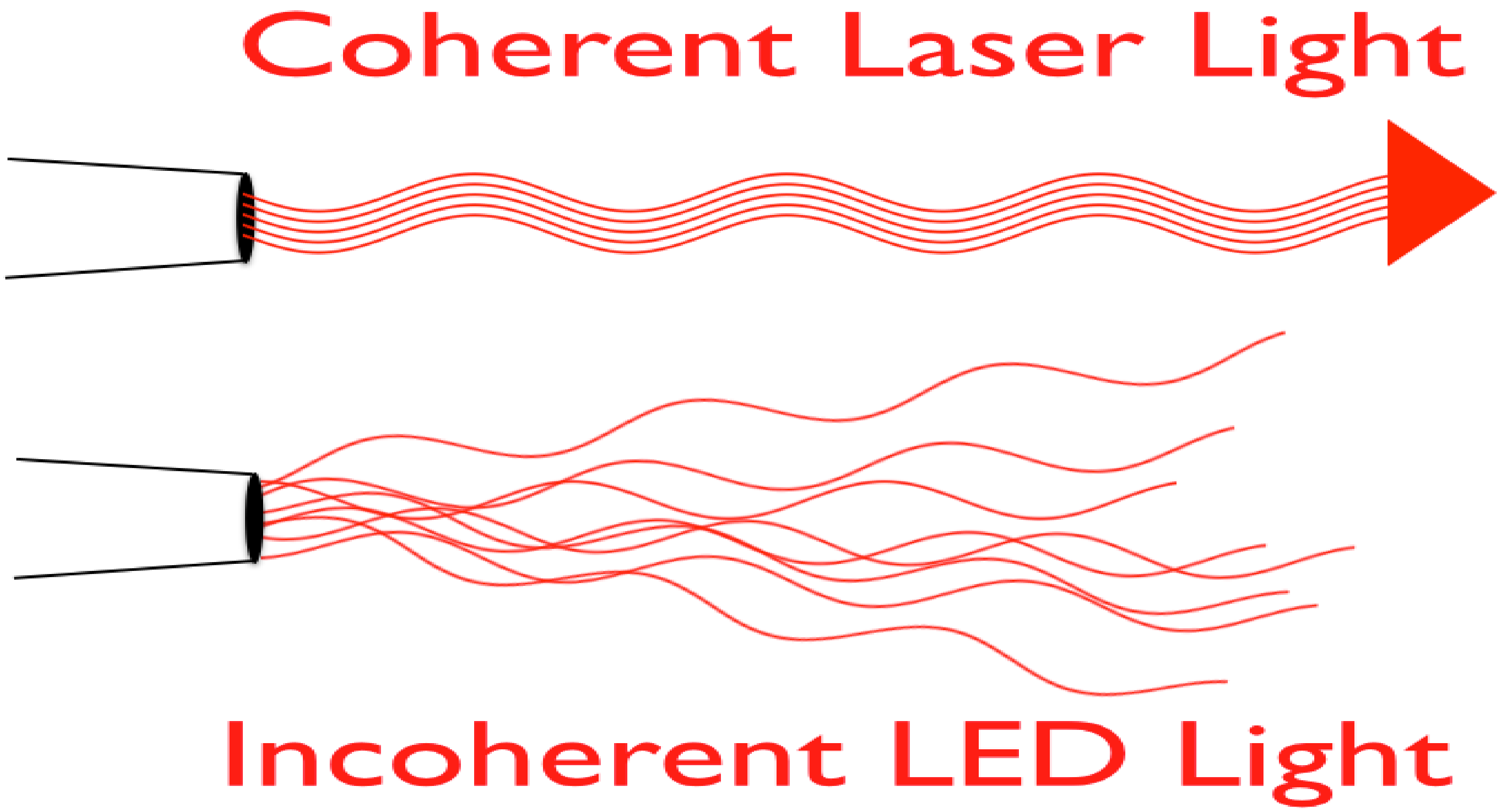

Module – 3
Optical Transmitters

Optical Sources

- High Radiance output
  - Optical power radiated per unit solid angle per unit area of the emitting surface
- Fast emission response time
  - Time delay between application of current pulse and the onset of optical emission
- High quantum efficiency
  - Efficiency of conversion from electrical to optical form
- Optical Sources
  - Incoherent Optical Source LED
  - Coherent Optical Source Laser Diodes
- Direct Intensity Modulation / External Modulation

LEDs & LDs

LED

- Incoherent output
- No wavelength selectivity
- Broad spectral width
- Large beam divergence
- MMF

LASER DIODE

- Coherent output
  - Spatial
  - Temporal
- Highly monochromatic
  - Resonant cavity
- Directional beam
- MMF / SMF

Bandgap energy and wavelength

- The energy of a photon of frequency ν is

$$E = h\nu = hc/\lambda = (1239.8 \text{ eV.nm})/\lambda$$

where $h = 6.625 \times 10^{-34}$ J.s is the Plank's constant.

- The characteristic wavelength associated with the bandgap energy is

$$\lambda = hc/E_g$$

- E.g. E_g of GaAs = 1.42 eV, λ = ??

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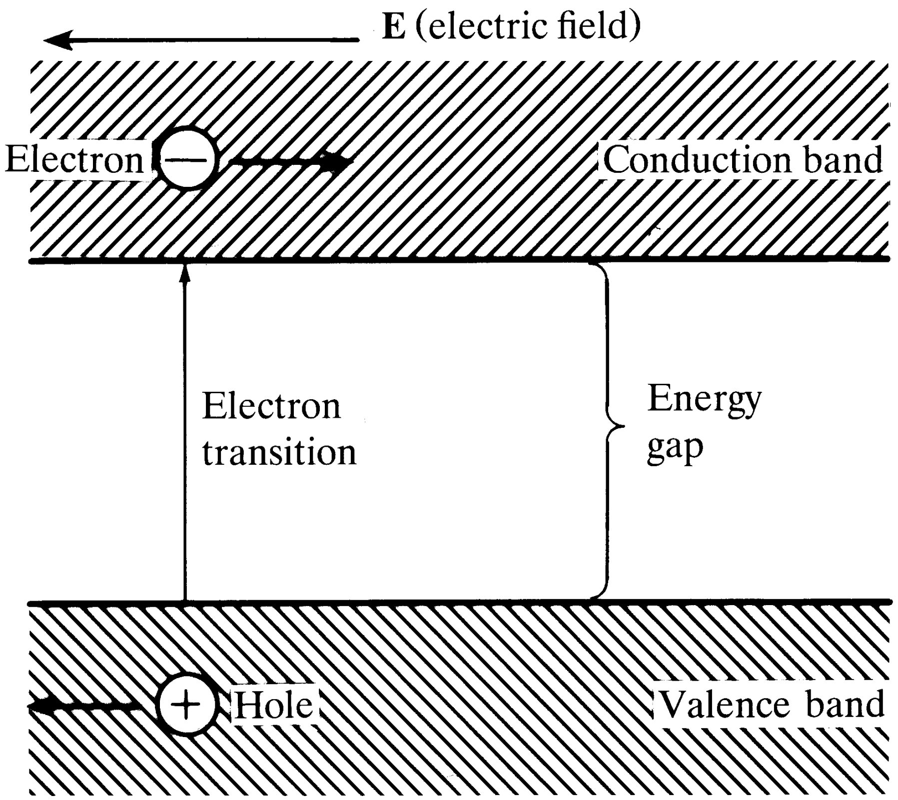
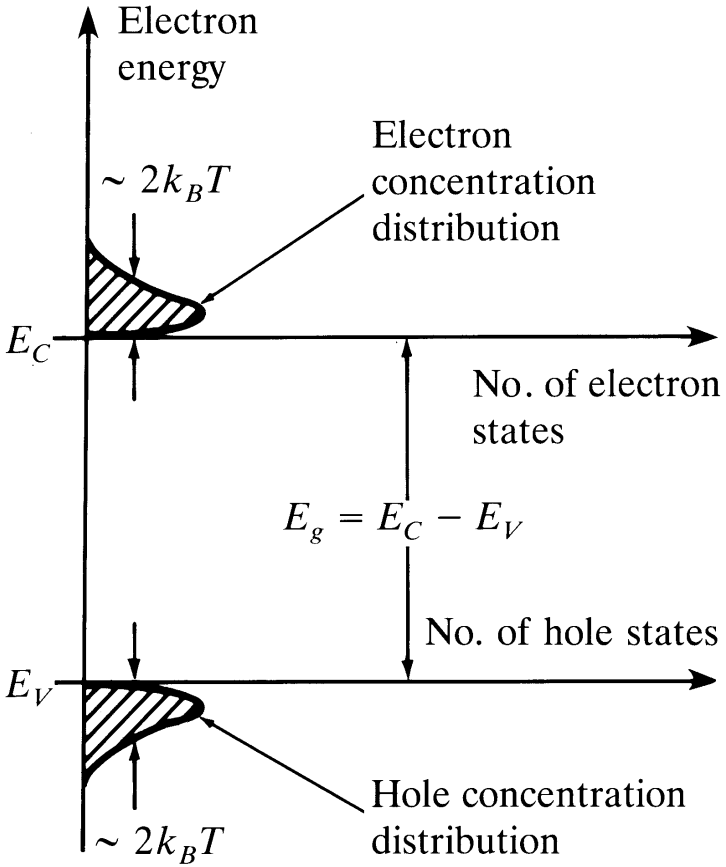
- E.g. E_g of GaAs = 1.42 eV, λ = 876 nm

Pure crystal energy band diagram (Intrinsic Semiconductor)

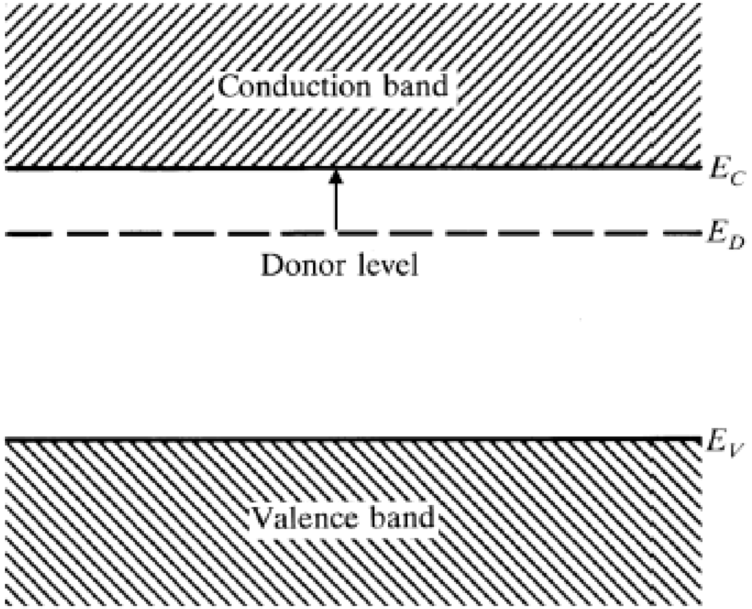


(a)

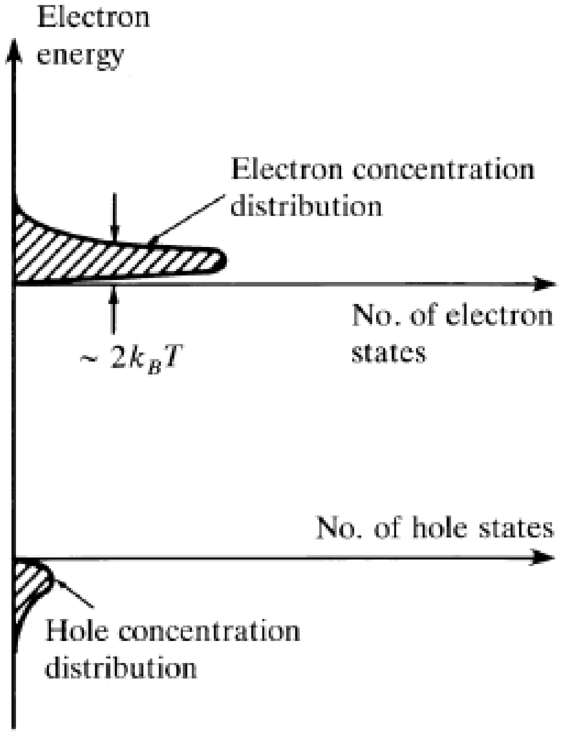


(b)

n-type materials

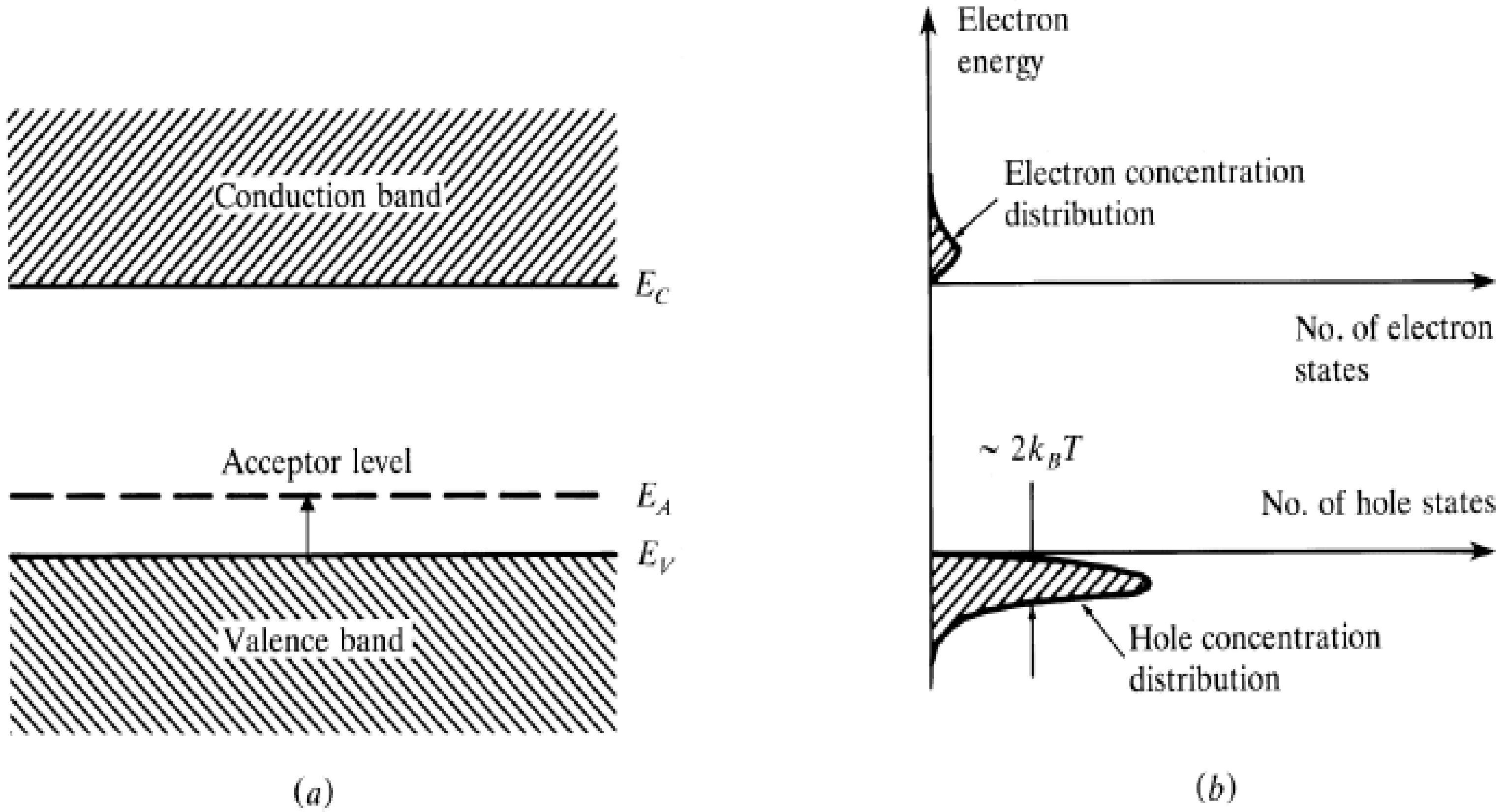


(a)



(b)

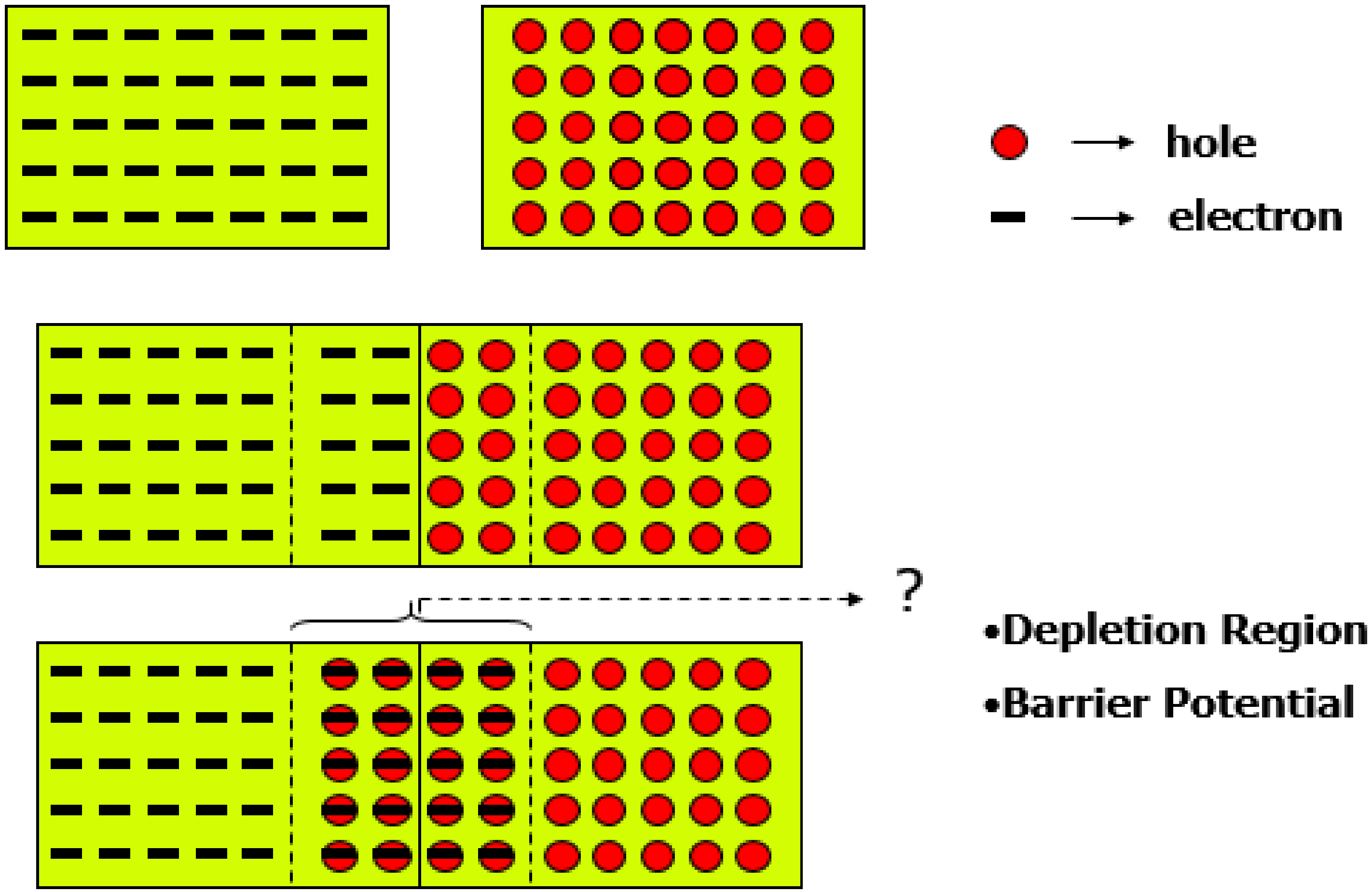
p-type materials



PN Junction

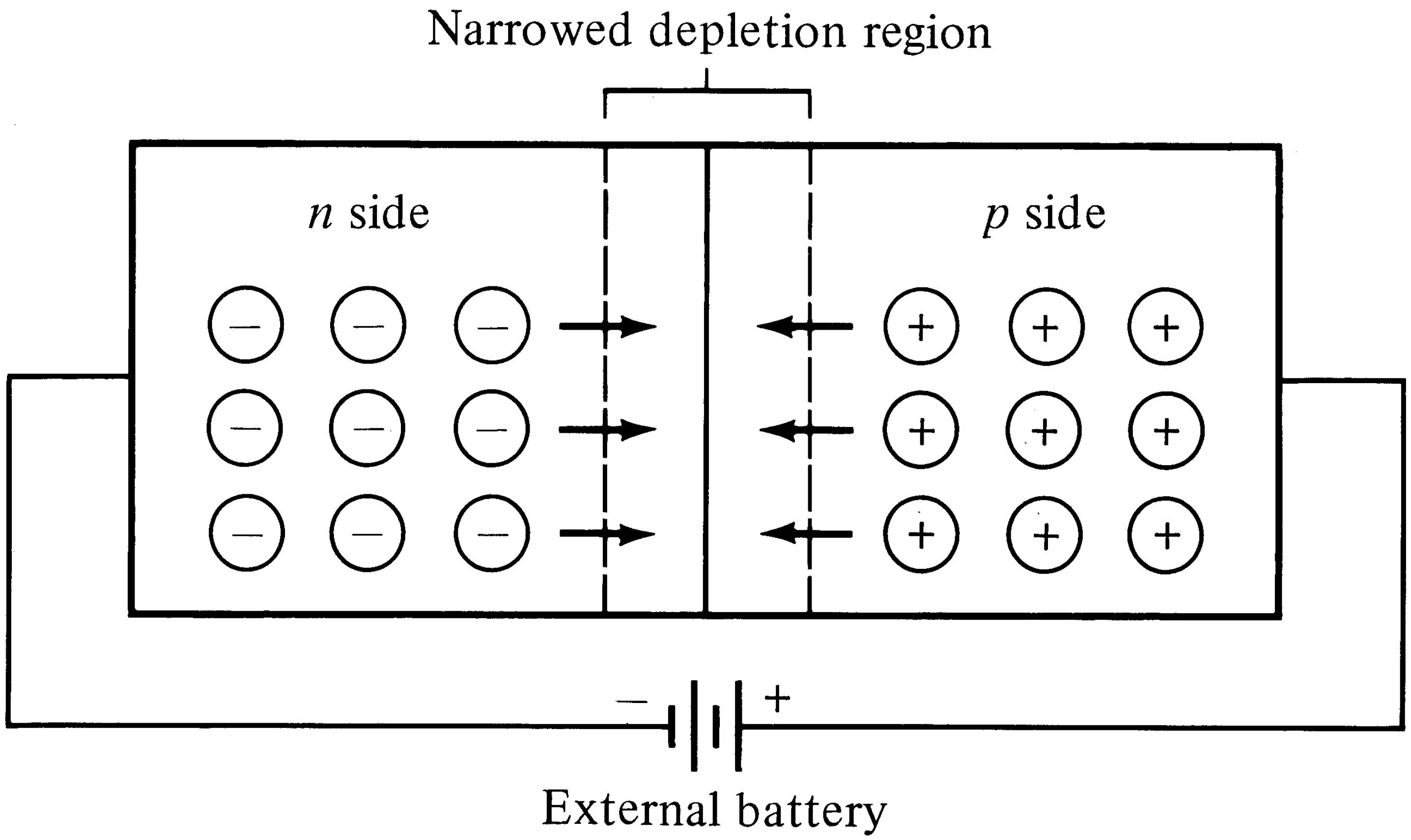
- The semiconductor laser, light-emitting diode (LED) and detector have electronic structures very similar to a semiconductor diode.
- The diode structure allows current to flow in only one direction and it exhibits a “turn-on” voltage.
- Typical turn-on voltages are ~1.5 V for GaAs, ~0.7 V for Si, ~0.5 V for Ge.
- The emitter and detector use adjacent layers of p and n type material or p, n and i (intrinsic or undoped or lightly doped) material. (forming p-n junctions or p-i-n junctions)
- For emitters, applying a forward-bias voltage, controls the high concentration of holes and electrons near the junction and produces efficient carrier recombination for photon production.
- For detectors, reverse-bias voltages increase the electric field at the junction, which efficiently sweeps out any hole-electron pairs created by absorbing incident photons.

Electron diffusion across a pn junction

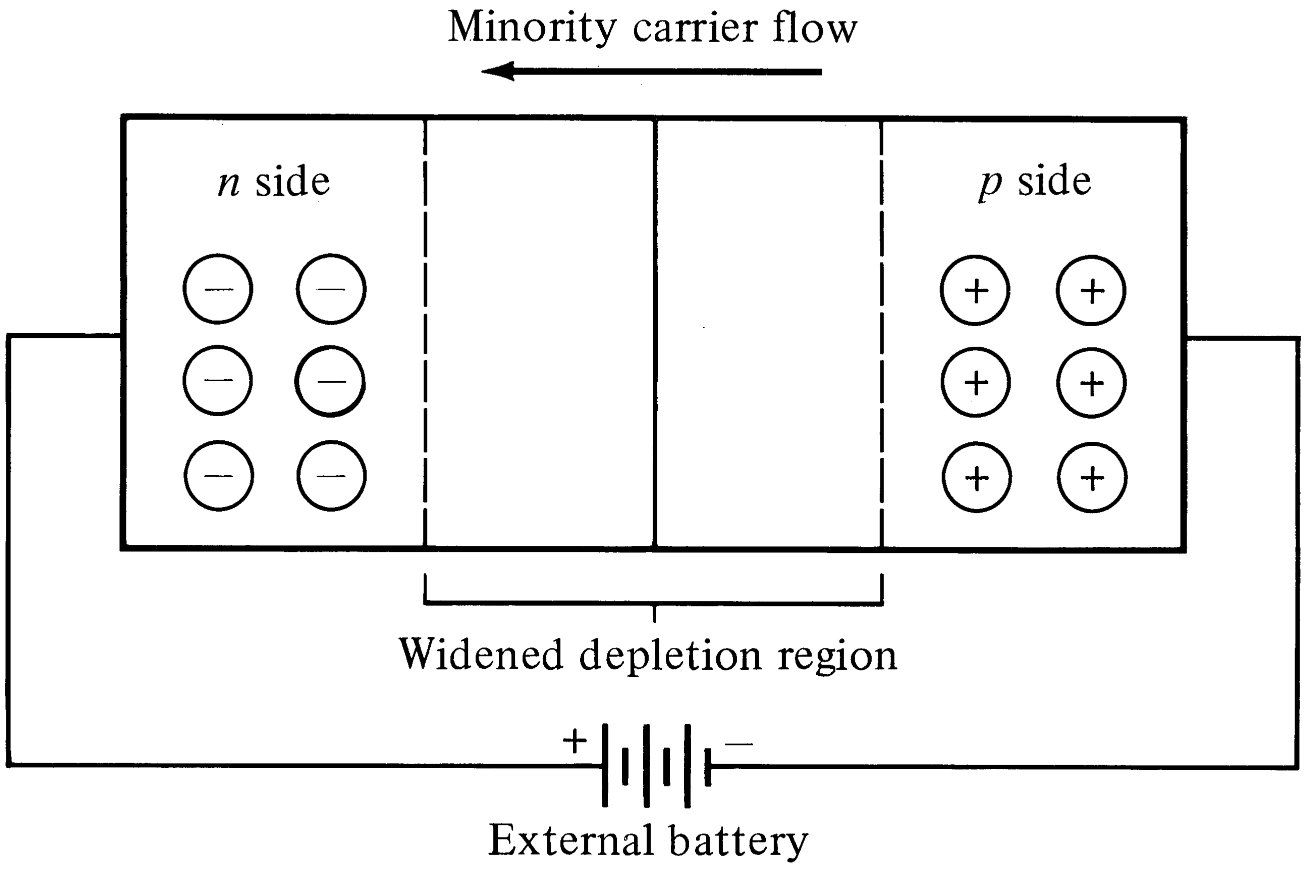


- Depletion Region
- Barrier Potential

Forward bias condition



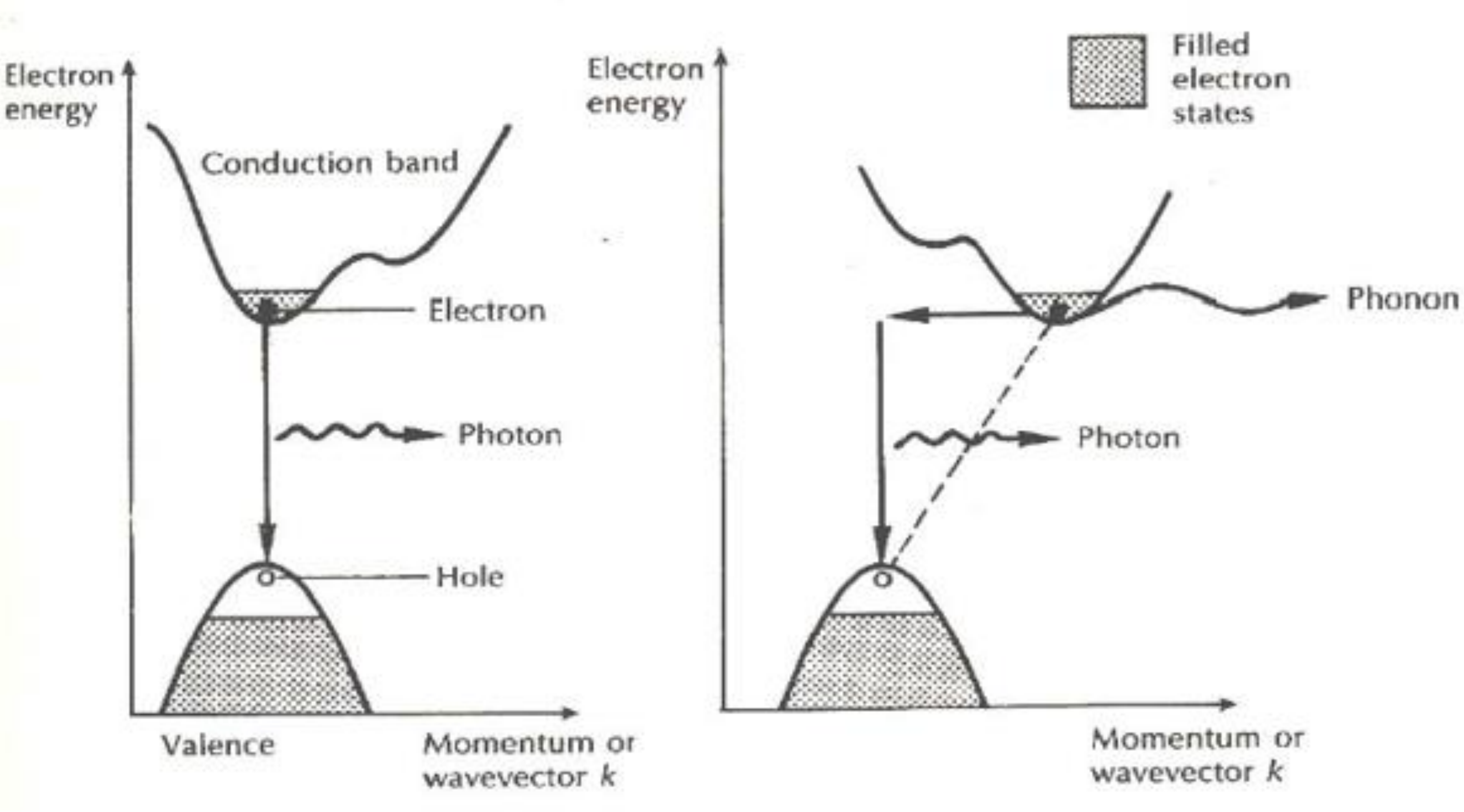
Reverse bias condition



Direct and indirect bandgap materials

- Not all semiconductor junctions produce light under forward bias.
- Only the direct-bandgap materials such as GaAs or InP efficiently emit light (a photon dominated process)
- III-V compound gallium arsenide (GaAs) serves as a prototypical material for light-emitting devices.
- The indirect-bandgap materials like silicon support carrier recombination through processes involving phonons (lattice vibrations).
- Although indirect bandgap materials can emit some photons, the number of photons is of orders of smaller magnitude than for the direct bandgap materials.

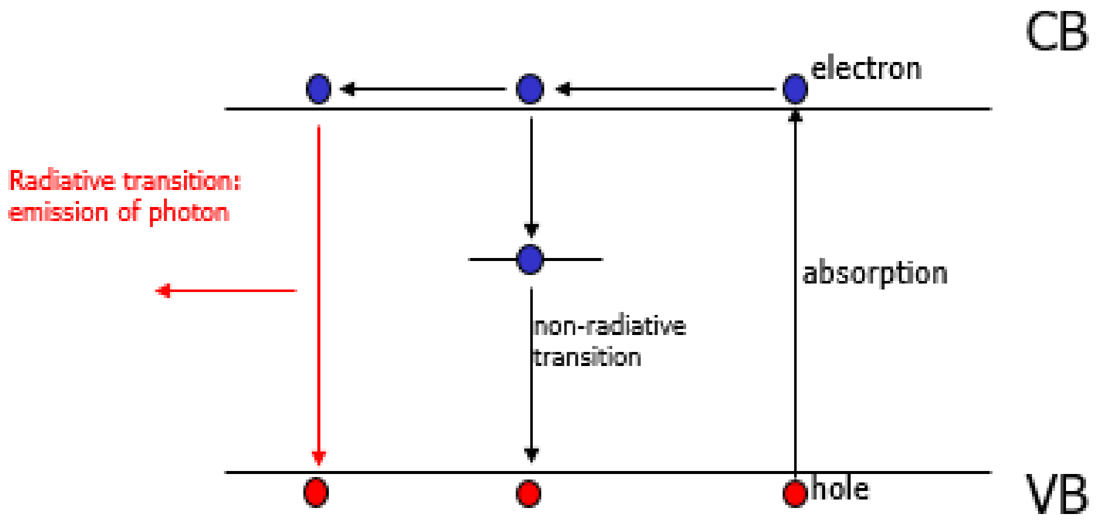
Band diagram of Direct and indirect bandgap materials



Direct and indirect bandgap materials

Semiconductor material	Energy bandgap (eV)	Recombination coefficient (cm^3/s)
GaAs	Direct: 1.43	7.21×10^{-10}
GaSb	Direct: 0.73	2.39×10^{-10}
InAs	Direct: 0.35	8.5×10^{-11}
InSb	Direct: 0.18	4.58×10^{-11}
Si	Indirect: 1.12	1.79×10^{-15}
Ge	Indirect: 0.67	5.25×10^{-14}
GaP	Indirect: 2.26	5.37×10^{-14}

What happens under forward bias in an LED ?



$$E_g = h\nu = hc/\lambda$$
$$\lambda\ (\mu m) = 1.24 / E_g\ (eV)$$

- Luminescence = emission of optical radiation as a result of absorption of external energy
  - Photoluminescence: optical excitation
  - Catholuminescence: excitation by electron irradiation
  - Electroluminescence: excitation by current

Light Emitting Diodes (LEDs)

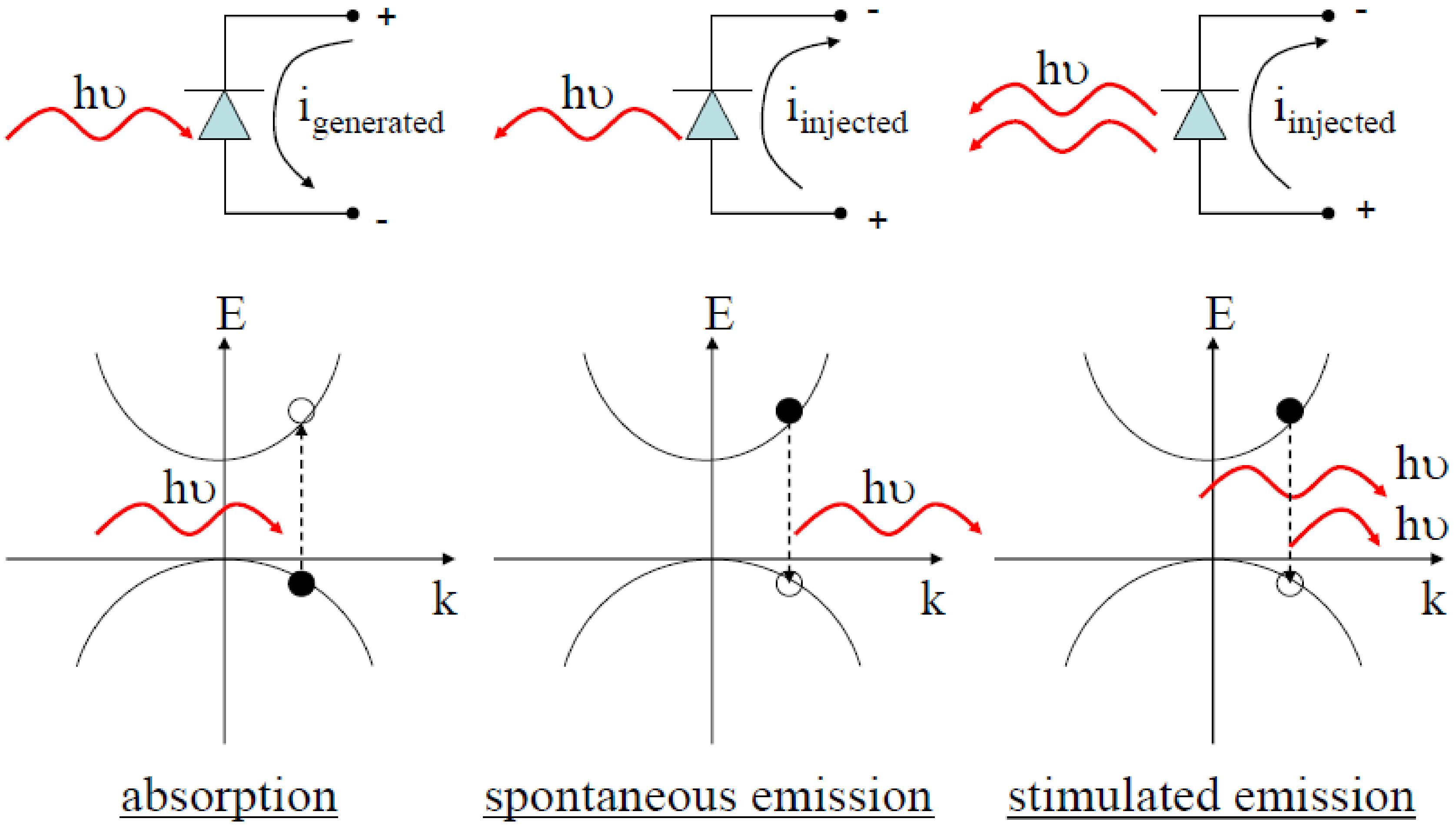
- The light output of an LED is the spontaneous emission generated by radiative recombination of electrons and holes in the active region of the diode under forward bias.

- The semiconductor material is direct-bandgap to ensure high quantum efficiency, often III-V semiconductors.

- An LED emits incoherent, non-directional, and unpolarized spontaneous photons that are not amplified by stimulated emission.

- An LED does not have a threshold current. It starts emitting light as soon as an injection current flows across the junction.

Optical emission and absorption in semiconductors



LED characteristics

LEDs must have

- High radiance output or brightness
  - Measure of optical power radiated into a unit solid angle per unit area of the emitting surface.(unit is Watts.)
- Fast emission response time
  - Time delay between application of a current pulse and respective optical emission.
- High Quantum Efficiency
  - Related to fraction of electron hole pairs recombine radiatively.

LED structures

- For high radiance and quantum efficiency, the LED must have

- Optical confinement
  - Achieve high level Radiative Recombination in the active region of the device which yields high quantum efficiency
- Carrier confinement
  - Preventing absorption of the emitted radiation by the material surrounding the PN junction.

- For photonic communications requiring data rate 100-200 Mb/s with multimode fiber with tens of microwatts, LEDs are usually the best choice.

- LED configurations being used in photonic communications:
  - Surface Emitters (Front Emitters)
  - Edge Emitters

Double heterostructures

- Very effective carrier and optical confinement can be simultaneously accomplished with double heterostructures.
- Consists of two adjoining semiconductor with different band gap energies
- Band gap energy difference of adjacent layers confines charge carriers.
- RI differences of adjoining layers confines optical field to the central active layer.
- A basic configuration can be either P-p-N or P-n-N (the capital P, N represents wide-gap materials, p, n represents narrow-gap materials).

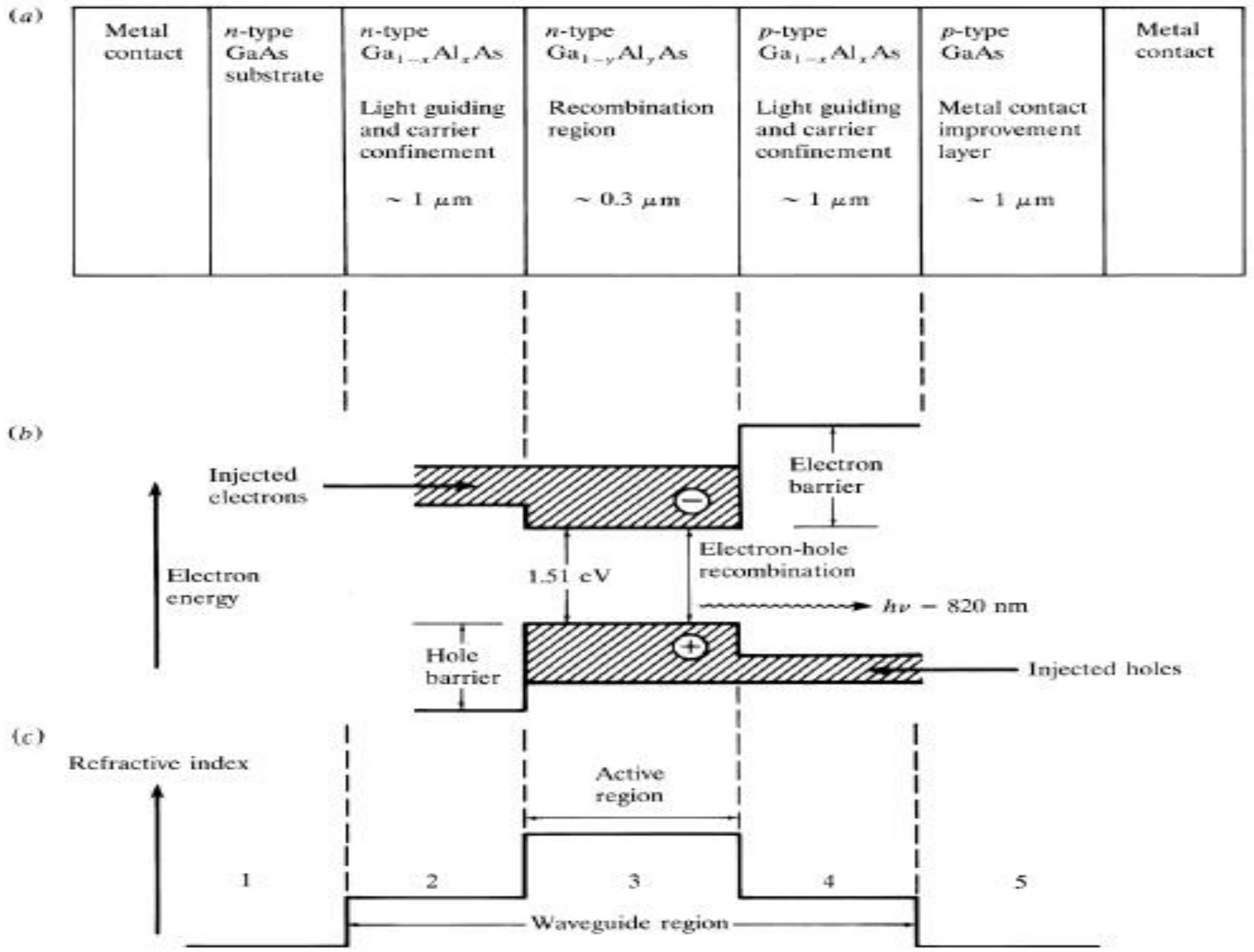
Double heterostructures

- The middle layer is a narrow-gap material. (e.g. $Ga_{1-y}Al_yAs$-GaAs-$Ga_{1-x}Al_xAs$)

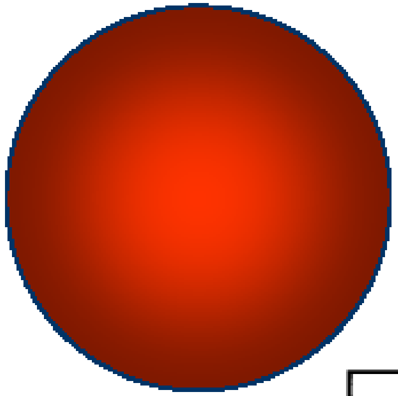
- Almost all of the excess carriers created by current injection are injected into the narrow-gap active layer and are confined within this layer by the energy barriers of the heterojunctions on both sides of the active layer.

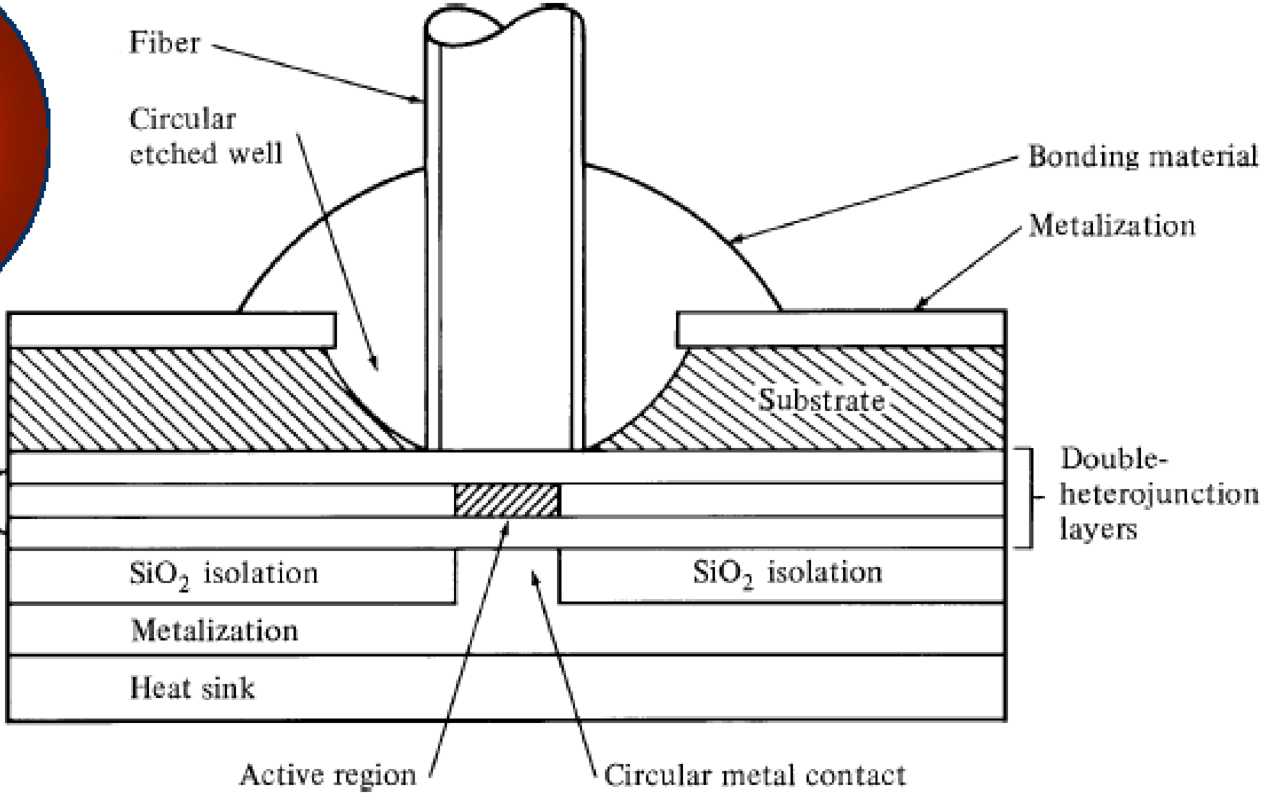
- Because the narrow-gap active layer has a higher refractive index than the wide-gap outer layers on both sides, an optical waveguide with the active layer being the waveguide core is built into the double heterostructure.

Double heterostructures



Surface-emitting LED





50 µm dia; 2.5 µm thick

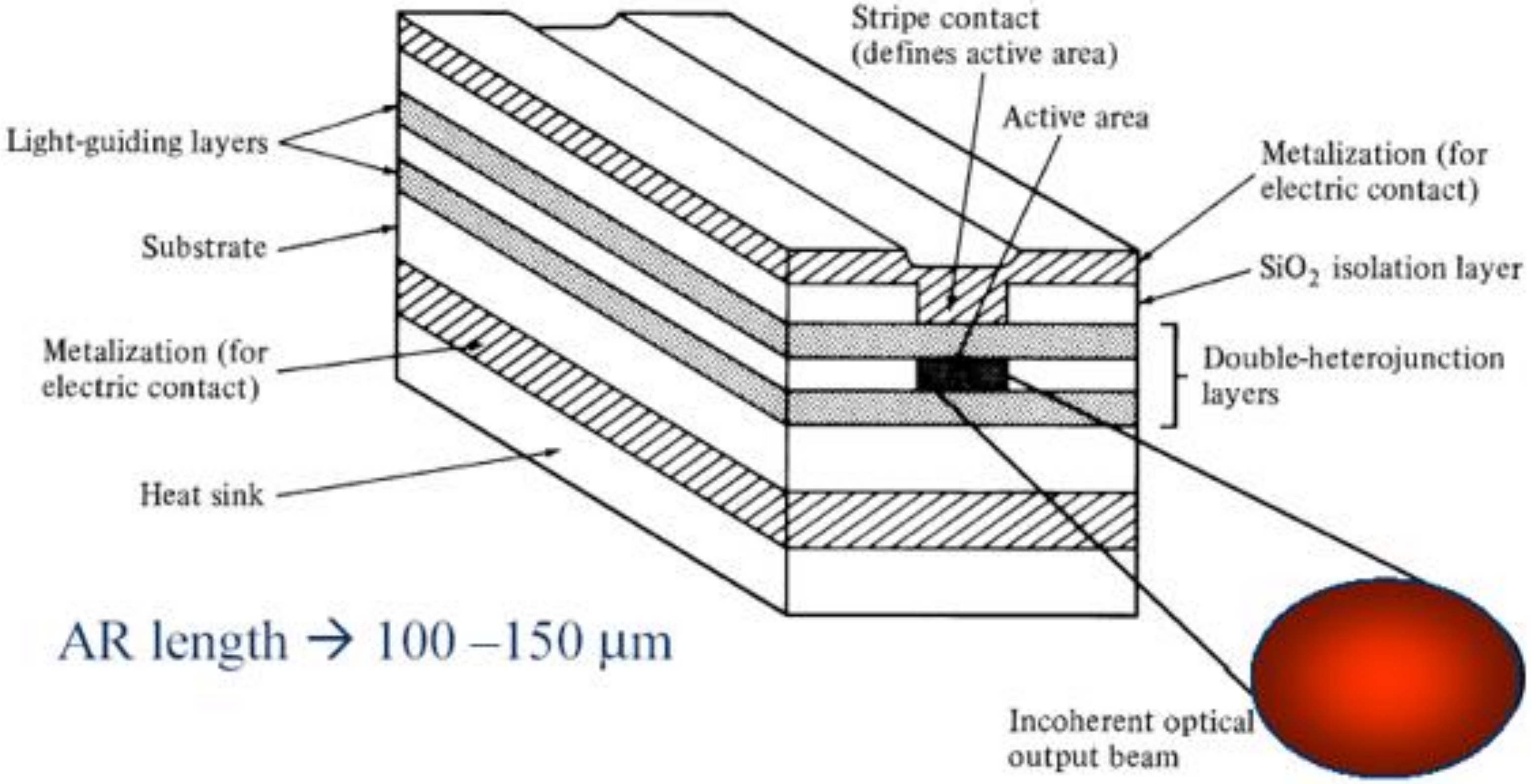
Surface-emitting LED

- High radiance etched well is 0.8 to 0.9 um
- Due to large band gap in confining layer , very low internal absorption.
- GaAs is used in well to avoid heavy absorption of emitted light.
- Circular active area of surface emitter is 50 um dia and 2.5um thick.
- Emission pattern is isotropic with 120^0 half power beam width.

Lambertian pattern

- Isotropic pattern from surface emitter.
- Source equally bright in all directions of view
- It decides the coupling efficiency
- Source equally bright but power dismisses cos θ.
- Power 50% down in its peak when $\theta = 60$.
- So total half power beam width is 120^0.

Edge-emitting LED



AR length → 100 –150 μm

Edge-emitting LED

- DH Edge Emitter LED Emit more directional light
- Reduce lose by absorption and more directional – light collected from edge.
- Has transparent guiding layers with very thin active layer of 50 um to 100 um – reducing self absorption.
- Guiding layer RI < surrounding material(core&cladding)> outer surrounding material.
- Form wave guide channel that directs the optical radiation towards fiber.
- To match fiber core diameter (50 to 100um), the contact stripes for the edge emitters are 50-70um wide.
- In the plane parallel to the junction no waveguide effects.
- In the plane highly directional perpendicular to the junction-when half power beam width is 25^0 to 35^0 by proper choice of waveguide thickness.

Comparison of SLED and ELED

S.No.	SLED	ELED
1.	Easy of fabricate	Difficult to Fabricate
2.	Easy to mount and handle	Difficult to mount and handle
3.	Require less critical tolerances	Need critical tolerances on Fabrication
4.	Less Reliable	Highly reliable
5.	Low System performance	High system performance
6.	Less Modulation BW	Betters Modulation BW of the order of hundred of MHz.
7.	Couple less optical power into low NA fiber	Couple more optical power into low NA fiber.

Light Source Material

- Most of the light sources contain III-V ternary & quaternary compounds.
- $Ga_{1-x}Al_xAs$ by varying x it is possible to control the band-gap energy and thereby the emission wavelength over the range of 800 nm to 900 nm.
- The spectral width is around 20 to 40 nm.
- $In_{1-x}Ga_xAs_yP_{1-y}$ - By changing $0<x<0.47$; y is approximately 2.2x, the emission wavelength can be controlled over the range of 920 nm to 1600 nm.
- The spectral width varies from 70 nm to 180 nm when the wavelength changes from 1300 nm to 1600 nm.
- These materials are lattice matched.

Light Source Material

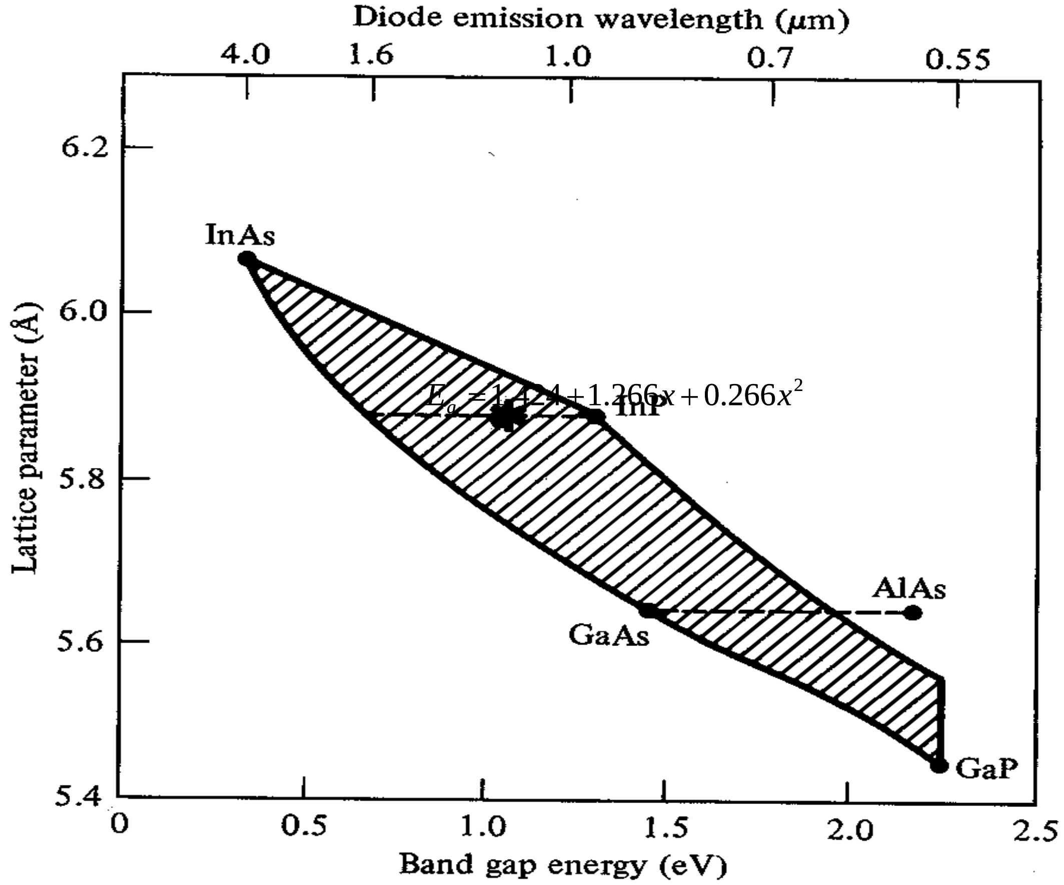
- The value of band gap energy (eV) for values of x between 0 and 0.437 can be found by using the empirical relation (GaAlAs)

$$E_g = 1.424 + 1.266x + 0.266x^2$$

- The value of band gap energy (eV) for values of x between 0 and 0.47 and y is 2.20x can be found by using the empirical relation (InGaAsP)

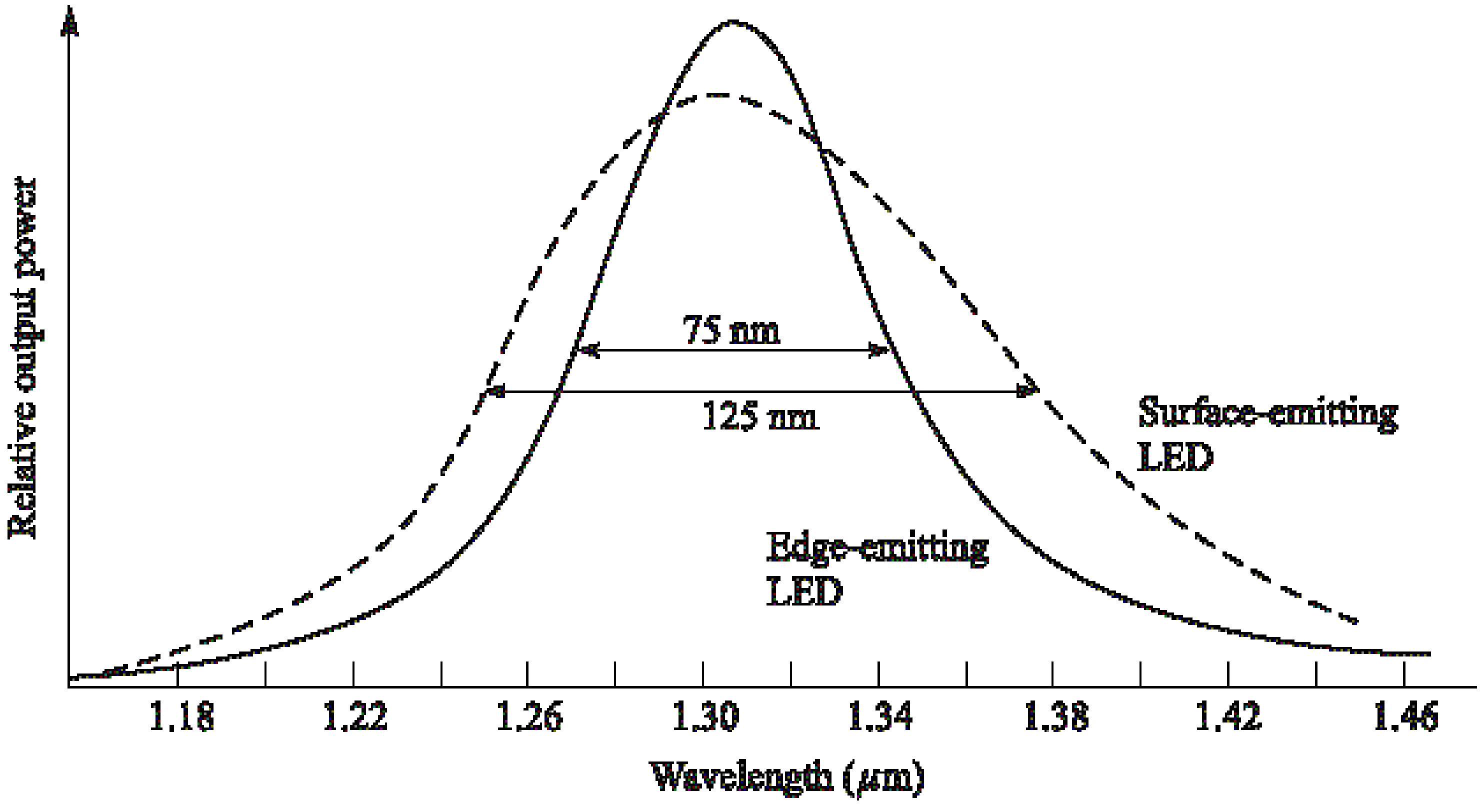
$$E_g = 1.35 - 0.72y + 0.12y^2$$

Light Source Material



$E_g = 1.424 + 1.266x + 0.266x^2$

Spectral width of LED types



Numerical Problem

- An engineer has two $Ga_{1-x}Al_xAs$ LEDs: One has the band gap energy of 1.540 eV and the other has x=0.15.
- (a). Find the Al mole fraction x and the emission wavelength for the first LED.
- (b). Find the band gap energy and the emission wavelength of the second LED.

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$$E_g = 1.424 + 1.266x + 0.266x^2$$

$$1.540 = 1.424 + 1.266x + 0.266x^2$$

$$x^2 + 4.759x - 0.436 = 0$$

$$x = 0.090, \lambda = 805nm$$

$$E_g = 1.424 + 1.266(0.15) + 0.266(0.15)^2 = 1.620eV$$

$$\lambda = 766nm$$