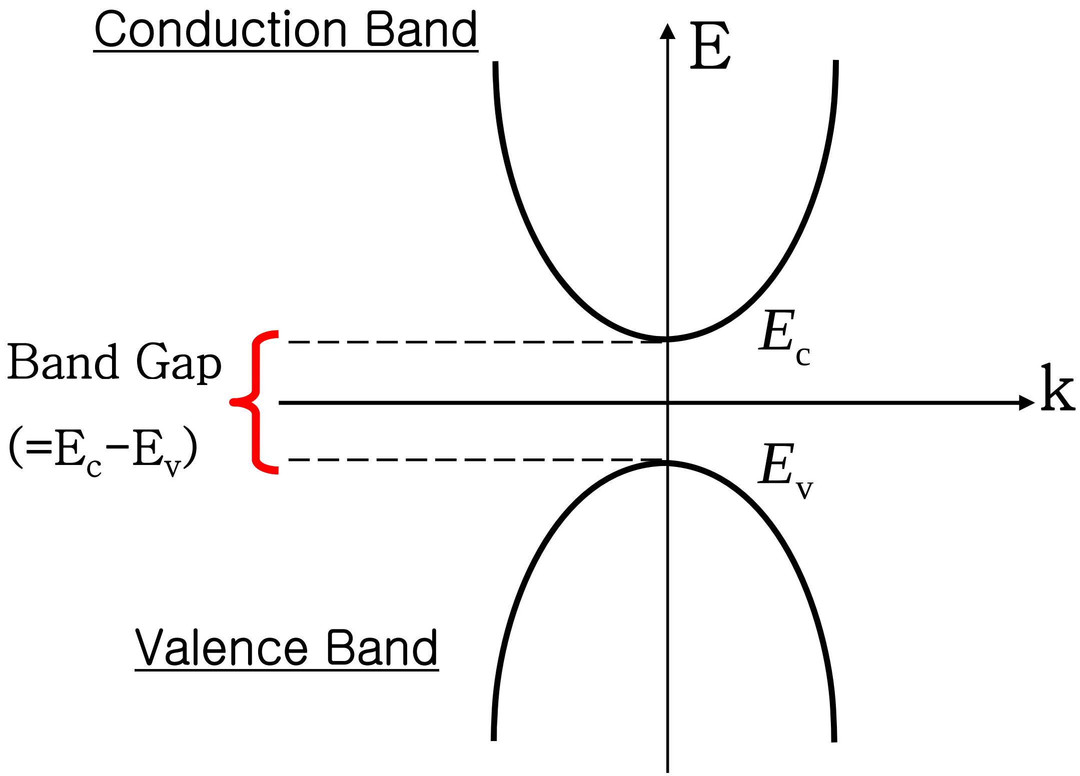

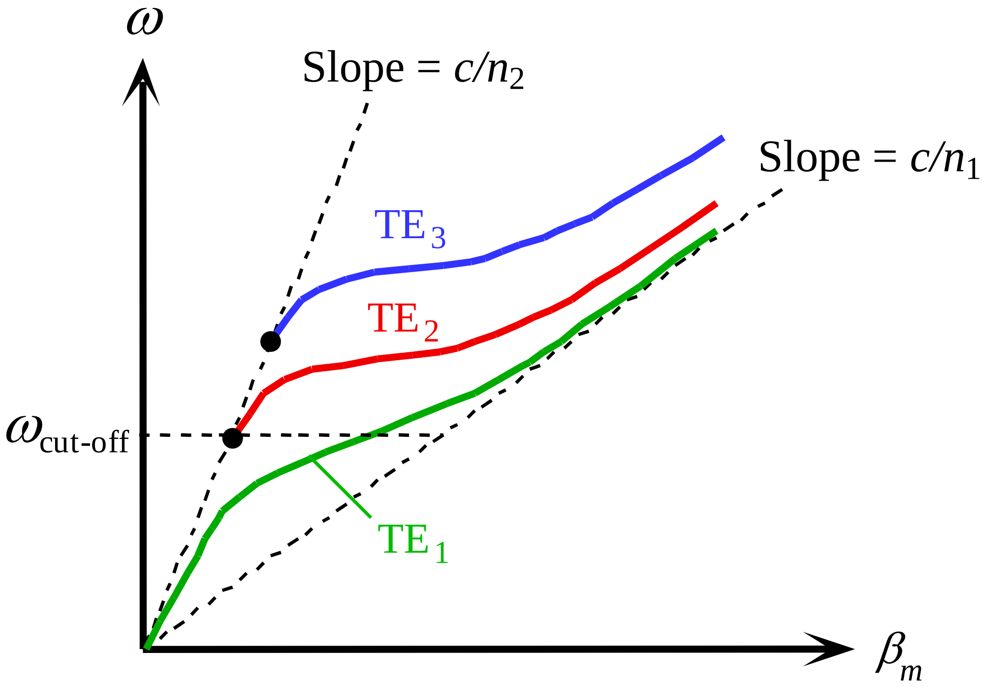

Example for E vs k diagram: EM waves in a dielectric waveguide

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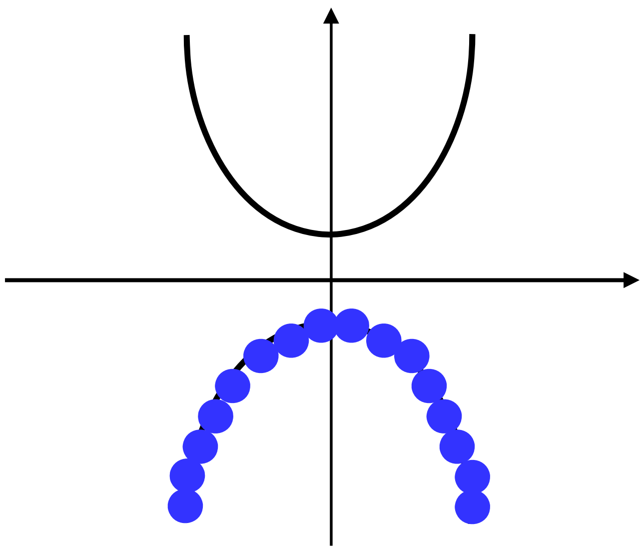
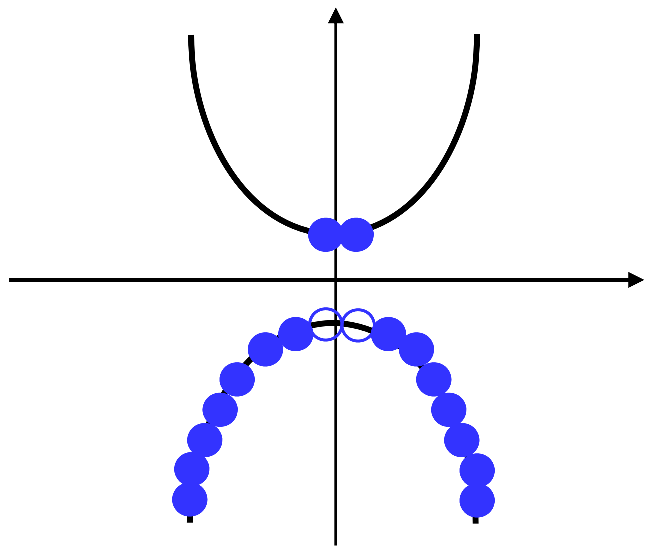
Where are electrons?

T=0 K



no electrons in conduction band and no holes in valence band

T > 0 K



same number of electrons in conduction band as holes in valence band

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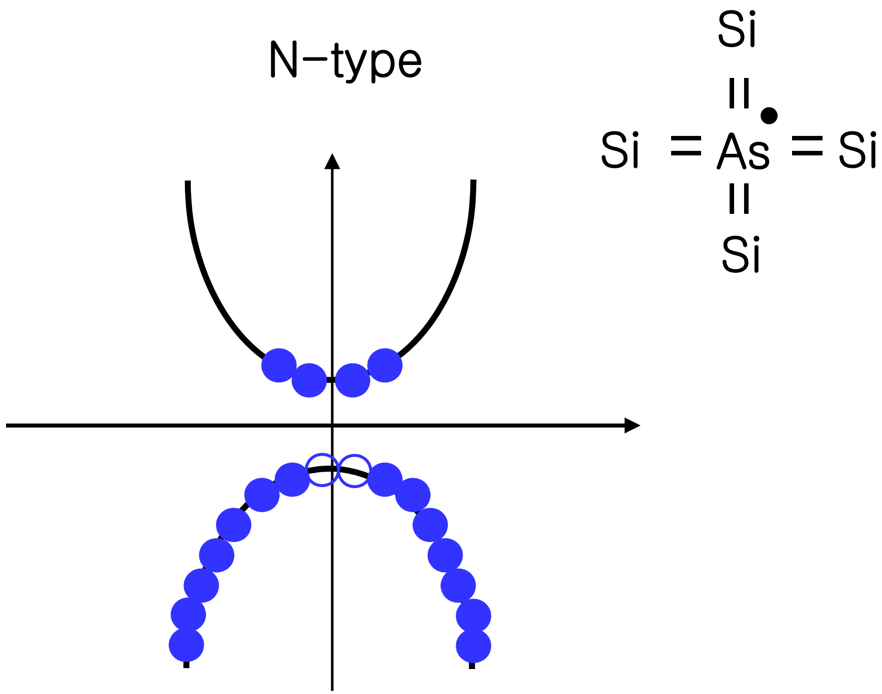
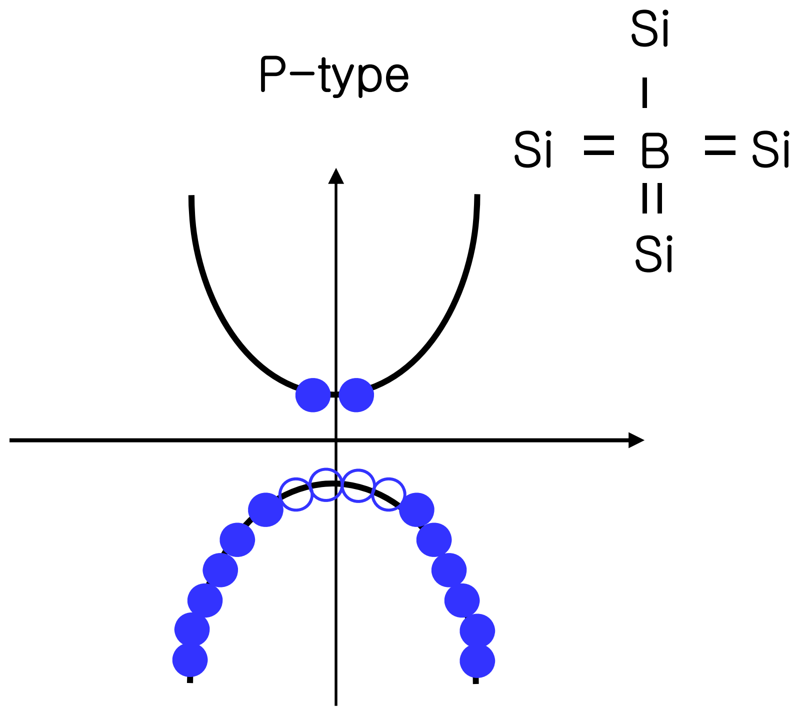
Doping with impurities





More electrons in conduction band than holes in valence band

More holes in valence band than electrons in conduction band

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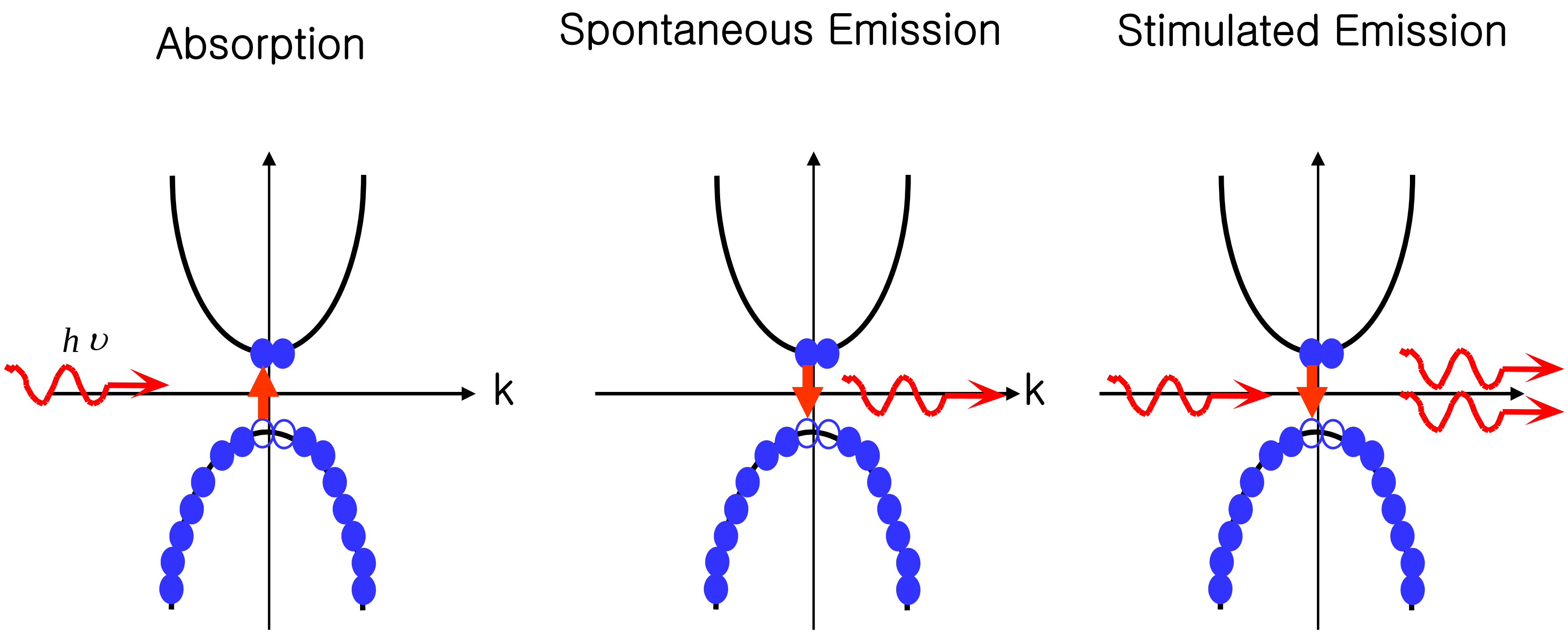
Interaction of light with semiconductor



hν > Eg

Momentum (k) conservation required for photon emission

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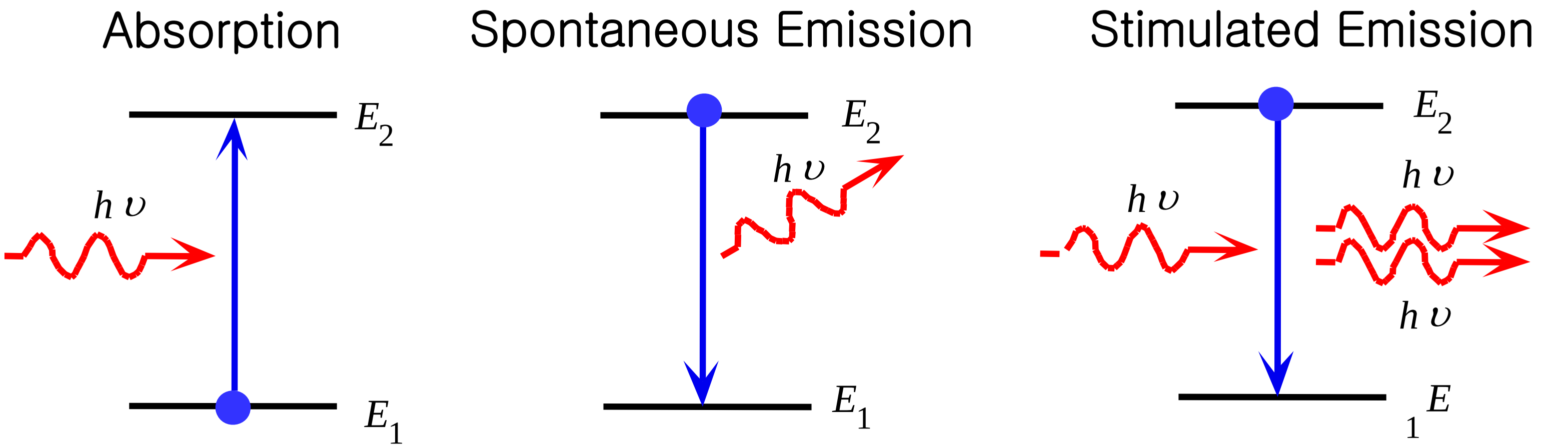
Remember



$$R_{12} = B_{12} \cdot N_1 \cdot \rho \qquad R_{sp} = A_{21} \cdot N_2 \qquad R_{21} = B_{21} \cdot N_2 \cdot \rho$$

ρ : photon density

$N_{1,2}$: electron density at $E_{1,2}$

B_{12}, B_{sp}, B_{21} : constants

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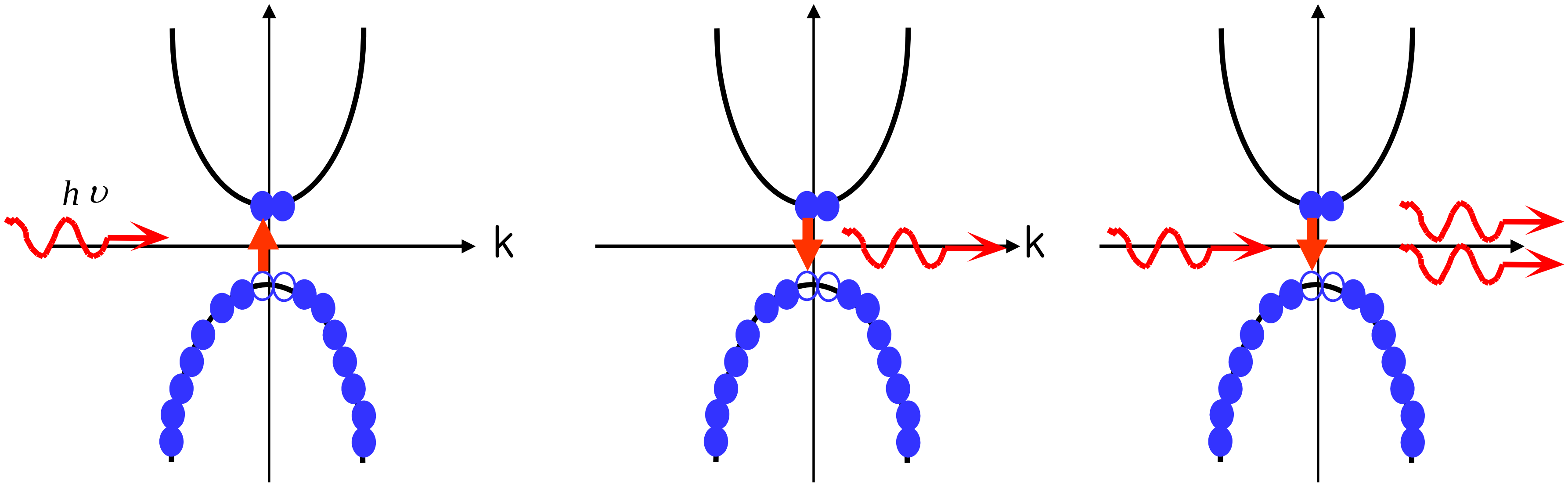
Absorption | Spontaneous Emission | Stimulated Emission



$R_{12}(h\nu) = B_{12} \cdot N_1(E_1) \cdot P_2(E_2) \cdot \rho(h\nu)$

$R_{sp}(h\nu) = A_{21} \cdot N_2(E_2) \cdot P_1(E_1)$

$R_{21}(h\nu) = B_{21} \cdot N_2(E_2) \cdot P_1(E_1) \cdot \rho(h\nu)$

For population inversion, $\dfrac{N_2 \cdot P_1}{N_1 \cdot P_2} > 1$ Electron and hole injection needed.

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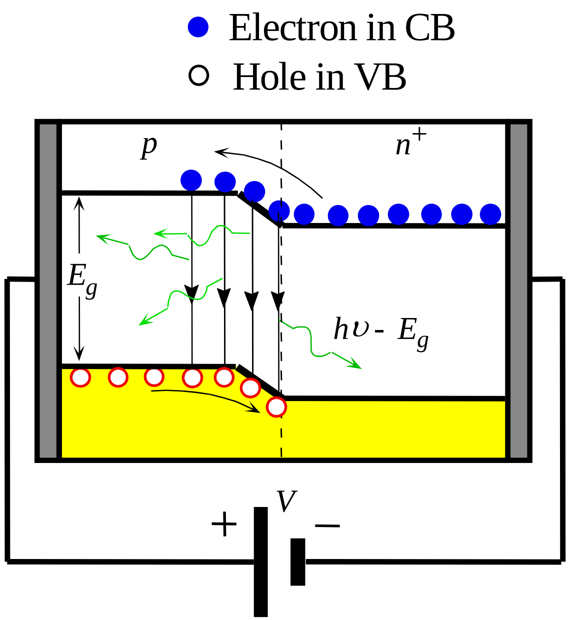
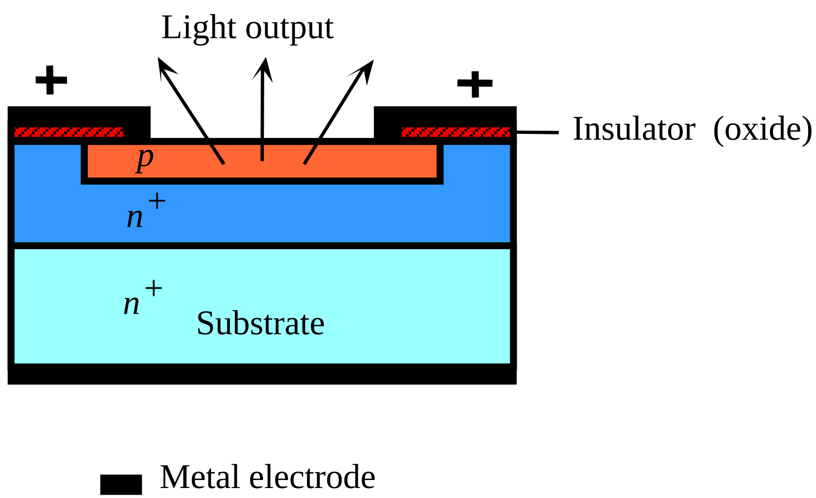
How to inject electrons and holes into a semiconductor? PN junction

Current flow in PN junction



Light emitting diode (LED)



Does any semiconductor emit light?

What determines the color of LED?

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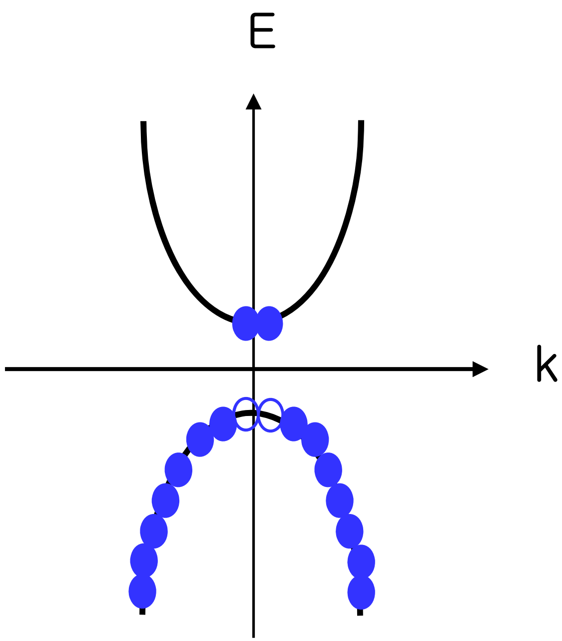
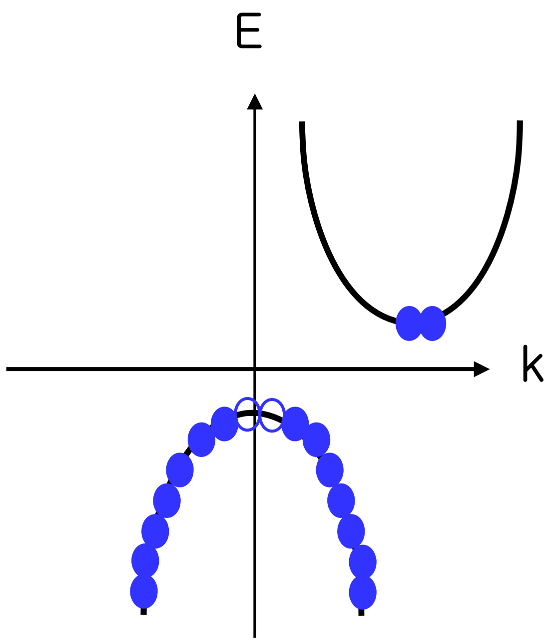
Direct semiconductor

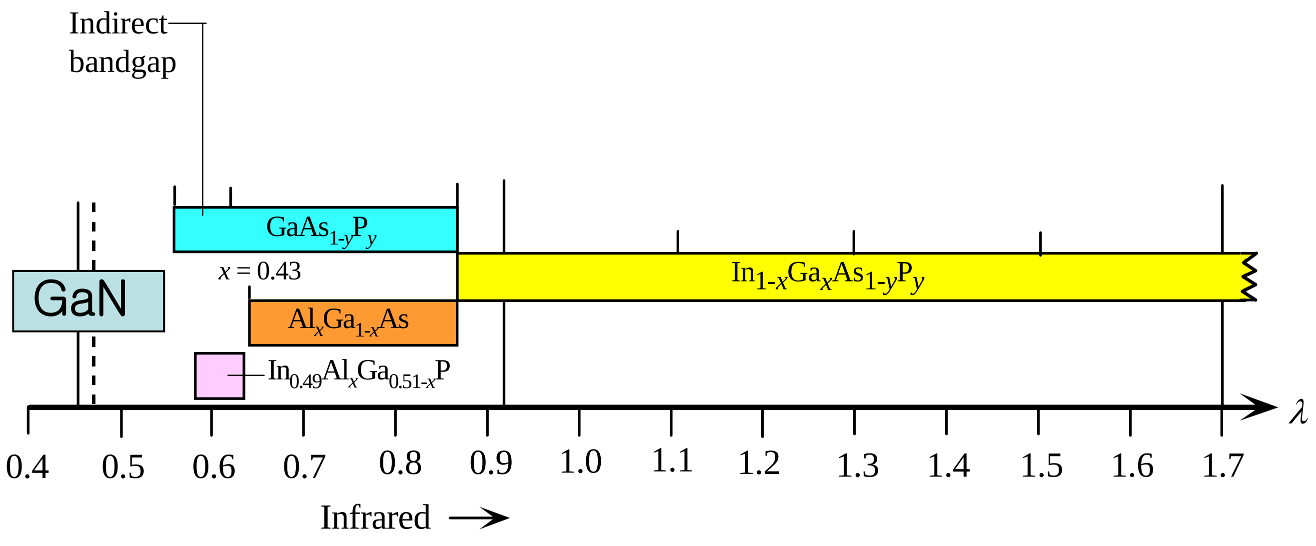


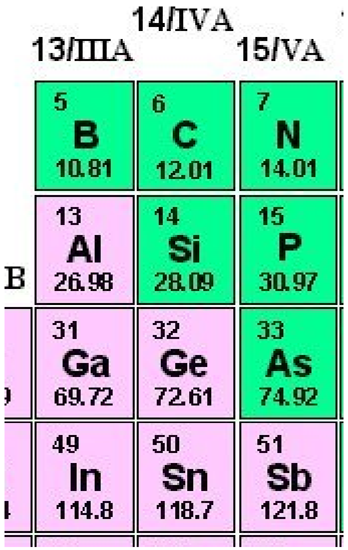
Indirect Semiconductor



Momentum conservation not possible
by photon emission
=> No emission (Examaple: Si)

Bandgap energies for major LED materials: III-V compound semiconductor





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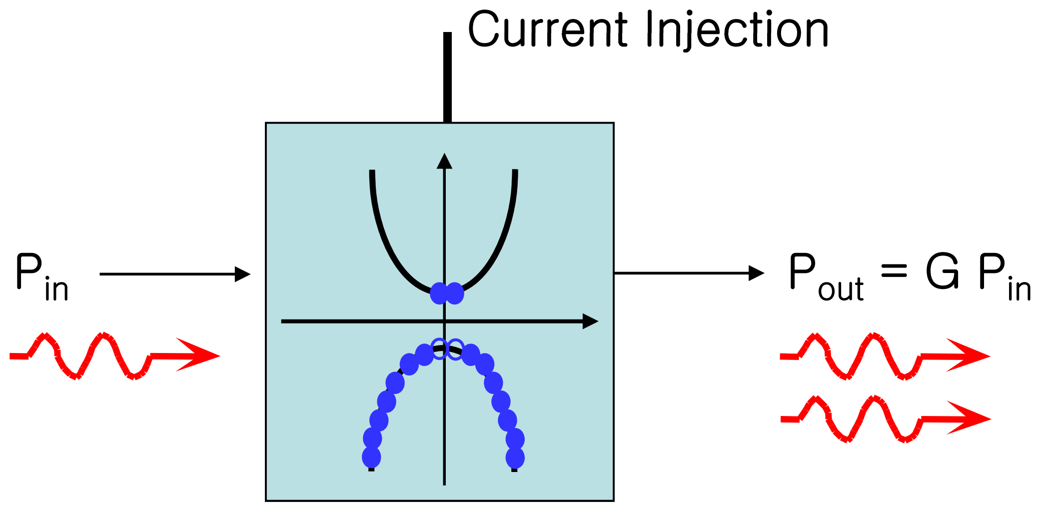
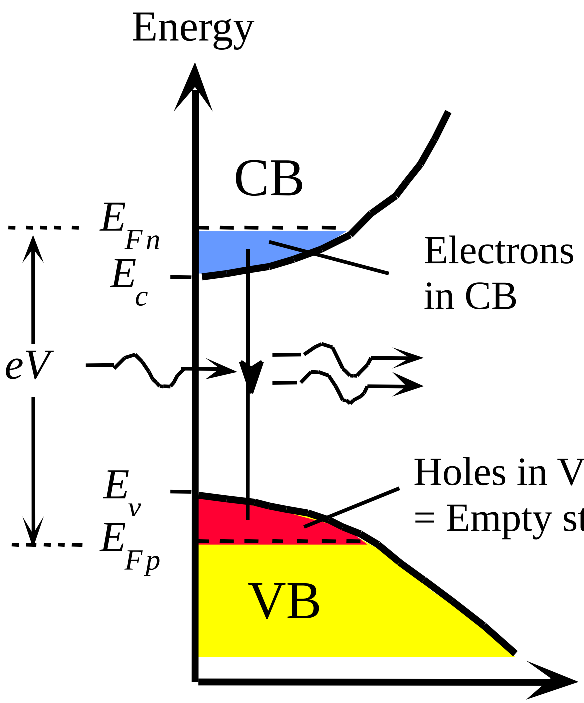
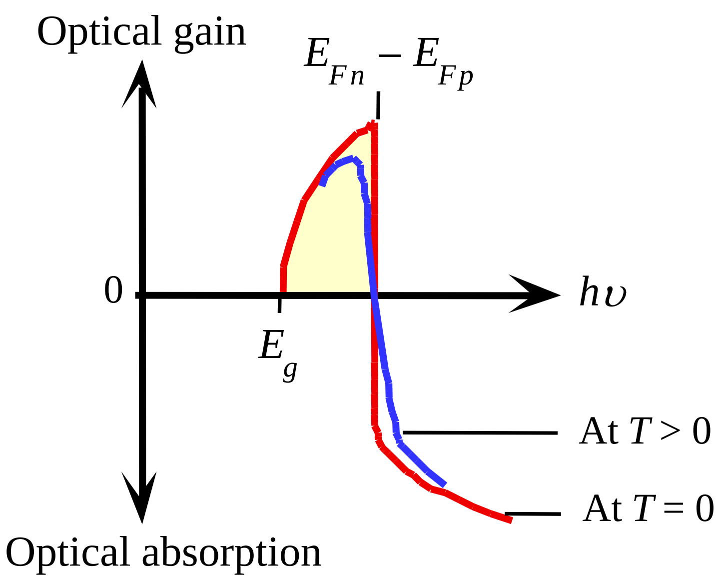
Current injection into PN Junction can be used for SOA
(Semiconductor Optical Amplifier)



Gain spectrum for SOA





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Homework (Due Nov. 22):

Assume the optical gain coefficient in semiconductor is given as
$g=a(N-N_0)$ [1/cm], where $a=10^{-17}cm^2$, $N_0=10^{18}cm^{-3}$ for $\lambda = 1\mu m$.

If 0.5cm long SOA is made up of above semiconductor,
what is the required carrier density in order to achieve SOA power gain of 20dB for $\lambda = 1\mu m$ input signal?