Advantages of LED

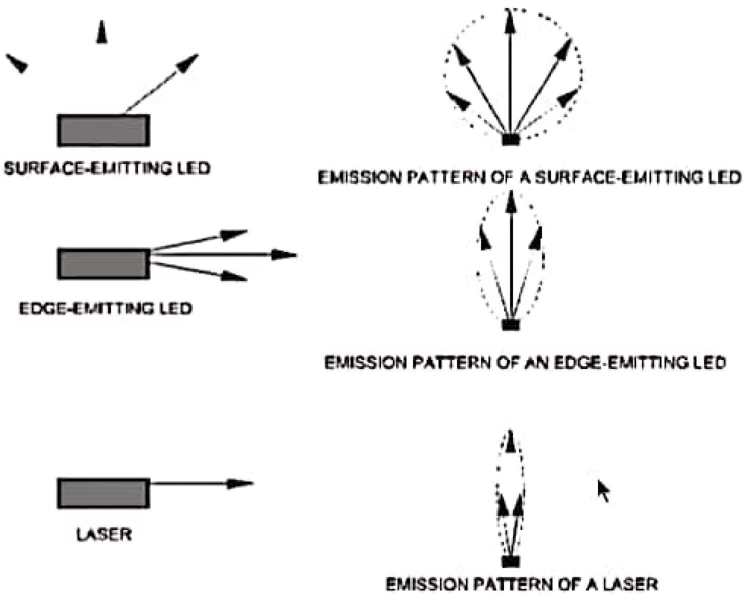
- Simple design.
- Ease of manufacture.
- Simple system integration.
- Low cost.

Disadvantages of LED

- Refraction of light at semiconductor/air interface.
- The average life time of a radiative recombination is only a few nanoseconds, therefore
- Modulation BW is limited to only few hundred megahertz.
- Low coupling efficiency.
- Large chromatic dispersion.

Light Emitters

- Two types
  - Light-emitting diodes (LED's)
    - Surface-emitting (SLED): difficult to focus, low cost
    - Edge-emitting (ELED): easier to focus, faster
  - Laser Diodes (LD's)
    - narrow beam
    - fastest



Quantum Efficiency and Power

The internal quantum efficiency (η_{int}) is defined as the ratio of radiative recombination rate to the total recombination rate.

$$\eta_{int} = \frac{R_r}{R_r + R_{nr}}$$

Where,

R_r is radiative recombination rate.

R_{nr} is non-radiative recombination rate.

$$\tau_r = \frac{n}{R_r}$$

If n are the excess carriers, then radiative life time, and non-radiative life time,

$$\tau_r = \frac{n}{R_{nr}}$$

The internal quantum efficiency is given. The recombination time of carriers in active region is τ. It is also known as bulk recombination life time. |

$$\eta_{int} = \frac{1}{1 + \frac{R_{nr}}{R_r}}$$

$$\boxed{\frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_{nr}}}$$

$$\eta_{int} = \frac{1}{1+\frac{\tau_r}{\tau_{nr}}}$$

Therefore, internal quantum efficiency is given as –

$$\boxed{\eta_{int} = \frac{\tau}{\tau_r}}$$

If the current injected into the LED is I and q is electron charge then total number of re combinations per second is –

$$R_r = R_{nr} = \frac{I}{q}$$

$$\eta_{int} = \frac{R_r}{I / q}$$

$$R_r = \eta_{int} \times \frac{I}{q}$$

Optical power generated internally in LED is given as –

$$P_{int} = R_r . h\, v$$

$$P_{int} = \left(\eta_{int} \times \frac{I}{q}\right) . h\, v$$

$$P_{int} = \left(\eta_{int} \times \frac{I}{q}\right) . h \frac{c}{\lambda}$$

- Not all internally generated photons will available from output of device. The external quantum efficiency is used to calculate the emitted power. The external quantum efficiency is defined as the ratio of photons emitted from LED to the number of photons generated internally. It is given by equation

$$\eta_{ext} = \frac{1}{n(n+1)^2}$$

The optical output power emitted from LED is given as –

$$P = \eta_{ext} \cdot P_{int}$$

$$\boxed{P = \frac{1}{n\,(n+1)^2} \cdot P_{int}}$$

1. The radiative and non radiative recombination life times of minority carriers in the active region of a double heterojunction LED are 60 nsec and 90 nsec respectively. Determine the total carrier recombination life time and optical power generated internally if the peak emission wavelength si 870 nm and the drive currect is 40 mA.

Given

- $\lambda = 870$ nm 0.87×10^{-6} m
- $\tau_r = 60$ nsec. $\tau_{nr} = 90$ nsec.
- $I = 40$ mA $= 0.04$ Amp.

i) Total carrier recombination life time:

$$\boxed{\frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_{nr}}}$$

$$\frac{1}{\tau} = \frac{1}{60} + \frac{1}{90}$$

$$\frac{1}{\tau} = \frac{150}{5400}$$

ii) Internal optical power

$$P_{int} = \eta_{int} \cdot \frac{hc\, I}{q\lambda}$$

iii)

$$P_{int} = \left(\frac{\tau}{\tau_r}\right)\left(\frac{hc\, I}{q\lambda}\right)$$

iv)

$$P_{int} = \left(\frac{30}{60}\right)\left[\frac{(6.625 \times 10^{-34})(3 \times 10^{8}) \times 0.04}{(1.602 \times 10^{-19})(0.87 \times 10^{-6})}\right]$$

2. A double heterjunciton InGaAsP LED operating at 1310 nm has radiative and non-radiative recombination times of 30 and 100 ns respectively. The current injected is 40 Ma. Calculate – Bulk recombination life time. Internal quantum efficiency Internal power level.

Given

λ = 1310 nm = (1.31×10^{-6} m)

- τr = 30 ns τnr = 100 ns
- I = 40 MA – 0.04 Amp.

Injection Laser Diode (ILD)

- The laser is a device which amplifies the light, hence the LASER is an acronym for light amplification by stimulated emission of radiation.
- The operation of the device may be described by the formation of an electromagnetic standing wave within a cavity (optical resonator) which provides an output of monochromatic highly coherent radiation.

Principle

- Material absorb light than emitting.
- Three different fundamental process occurs between the two energy

  1) Absorption 2) Spontaneous emission 3) Stimulated emission

- Laser action is the result of three process absorption of energy packets (photons) spontaneous emission, and stimulated emission. (These processes are represented by the simple two-energy-level diagrams). Where E1 is the lower state energy level. E2 is the higher state energy level.

- Quantum theory states that any atom exists only in certain discrete energy state, absorption or emission of light causes them to make a transition from one state to another.
- The frequency of the absorbed or emitted radiation f is related to the difference in energy E between the two states.

$$E = (E2 - E1) = h.f.$$

Where, h = Plank's constant, E1 is lower state energy level, E2 is higher state energy level.

- An atom is initially in the lower energy state, when the photon with energy (E2 – E1) is incident on the atom it will be excited into the higher energy state E2 through the absorption of the photon.
- When the atom is initially in the higher energy state E2, it can make a transition to the lower energy state E1 providing the emission of a photon at a frequency corresponding to E = h.f.
- The emission process can occur in two ways.

By spontaneous emission in which the atom returns to the lower energy state in random manner.

By stimulated emission when a photon having equal energy to the difference between the two states (E2 – E1) interacts with the atom causing it to the lower state with the creation of the second photon

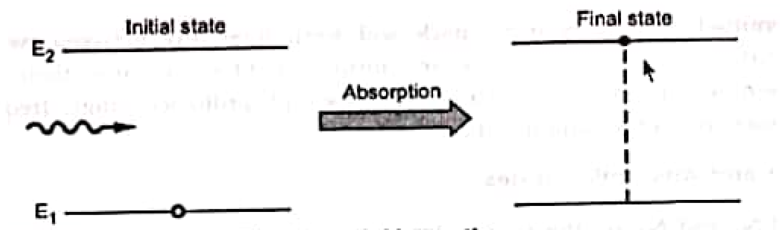


Fig. 3.1.7 Absorption

Fig. 3.1.8 Spontaneous emission

Fig. 3.1.9 Stimulated emission

- Under equilibrium condition the atomic densities N_1 and N_2 are given by Boltzmann statistics.

$$\frac{N_2}{N_1} = eg^{(-E_B\,/\,K_B T)}$$

$$\frac{N_2}{N_1} = eg^{(-h_v\,/\,K_B T)}$$

- Under equilibrium the upward and downward transition rates are equal.

$$AN_2 + BN_2\,\rho em = B'\,N_1\,\rho em$$

- Spontaneous emission gives incoherent radiation while stimulated emission gives coherent radiation.

  Hence the light associated with emitted photon is of same frequency of incident photon, and in same phase with same polarization.

Emission and Absorption Rates

- If N1 and N2 are the atomic densities in the ground and excited states.
- Rate of spontaneous emission Rspon = AN2
- Rate of stimulated emission Rstim = BN2 ρem
- Rate of absorption Rabs = B′ N1 ρem

where, A, B and B′ are constants. ρem is spectral density.

Advantages of Laser Diode

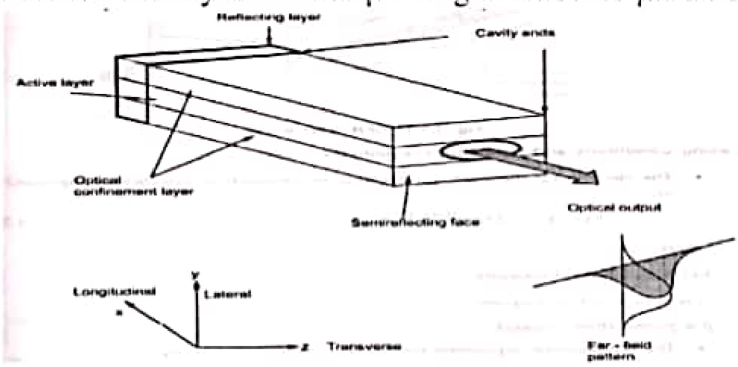
- Simple economic design.
- High optical power.
- Production of light can be precisely controlled.
- Can be used at high temperatures.
- Better modulation capability.
- High coupling efficiency.
- Low spectral width (3.5 nm)
- Ability to transmit optical output powers between 5 and 10 mW.
- Ability to maintain the intrinsic layer characteristics over long periods.

Disadvantages of Laser Diode

- At the end of fiber, a speckle pattern appears as two coherent light beams add or subtract their electric field depending upon their relative phases.
- Laser diode is extremely sensitive to overload currents and at high transmission rates, when laser is required to operate continuously the use of large drive current produces unfavourable thermal characteristics and necessitates the use of cooling and power stabilization.

Lasing Action

- Spontaneous emitted photons makes back & forth motion in the cavity to gain energy.
- Lasers are oscillators operating at frequency. The oscillator is formed by a resonant cavity providing a selective feedback. The cavity is normally a Fabry-Perot resonator i.e. two parallel plane mirrors separated by distance L.
- Light propagating along the axis of the interferometer is reflected by the mirrors back to the amplifying medium providing optical gain. The dimensions of cavity are 25-500 μm longitudinal 5-15 μm lateral and 0.1-0.2 μm transverse.



- The two heterojunctions provide carrier and optical confinement in a direction normal to the junction. The current at which lasing starts is the threshold current. Above this current the output power increases sharply.

Comparison of LED and Laser Diode

S. No.	Parameter	LED	LD (Laser Diode)
1	Principle of operation	Spontaneous emission.	Stimulated emission.
2	Output beam	Non – coherent	Coherent.
3	Spectral width	Board spectrum (20 nm – 100 nm)	Much narrower (1-5 nm).
4	Data rate	Low.	Very high.
5	Transmission distance	Smaller.	Greater.
6	Temperature sensitivity	Less sensitive.	More temperature

Butt Joint Connectors

Butt joint connectors employ a metal, ceramic or molded plastic ferrule for each fiber and a precision sleeve into which the ferrule fit.

The fiber is epoxied into a precision hole which has been drilled into the ferrule.

They are of two type: Straight Sleeve and Tapered Sleeve.

In Straight sleeve connector, the length of the sleeve and a guide ring on the ferrules determine the end separation of fibers.

- In tapered sleeve, it uses a tapered sleeve to accept and guide tapered ferrules.

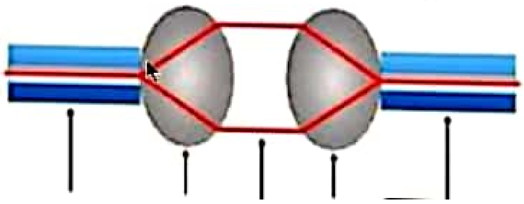
- Again the sleeve length and guide rings maintain a given fiber-end separation.

EXPANDED BEAM CONNECTOR

- It employs lenses on the ends of the fibers.
- These lenses either collimate the light from transmitting fiber or focus the expanded beam onto the core of the receiving filter.
- Fiber to lens distance = focal length of lens.

Advantages:

- Connector is less dependent on lateral alignments.
- Beam splitters and switches can be easily inserted into expanded beam between fiber ends.



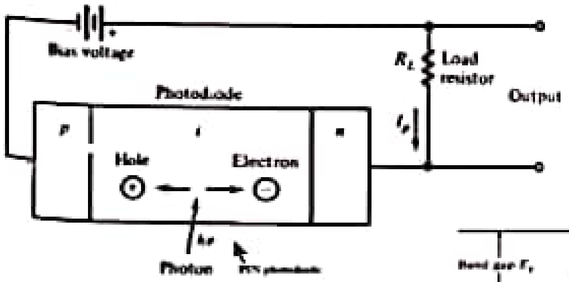
Photodiode is used exclusively for fiber optic

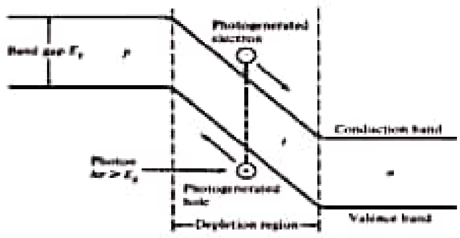
- Small size
- Suitable material
- High sensitivity
- Fast response time

Types of Photodiode

- Pin Photodetector
- Avalanche photodiode

- PIN Photodetector
  - The device structure consists of p and n semiconductor regions separated by a very lightly n-doped intrinsic (i) region.
  - In normal operation a reverse-bias voltage is applied across the device so that no free electrons or holes exist in the intrinsic region.
  - Incident photon having energy greater than or equal to the band gap energy of the semiconductor material, give up its energy and excite an electron from the valence band to the conduction band





PHOTODETECTORS

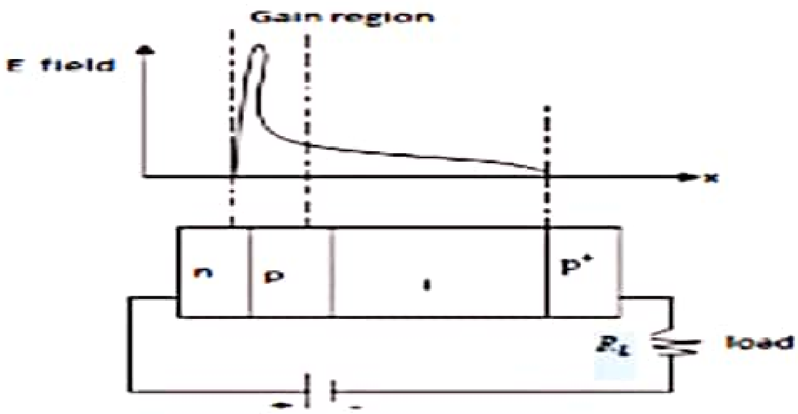
- Devices which senses the luminescent power falling upon it and converts the variation into a corresponding varying current.

  Ex: Photomultipliers, pyroelectric detectors, Photoconductors, phototransistors, Photodiodes.

Requirements

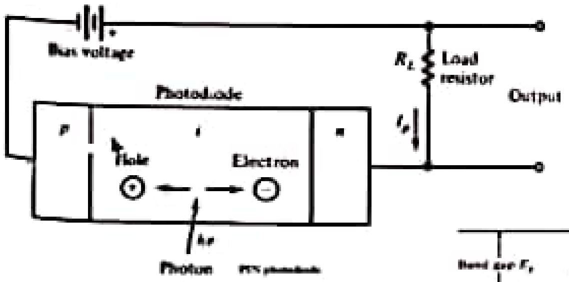
- High fidelity
- High sensitivity at the operating wavelength
- High reliability
- Small size
- Low bias voltages
- Large electrical response to the received optical signal
- Minimum noise introduced by detector

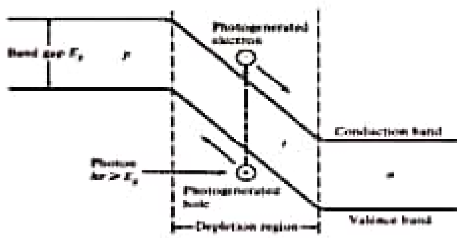
- Avalanche Photodiode (APD)



APD showing high electric field

- PIN Photodetector
  - The device structure consists of p and n semiconductor regions separated by a very lightly n-doped intrinsic (i) region.
  - In normal operation a reverse-bias voltage is applied across the device so that no free electrons or holes exist in the intrinsic region.
  - Incident photon having energy greater than or equal to the band gap energy of the semiconductor material, give up its energy and excite an electron from the valence band to the conduction band





PHOTODETECTORS

- Devices which senses the luminescent power falling upon it and converts the variation into a corresponding varying current.

  Ex: Photomultipliers, pyroelectric detectors, Photoconductors, phototransistors, Photodiodes.

Requirements

- High fidelity
- High sensitivity at the operating wavelength
- High reliability
- Small size
- Low bias voltages
- Large electrical response to the received optical signal
- Minimum noise introduced by detector
- Low cost, Compatible with the physical dimensions of the fiber.
- Long operating life.

Types of Noises

- Shot or quantum noise
- Bulk dark current
- Surface dark / Leak current

Photo detector materials

- Operating Wavelength Ranges for Several Different Photo detector Materials.
- InGaAs is used most commonly for both long-wavelength pin and avalanche photodiodes

Material	Energy gap, eV	λ_{cutoff}, nm	Wavelength range, nm
Silicon	1.17	1060	400–1060
Germanium	0.775	1600	600–1600
GaAs	1.424	870	650–870
InGaAs	0.73	1700	900–1700
InGaAsP	0.75–1.35	1650–920	800–1650

Photo Detector Noise

- Noise Sources
- A photodetector must introduce small amount of internal noise.

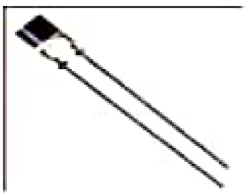
  SNR = signal noise / Noise power

Noise power = Noise due to photodetector+ noise due to load resistor

(Shot noise) (thermal noise)

To achieve high SNR

- Photodetector must have a high quantum efficiency to generate large signal power
- Photodetector and amplifier noises should be kept as low as possible



Fiber connectors and couplers

Interconnection

Temporary - connector

Permanent - Splicing

An optical fiber connector is a flexible device that connects fiber cables requiring a quick connection and disconnection.

The fiber – to – fiber coupling efficiency is given as

common mode volume Mcommon

ME is number of modes in fiber which launches power into next fiber

$$\eta_F = \frac{M_{common}}{M_E}$$

The fiber – to – fiber coupling loss LF is given as – $L_F = -10\log \eta_F$

The main components of an optical fiber connector are

- a ferrule
- sub-assembly body
- Cable
- stress relief boot and
- connector housing.

For avalanche photodetectors,

$$\langle i_s^2 \rangle = \sigma_{s,APD}^2 = \langle i_p^2(t) \rangle M^2 \qquad \text{..... } 3.45b$$

where M is the average of the statistically varying avalanche gain.

For a sinusoidally varying input signal of modulation index m, the signal component $\langle i_p^2 \rangle$ is of the form

$$\langle i_p^2(t) \rangle = \sigma_p^2 = \frac{M^2}{2} I_p^2 \qquad \text{..... } 3.46$$

The shot noise current has a mean-square value in a receiver bandwidth B_e which is proportional to the average value of the photo current I_p.

$$\langle i_{shot}^2 \rangle = \sigma_{shot}^2 = 2q\, I_p\, B_e\, M^2\, F(M) \qquad \text{..... } 3.47$$

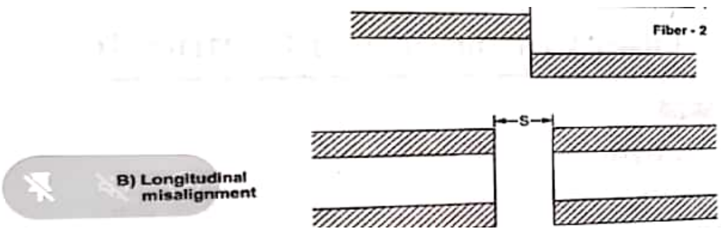
where F(M) is a noise figure associated with the random nature of the avalanche process.

The mean-square value of bulk dark current is given by,

$$\langle i_{DB}^2 \rangle = \sigma_{DB}^2 = 2q\, I_D\, M^2\, F(M)\, B_e \qquad \text{..... } 3.48$$

where I_D is the primary detector bulk dark current.

Longitudinal misalignment
Angular misalignment



The principal requirements of a good connector design are as follows:

- Low losses
- Interchangeability
- Ease of assembly
- Low environmental sensitivity
- Low-cost and reliable construction
- Ease of connection