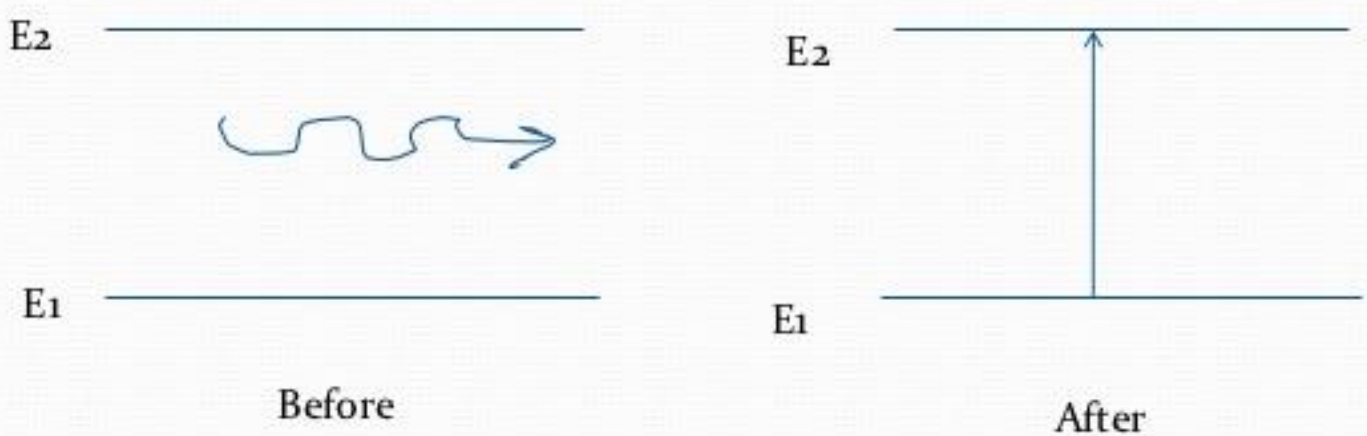
Optical Sources

Induced absorption (stimulated absorption)

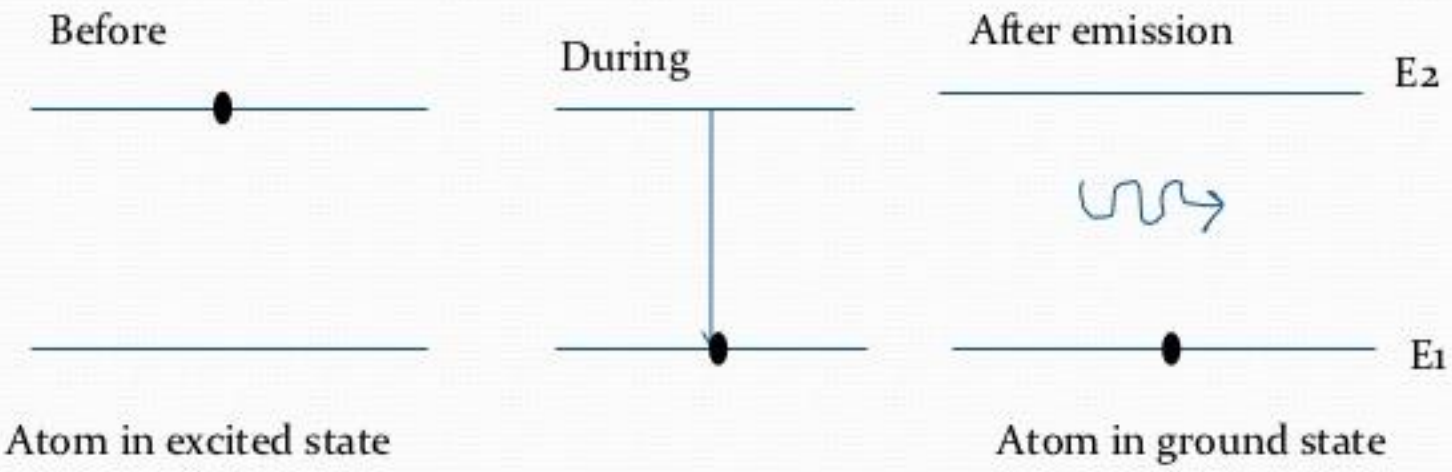
The process in which an atom sized system in lower energy state is raised in to higher energy state by electro magnetic radiation which is quanta of energy is equal to the difference of energy of the two states is called stimulated absorption.

i.e., $h\nu = E_2 - E_1$



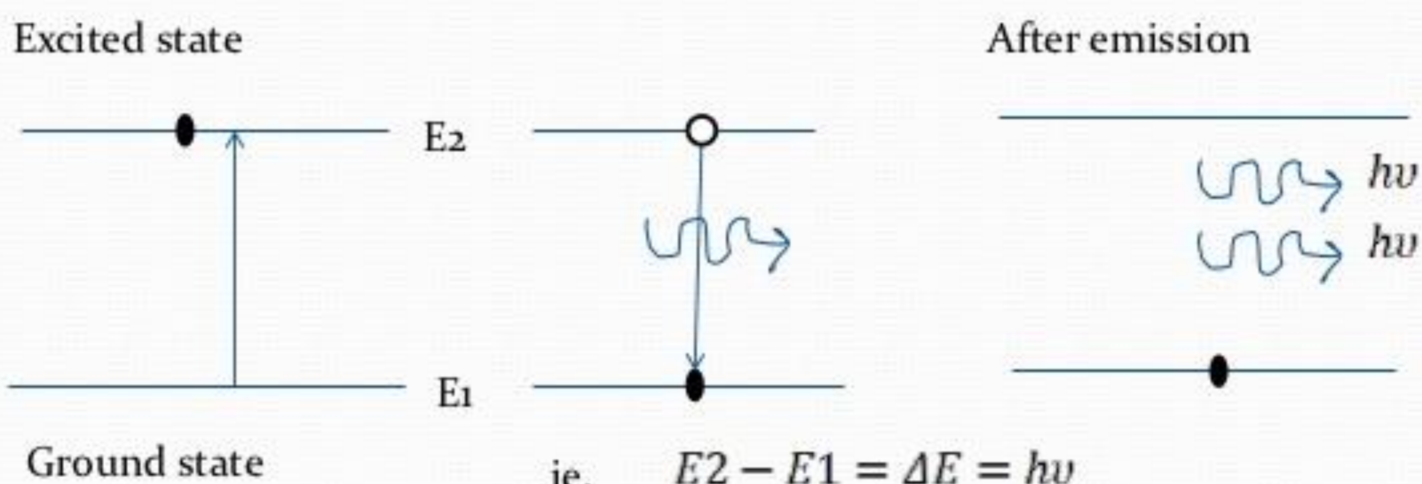
Spontaneous emission

In the atom initially at upper state E_2, it can brought to E_1 by emitting photon of energy $h\nu$.This is known as spontaneous emission.

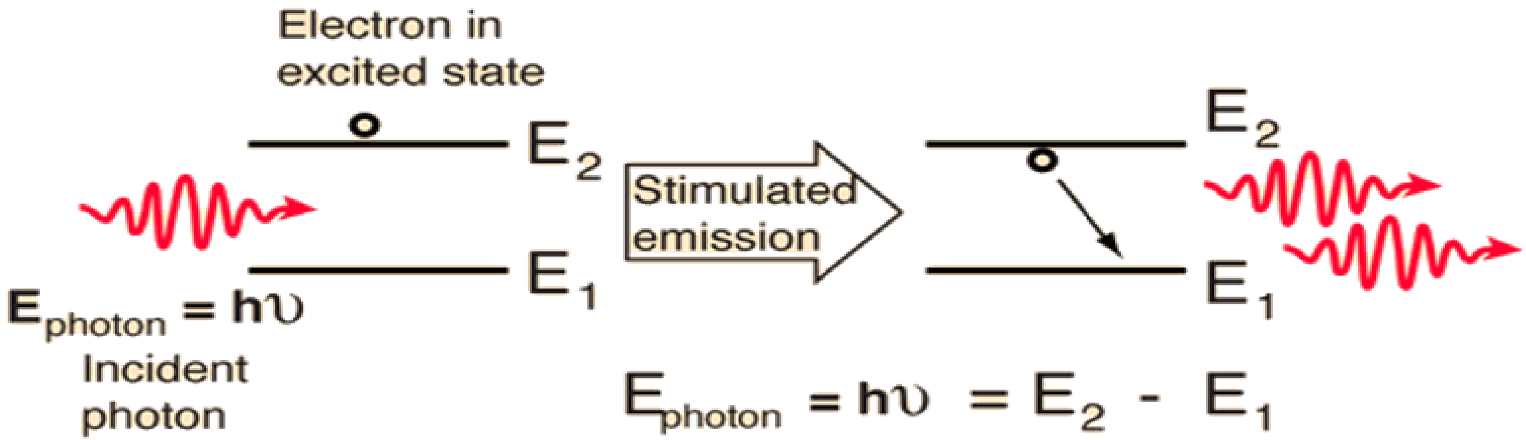


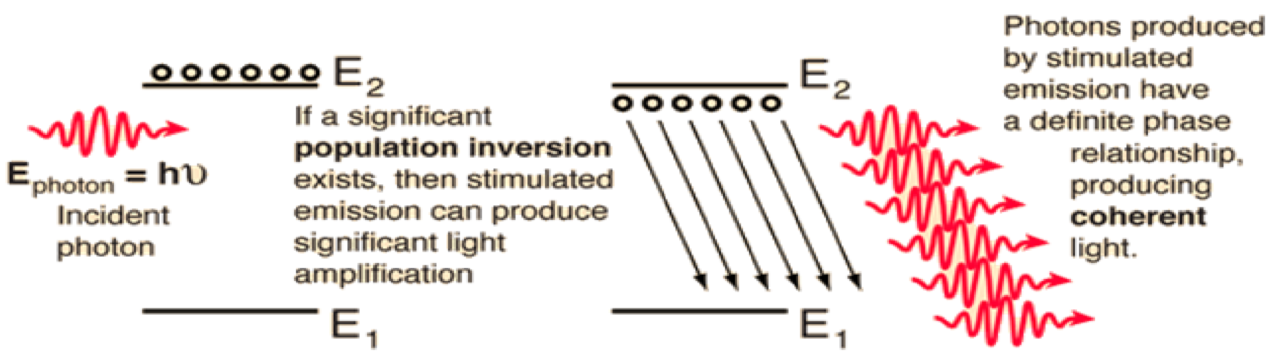
Stimulated emission

According to Einstein's, under certain condition it is possible to force an excited atom emit a photon by another photon and the incident light wave must be in same phase .hence we get an enhance beam of coherent light



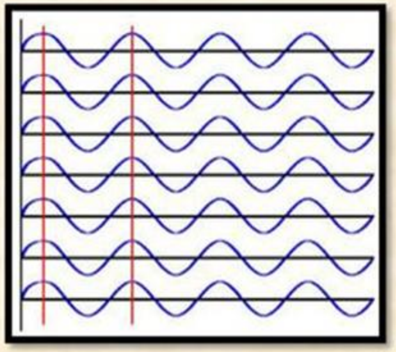
ie, $E2 - E1 = \Delta E = h\upsilon$


Electron in
excited state
E_2
E_1
$E_{photon} = h\upsilon$
Incident
photon
Stimulated
emission
E_2
E_1
$E_{photon} = h\upsilon = E_2 - E_1$


E_2
$E_{photon} = h\upsilon$
Incident
photon
If a significant
population inversion
exists, then stimulated
emission can produce
significant light
amplification
E_1
E_2
E_1
Photons produced
by stimulated
emission have
a definite phase
relationship,
producing
coherent
light.

DIFFERENCE

LASER LIGHT




1. **Coherent :** in phase (in harmony)

2. **Collimated:** parallel
   very narrow beam
   no divergence

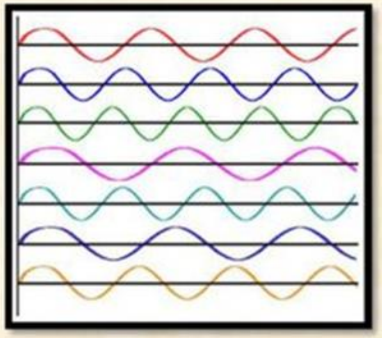
3. **Monochromatic:** single wavelength
   single color

4. **Directional:** unidirectional

↓

5. **Brightness :** extremely very high power density

ORDINARY LIGHT




1. Incoherent : random phase

2. Not collimated: unparallel
   very wide beam
   high divergence

3. Many wavelength
   Many color

4. Multi directional

5. Brightness : very low power density

Relation between Einstein’s A and B Coefficient

Einstein's coefficient and Einstein's relation

Let N_1 & N_2 be the no. of atoms in the ground state and excited state and $\rho(r)$ is the energy density per unit volume

Then the ratio of absorption per unit volume $= B12.\rho(r).N1$

Ratio of spontaneous emission per unit volume $= A21.N2$

Ratio of stimulated emission per unit volume $= B21.\rho(r).N2$

Where B_{12}, B_{21} and A_{21} are Einstein's coefficient under thermal equilibrium, the rate of absorption = rate of emission

$$B12.N1.\rho(r) = A21.N2 + B21.\rho(r).N2$$

$$\rho(r)[B12.N1 - B21.N2] = A21.N2$$

$$\rho(r) = \frac{A21.N2}{B12.N1 - B21.N2}$$

$$\rho(r) = \frac{A21/B21}{\frac{B12}{B21}\cdot\frac{N1}{N2}} - 1$$

$$N1 = \text{No.}\, e^{\frac{-E1}{KT}} \qquad N2 = \text{No.}\, e^{\frac{-E2}{KT}}$$

(Boltzman,s Distribution)

$$\frac{N1}{N2} = e^{\frac{(E2-E1)}{KT}}$$

$$\rho(r) = \frac{A21}{B21}\left[\frac{1}{\frac{B12}{B21}\left[e^{\frac{(E1-E2)}{KT}}\right] - 1}\right]$$

$$u(\nu) = \frac{A_{21}}{B_{21}} \frac{N_2}{e^{\frac{h\nu}{KT}} \left(\frac{B_{12}}{B_{21}}\right) - 1}$$

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{\frac{h\nu}{KT}} - 1}$$

- **B_{12} = B_{21}**, The probability of stimulated emission is same as that of induced absorption. This means that if these two processes will occur at equal rates, so that no population inversion can be attained in a two-level system.

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$$

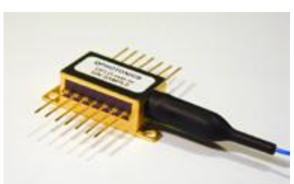
- The ratio of spontaneous emission and stimulated emission is proportional to v^3. This implies that the probability of spontaneous emission dominates over induced emission more and more as the energy difference between the two states increases.

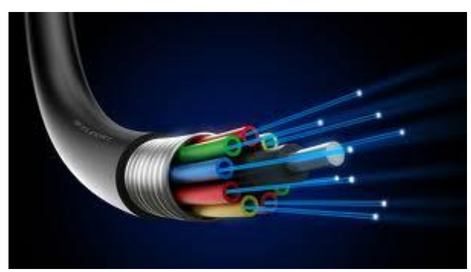
OPTICAL FIBER Communication

Optical Fiber

Tx **optical** Source

Rx **optical** detector





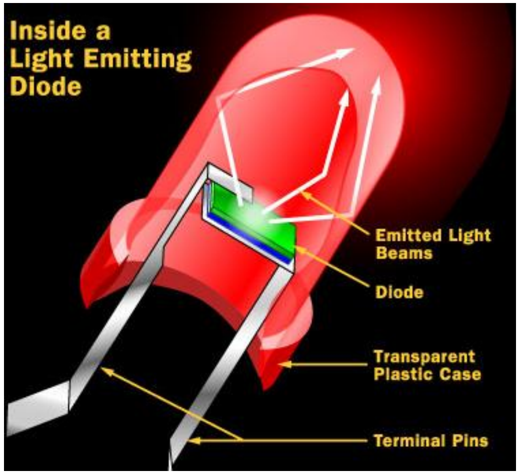
Types of Optical Fiber compatible Sources

- LED (Light Emitting Diodes)

- LASER

(Light Amplification by Stimulated Emission of Radiation)

LEDs



Emits incoherent light through spontaneous emission.

Used for Multimode systems with 100-200 Mb/s rates.

Broad spectral width and wide output pattern.

850nm region: GaAs and AlGaAs

1300–1550nm region: InGaAsP and InP

Two commonly used types: ELEDs and SLEDs

Optical Sources suited to Fiber Optic Communication:

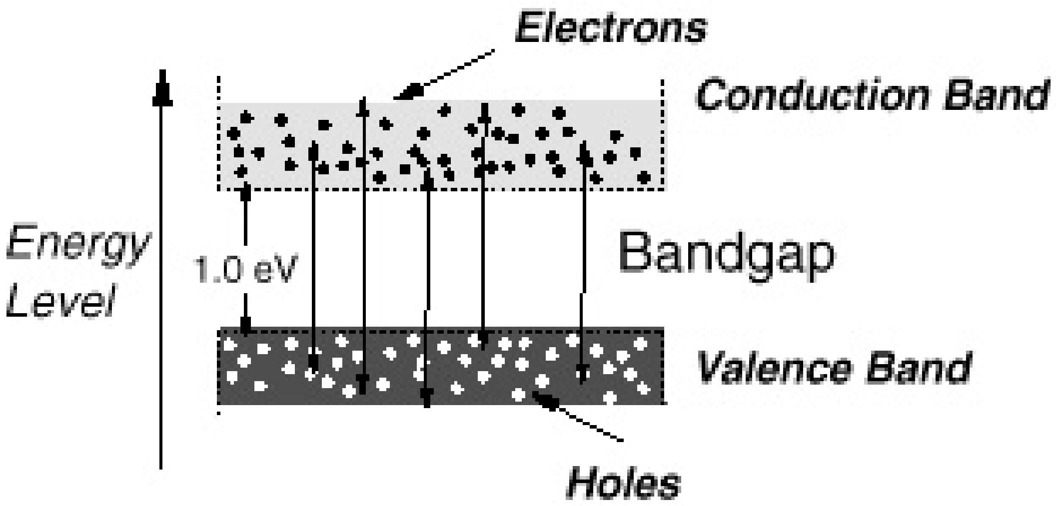
- **Light Emitting Diode (SLED, ELED, SLD)**
- **Semiconductor Laser (DFB, DBR, Vertical-Cavity Surface-Emitting Laser(VCSEL) , Multi Quantum Well , In-Fiber Lasers, Fiber Ring Lasers)**

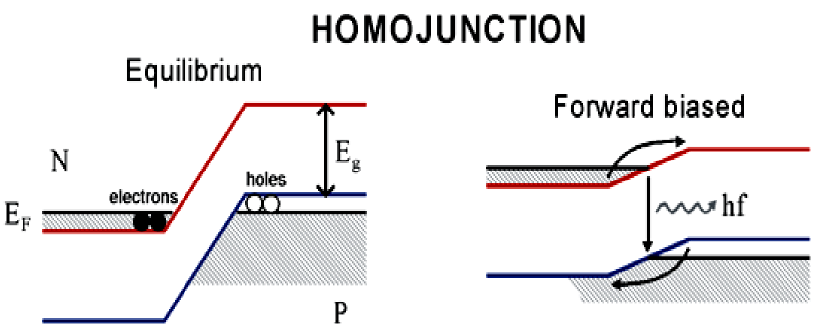
Optical Source Requirements:

- D**imensions to suit the optical fiber geometry**
- **Narrow radiation pattern (beam width)**
- **Ability to be directly modulated by varying driving current**
- **Fast response time**
- **Adequate output power to couple into the optical fiber**
- **Narrow spectral width**
- **Driving circuit issues**
- **Stability, Efficiency, Reliability and cost**

LED Basic operation

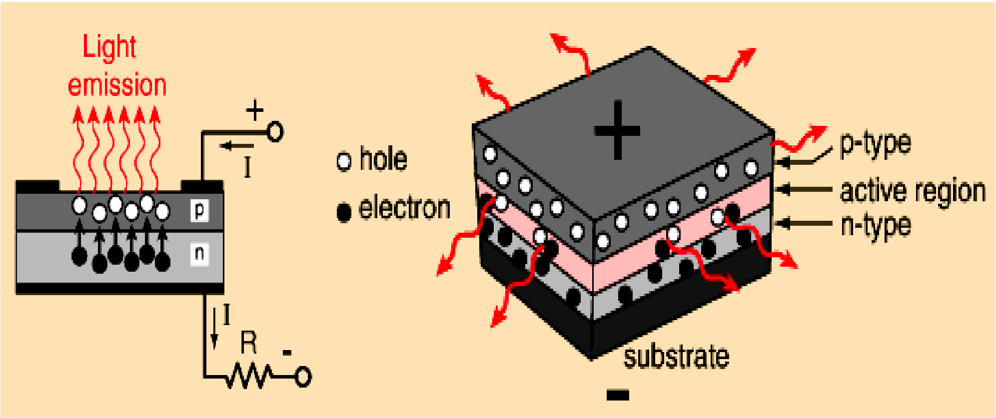
- A PN junction acts as the active or recombination region.
- When PN junction is forward biased, electrons and holes recombine either radiatively (emitting photons) or non-radiatively (emitting heat). This is simple LED operation.





- Emitted wavelength depends on bandgap energy
- Transitions take place from any energy state in either band to any state in other band. Results in a range of wavelengths produced (spontaneous emission). Typically the wavelength range is more than 80 nm.

Light Emitting Semiconductors



Material	Wavelength Range (μm)	Bandgap Energy (eV)
AlGaInP	0.61 - 0.68	1.82 - 1.94
GaAs	0.9	1.4
AlGaAs	0.8 - 0.9	1.4 - 1.55
InGaAs	1.0 - 1.3	0.95 - 1.24
InGaAsP	0.9 - 1.7	0.73 - 1.35

- **Light is emitted at the site of carrier recombination which is primarily close to the junction.**
- **The amount of radiative recombination and the emission area within the structure is dependent upon the semiconductor materials used and the fabrication of the device.**

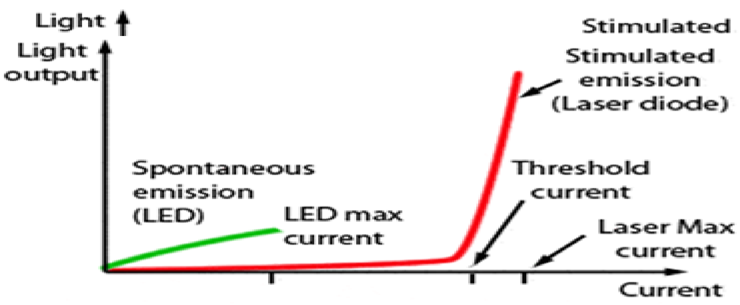
TYPES of LEDs

- Edge Emitting LED's
- Surface Emitting LED's

- **Direct Band gap-**

  III V compounds like GaAlAs , GaAsP, InGaAsP

LED - Light emitting diode	LASER - Light amplification by stimulated emission of radiation
It is polychromatic	Highly monochromatic
It is not coherent	It is coherent
Spontaneous emission is responsible for it.	Stimulated emission is responsible for it.
Not directional	Highly directional
Feedback is not required in LED.	Proper feedback is essential in LASER to be treated as an optical source.



LEDs for FO Communication

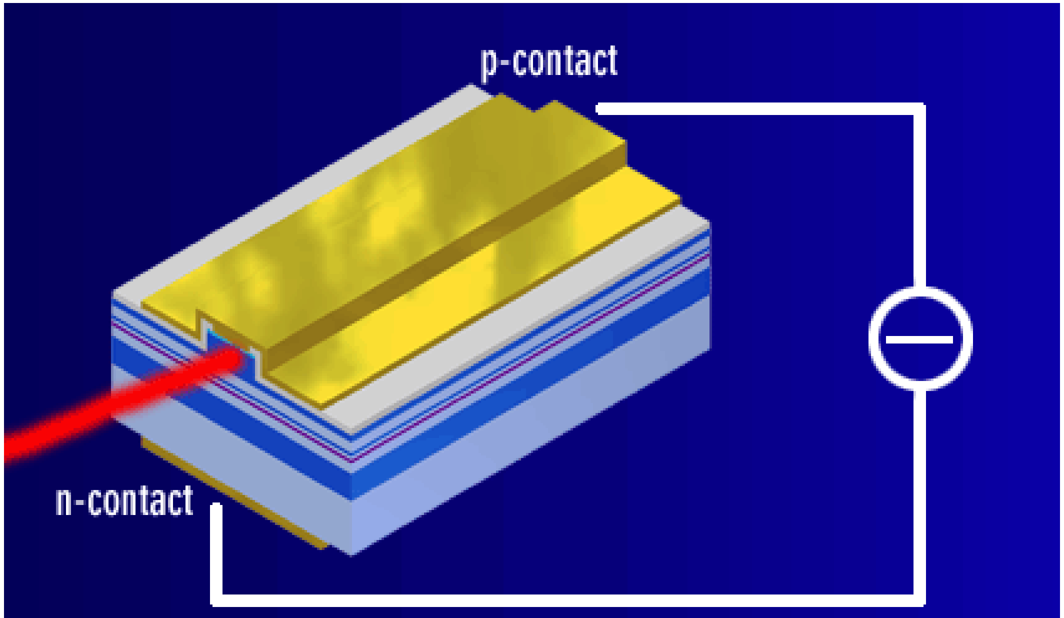
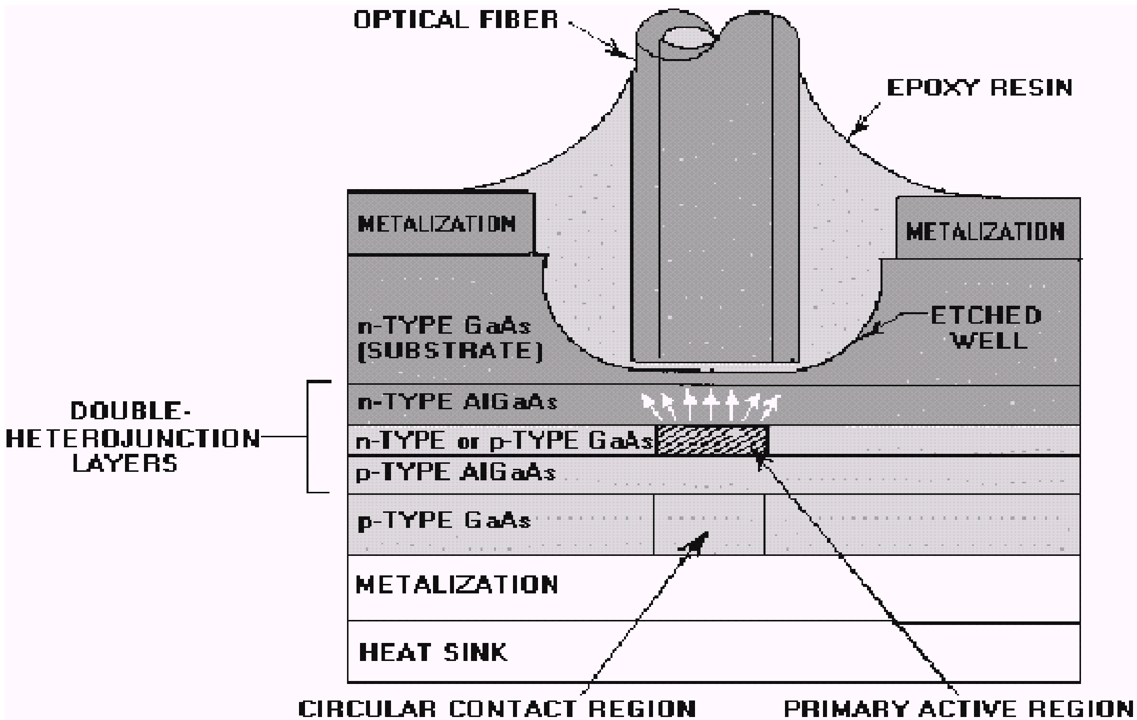


Fig. 2: Current injection is generating light

- ➢Coupling lens used to increase efficiency.
- ➢Short optical Links with Large NA fibers.
- ➢Data rates less than 20 Mbps.

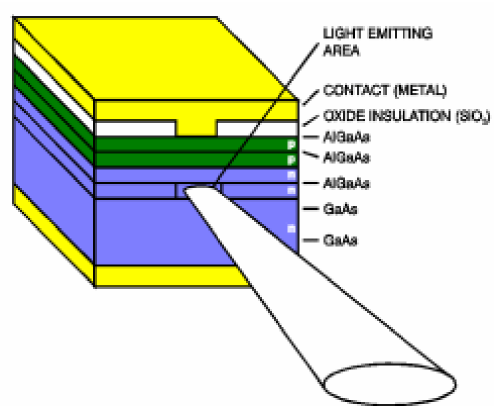
SURFACE EMITTING LED'S

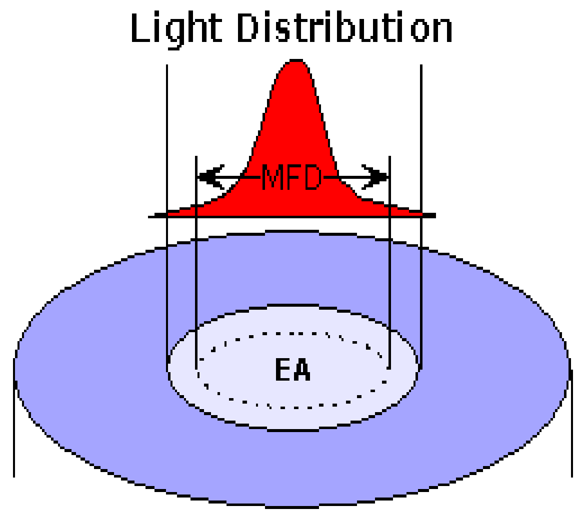


- **Coupling lens used to increase efficiency.**
- **Short optical Links with Large NA fibers.**
- **Data rates less than 20 Mbps.**

Edge Emitting LED's

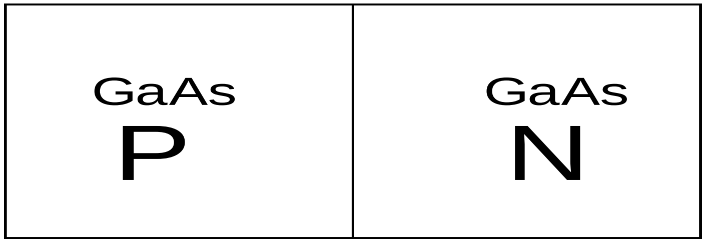
<u>Edge-emitting Diode</u>: An <u>LED</u> that emits light from its edge, producing more directional output than <u>surface-emitting LED's</u>that emit from their top surface.

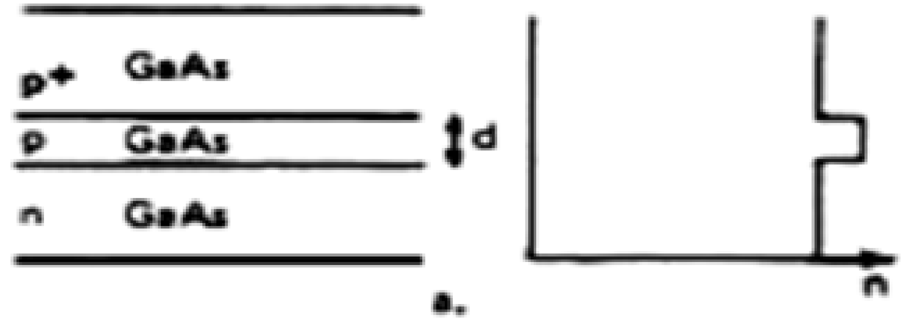




<u>Effective Area</u>: Light is not distributed in the fiber core uniformly. Rather, it follows a distribution that typically peaks in the center of the core and then tails off near the core-cladding interface. It usually extends some short distance into the cladding as well.

- **Homojunctions: P- type and N-type from same material**





- **Carriers are not confined**
- **Light is not confined**

Structure and index of refraction in gallium arsenide with a junction width d

- **<u>LED should have a high radiance (light intensity), fast response time and a high quantum efficiency for Fiber Optic Communication system</u>**

Heterojunction

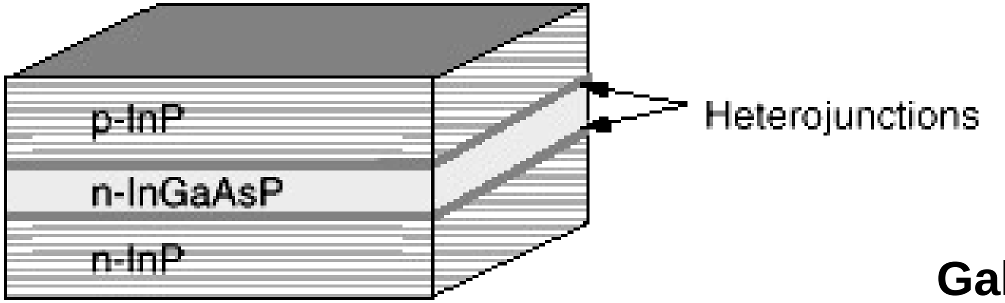
- **Heterojunction is the advanced junction design to reduce diffraction loss in the optical cavity.**
- **This is accomplished by modification in the material to control the <u>index of refraction of the cavity</u> and the <u>width of the junction</u>.**
- **The index of refraction of the material depends upon the impurity used and the doping level.**
- **The Heterojunction region is actually <u>lightly doped</u> with p-type material and has the <u>highest index of refraction</u>.**
- **The n-type material and the more heavily doped p-type material both have lower indices of refraction.**
- **This produces a <u>light pipe effect</u> that helps to confine the light to the active junction region. <u>In the homojunction, this index difference is low</u> and much light is lost.**
- **<u>Double or single hetero-structure junction</u> with better light output**

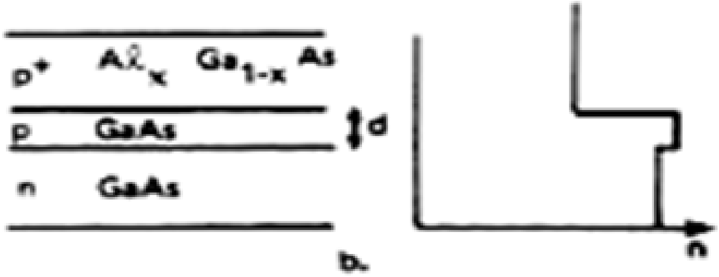
Heterojunctions: Different p- and n- materials

- Carriers are confined
- Light is also confined
- Single Heterojunction, Double Heterojunction.

➢ A heterojunction is a junction between two different semiconductors with different bandgap energies.

➢ The difference in bandgap energies creates a one-way barrier. Charge carriers (electrons or holes) are attracted over the barrier from the material of higher bandgap energy to the one of lower bandgap energy.





Gallium Arsenide-Aluminum Gallium Arsenide <u>single heterojunction</u>

Double Heterojunction

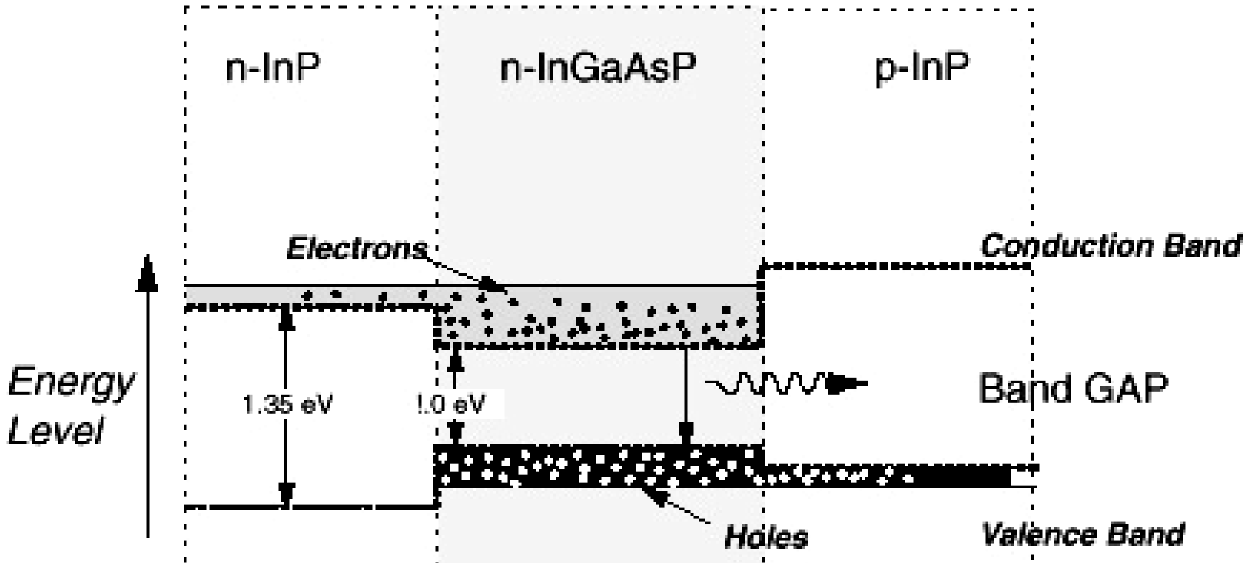
- **When a layer of material with a lower bandgap energy is sandwiched between layers of material with a higher energy bandgap a *double heterojunction* is formed. This is called a double heterojunction because there are two heterojunctions present - one on each side of the active material.**

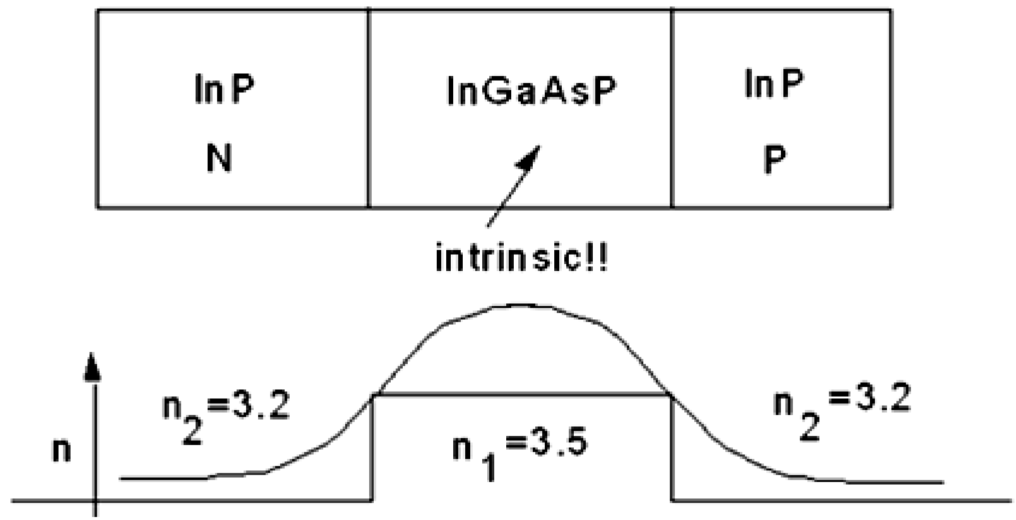
- **The <u>double heterojunction forms a barrier which restricts the region of electron-hole recombination to the lower bandgap materia</u>l. This region is then called the “active” region**

Double Heterojunction

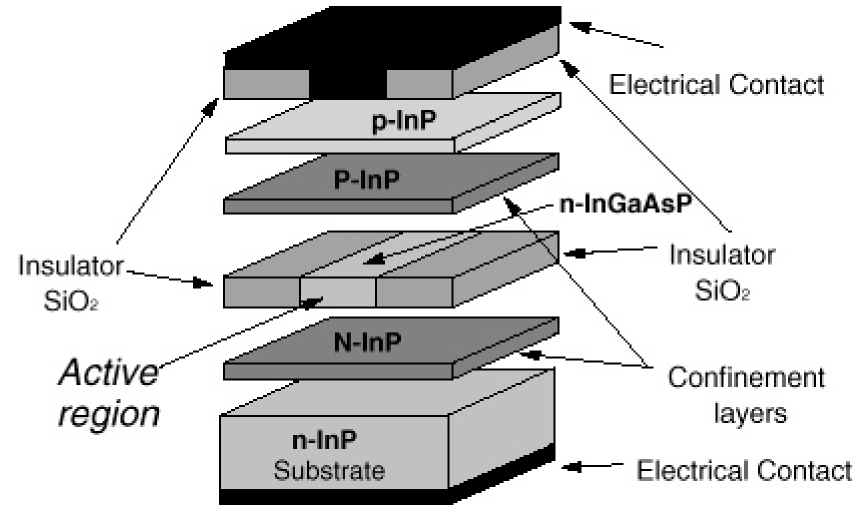
- The valence band of n-InGaAsP is at a higher energy than the valence band of the adjacent n-InP. The conduction band is at a lower energy level.

- p-InP has higher energy levels than n-InP but the bandgap is the same



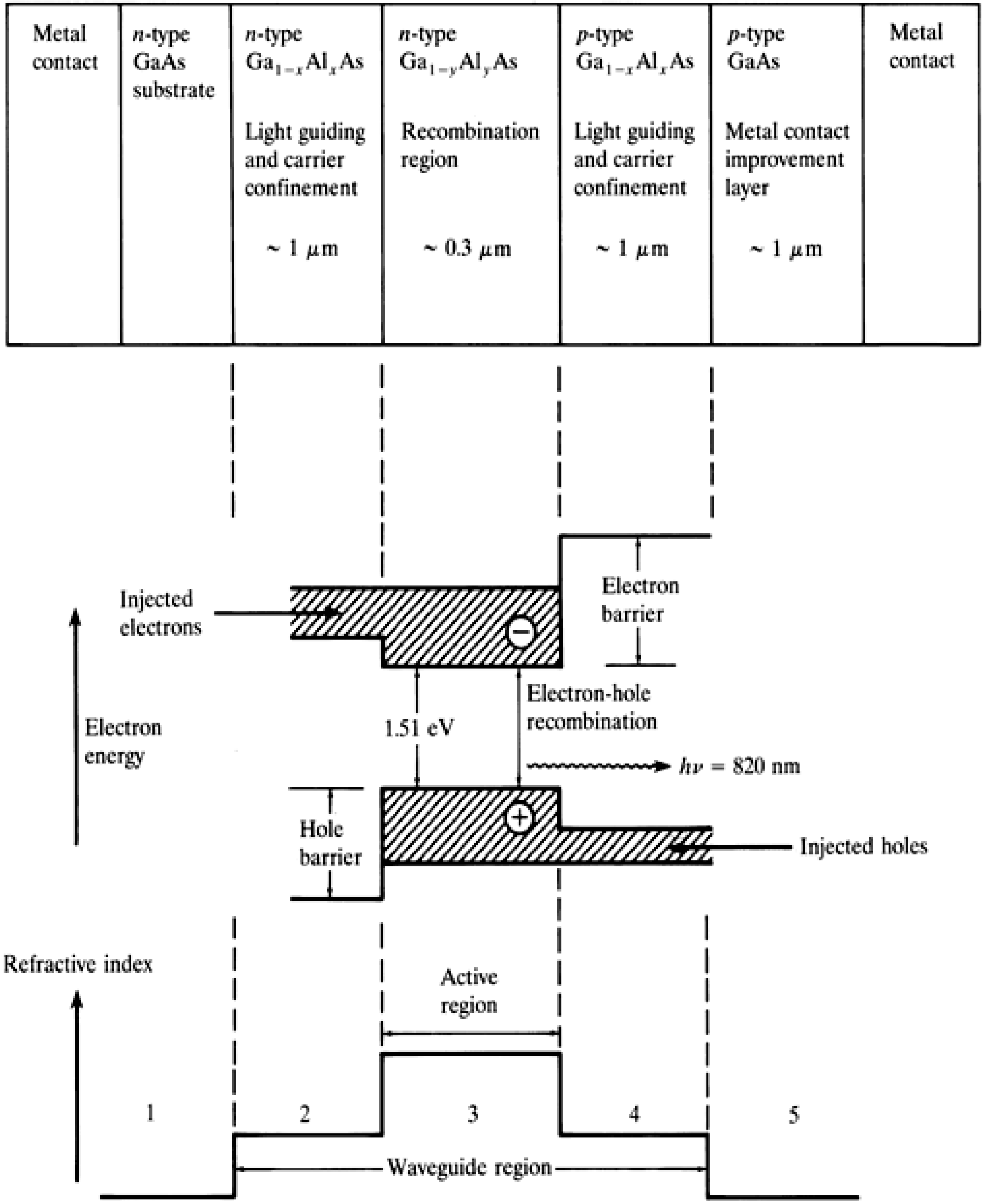


- Electrons are attracted across the left-hand junction from the n-InP to the n-InGaAsP.
- Holes are attracted across the right-hand junction from the p-InP into the n-InGaAsP.



- Recombination takes place in the n-InGaAsP and spontaneous emission (or lasing) occurs.
- The heterojunction allows to have a small active region where the light is produced.
- The material in the <u>active region has a higher refractive index</u> than that of the material surrounding it. This means that a <u>mirror surface effect</u> is created at the junction which helps to confine and direct the light emitted.

Double Heterojunction



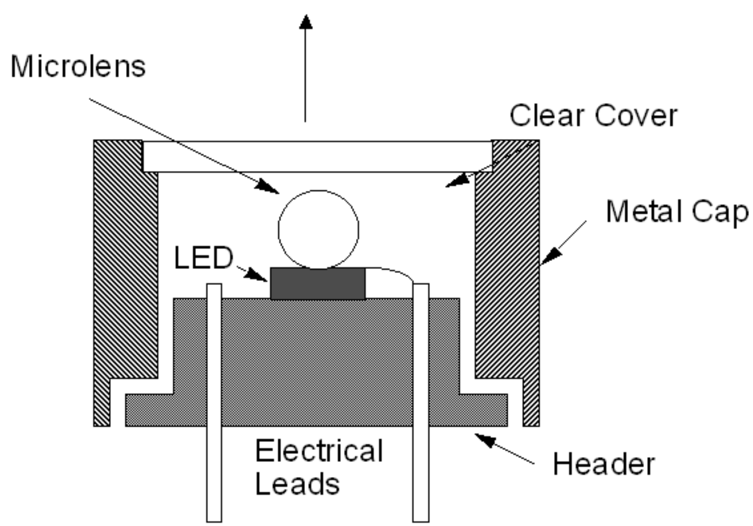
Confining and Guiding the Light within the Device

- **Within the device the light must be confined and directed to the exit aperture so that it can be directed into the fibre which is done using <u>insulating materials SiO_2 to confine the active region and the current path</u>.**
- **The active region in a heterostructure has a higher refractive index.**
- **This junction forms a mirror layer and helps to confine the light to the <u>active layer</u>. For this reason, the outer layers are often called <u>"confinement layers"</u>**

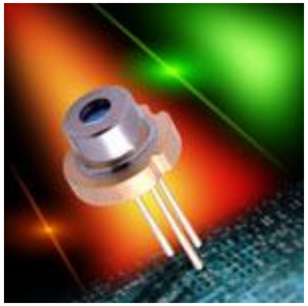
LED : Specifications of importance

- Optical Output Power
- Output Spectrum
- Light coupling into Fiber
- Modulation Bandwidth

Packaging – Microlensed LED

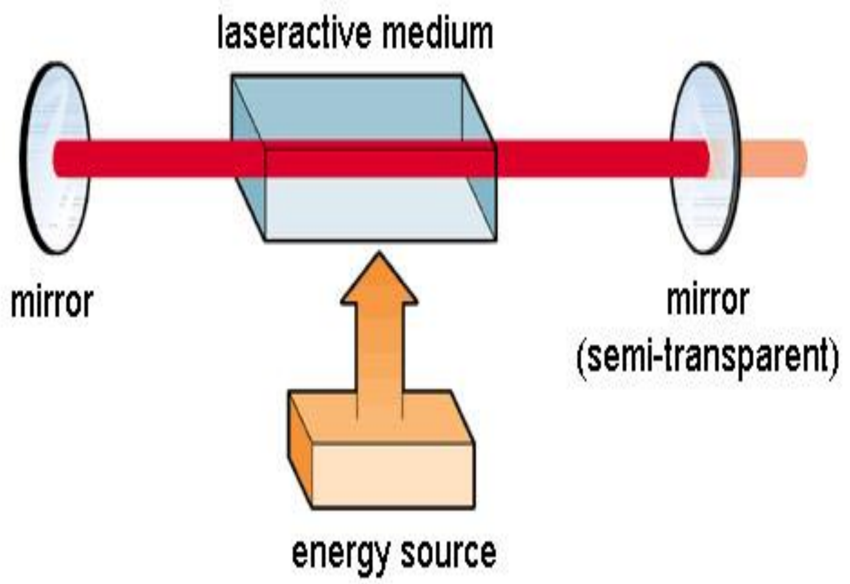


Microlens LED.



Laser Diodes

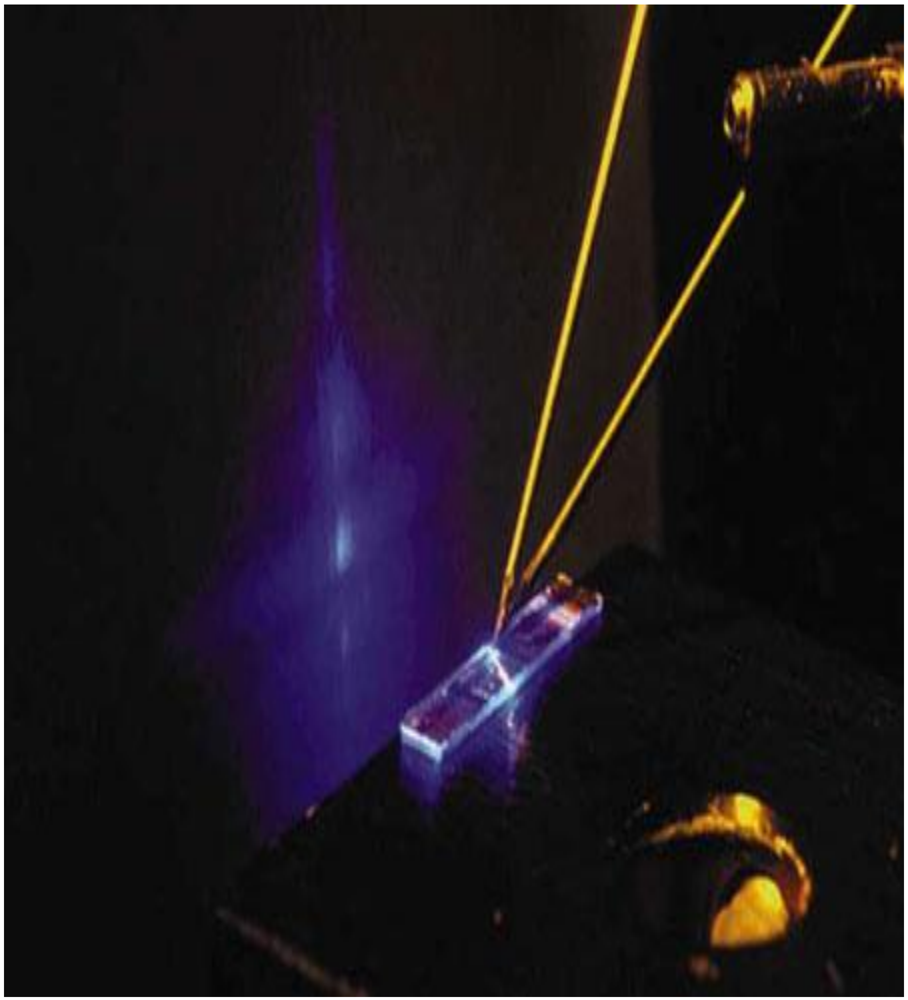
Laser Block Components



Major Components:

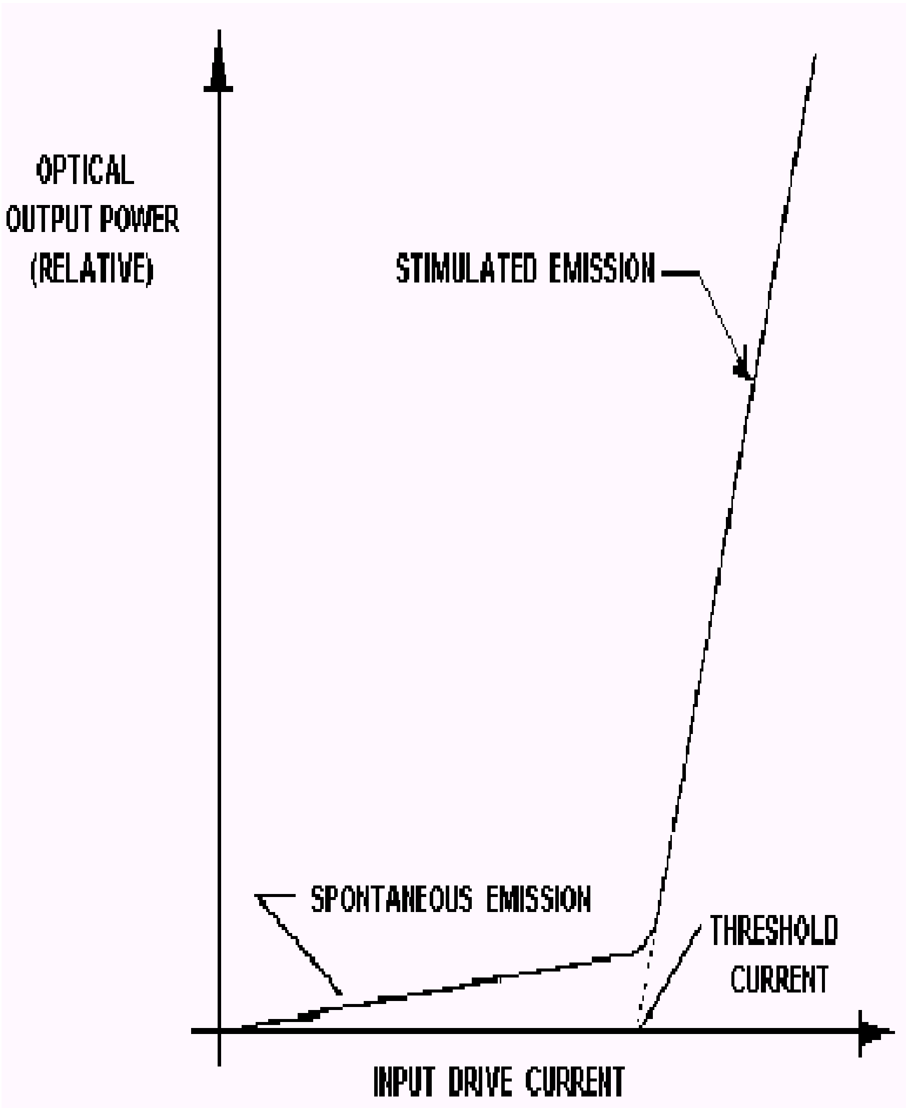
- **Active medium**
- **Pumping Source**
- **Mirrors**

LDs – Laser Diodes



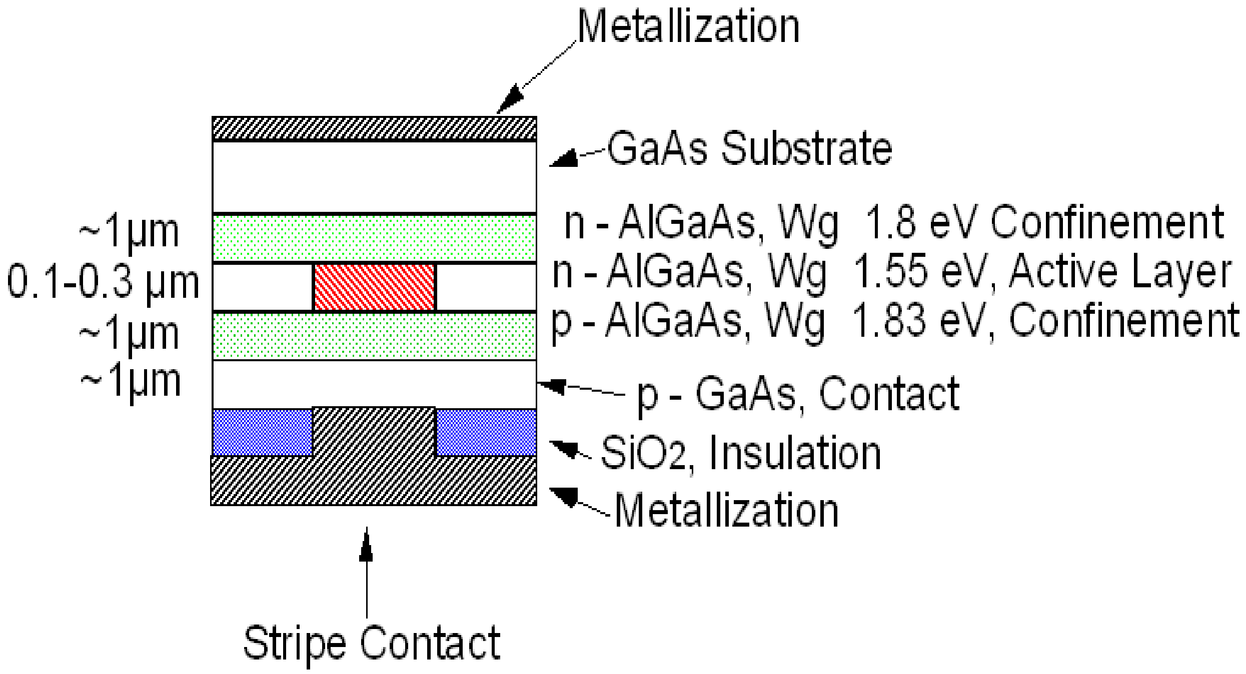
- Emit coherent light through stimulated emission
- Mainly used in Single Mode Systems
- Light Emission range: 5 to 10 degrees
- Require Higher complex driver circuitry than LEDs
- Laser action occurs from three main processes: photon absorption, spontaneous emission, and stimulated emission.

Lasing Characteristics



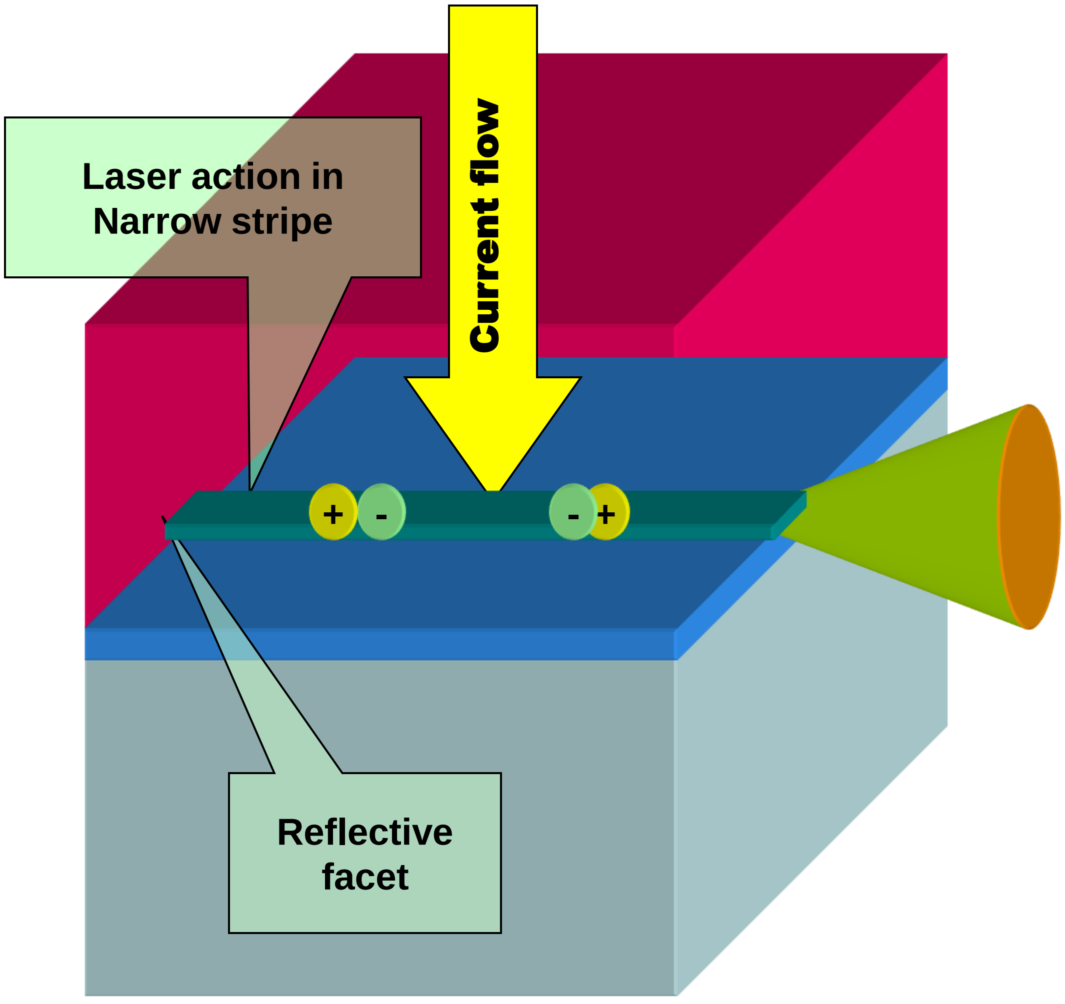
- Lasing threshold is minimum current that must occur for stimulated emission
- Any current produced below threshold will result in spontaneous emission only
- At currents below threshold LDs operate as ELEDs
- LDs need more current to operate and more current means more complex drive circuitry with higher heat dissipation
- Laser diodes are much more temperature sensitive than LEDs

Semiconductor Laser Diode



Edge emitting lasers

- Active layers very thin
- Light emitting area ~ 0.5 µm x 5 µm
- Diffraction causes rapid beam spread



Source Comparison

LDs.	**LED**	**SLED**	**LD**
Principle of Light Generation	Spontaneous Emission	Amplified Spontaneous Emission	Stimulated Emission
Optical Spectrum	Broadband	Broadband	Narrowband or multiple Fabry-Perot modes
Total optical output power	Medium	Medium	High
Optical power density	Low	Medium	High
Optical waveguide	No	Yes	Yes
Light Emittance	All directions	Divergence-limited	Divergence-limited
Spatial coherence	Low	High	High
Coupling into single-mode fibers	Poor	Efficient	Efficient
Temporal coherence	Low	Low	High
Generation of speckle noise	Low	Low	High

Thank you