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BASIC OPTICS

Basic Optics

- Light or visible light is the portion of electromagnetic spectrum that is visible to human eye and is responsible for the sense of sight.
- Visible light has a wavelength in the range of about 380 or 400 nm to about 760 or 780 nm, with a frequency of 405 THz To 790 THz.

  Speed of light in vacuum = 3×10^8 m/sec.

$$\boxed{\text{Refractive index of a material} = \frac{\text{Speed of light in vaccum}}{\text{Speed of light in that medium}}}$$

Reflection

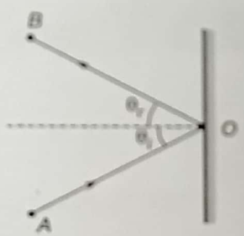
- Bending of light in the same medium in which it is travelling, when it strikes the surface of some other medium is called as the Reflection of light.

  AO = Incident light ray

  OB = reflected light ray

  θ_i = incident angle

  θ_r = reflected angle



Law of reflection

$$\boxed{\angle\theta_i = \angle\theta_r}$$

Refraction

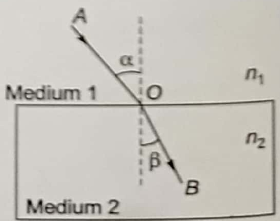
- Bending of light into the medium to which it strikes is called as the Refraction of light.

  AO = incident Ray

  OB = Refracted Ray

  α = angle of incidence; β = angle of Refraction

  n_1 = RI of medium 1; n_2 = RI of medium 2



Snell's Law

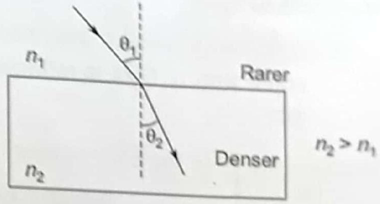
According to Snell's law $\boxed{n_1 \sin\alpha = n_2 \sin\beta}$

Conditions of Refraction

(i) Rarer to Denser medium:

$\boxed{\theta_1 > \theta_2}$

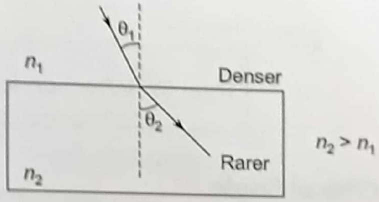
when a ray of light travels from rarer to a denser medium it bends towards the normal.



(ii) Denser to Rarer Medium:

$\boxed{\theta_1 < \theta_2}$

when a ray of light travels from denser to a rarer medium it bends away from the normal.



Refractive Index of one Medium with Respect to other

${}_1\mu_2$ = RI of 2nd medium with respect to 1st.

$${}_1\mu_2 = \frac{\mu_2}{\mu_1}$$

μ_2 = RI of medium 2nd with respect to air

μ_1 = RI of medium 1st with respect to air

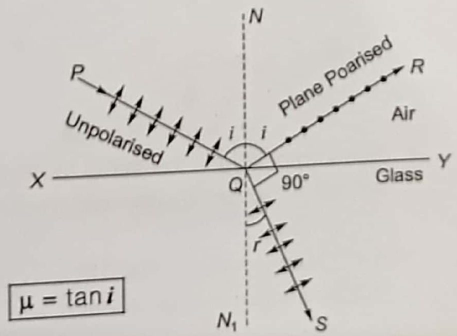
Note:

- Light velocity change from one medium to the other.
- Velocity of light in any medium = $\dfrac{\text{Velocity of light in air}}{\text{RI of medium } (\mu_m)}$

$$\boxed{V_m = \frac{3 \times 10^8}{\mu_m}} \qquad \boxed{{}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{V_{m_1}}{V_{m_2}} = \frac{\lambda_1}{\lambda_2}}$$

Brewster's Law

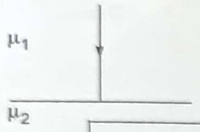
- This law states that when light is incident at a polarizing angle the reflected and refracted ray are at right angle to each other



$\boxed{\mu = \tan i}$

Reflection Loss

- When light falls on any medium then not all the light is refracted, some part of light is reflected back this is called as the reflection loss.



$$\text{Reflection loss (RL)} = \left(\frac{\mu_2 - \mu_1}{\mu_2 + \mu_1}\right)^2$$

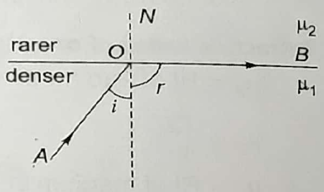
$$\boxed{\text{Total \% Reflection loss} = \left(\frac{\mu_2 - \mu_1}{\mu_2 + \mu_1}\right)^2 \times 100\%}$$

Critical Angle

- The critical angle is the angle of incidence at which the angle of refraction become 90° to the normal.

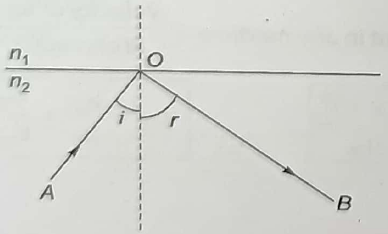
  AO = Incident Ray

  OB = Refrected Ray



$$\boxed{\sin i_c = \frac{\mu_2}{\mu_1}}$$

Total Internal Reflection (TIR)



where $n_2 > n_1$

$i > \theta_c$

θ_c = critical angle

- Bending of light in the same medium when it strikes the surface of any other medium at an angle greater then the critical angle is called as the TIR.
- Compulsory condition for TIR to occur in that light must travel from the denser to the rarer medium.

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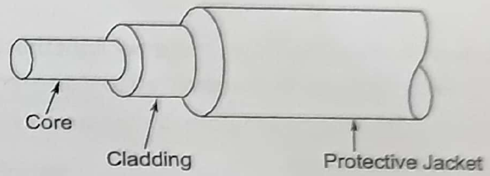
FIBER OPTICS 2

Optical Fiber

- Optical fiber is a very thin and flexible medium with a cylindrical shape.



(Optical Fiber Crossection)

It consists of three sections.

(i) Core (ii) Cladding (iii) Protective Jacket

- Principle of working of optical fiber is total internal reflection of light (TIR).
- The refractive index of core is always greater than the refractive index of the cladding, so that TIR can take place.

Refractive Index Sequence

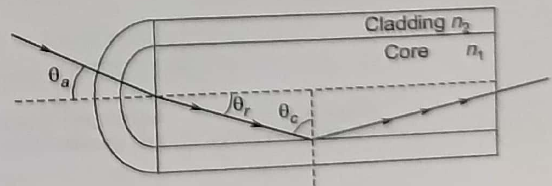
$$\boxed{\mu_{CORE} > \mu_{CLADDING} > \mu_{JACKET}}$$

Acceptance Angle

- The maximum angle of incidence to the fiber for which if light is incident, it gets totally internally reflected and hence travels successfully through the fiber is called as the acceptance angle (A.A.).

In air $\boxed{A.A = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)}$

In medium of RI (μ) $\boxed{A.A. = \sin^{-1}\left(\frac{\sqrt{n_1^2 - n_2^2}}{\mu}\right)}$



Numerical Aperture

- Numerical aperture is the light gathering ability of the optical fiber. Mathematically is the sine of the acceptance angle (θ_a).

$$\boxed{\text{N.A.} = \sqrt{n_1^2 - n_2^2} = \sin\theta_a}$$

For all light gathering N.A. of the fiber is unity.

Note:

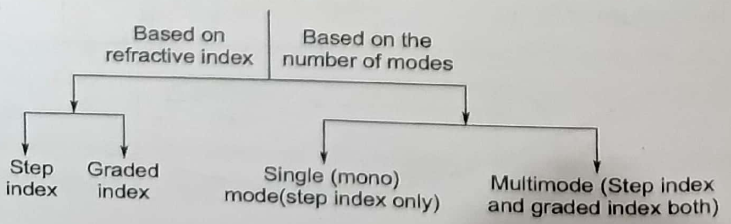
- The larger the N.A. the greater the amount of light that a optical fiber can accept, and hence light can be transmitted to a greater distance.
- If the N.A. is very large the band width of the transmission is decreased.
- N.A. is always less than unity.

Materials used to manufacture optical fibers

1. All glass fibers — Core → glass; Cladding → glass
2. All plastic fibers — Core → plastics; Cladding → plastics
3. Plastic clad silica (PCS) fibers — Core → silica/glass; Cladding → plastics
4. Core → plastic; Cladding → glass } not used

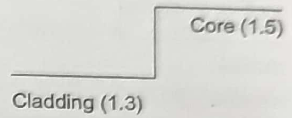
- In (1) and (2) combination doping elements are added to change its refractive index. Thus the original material is SiO_2, we can dope some other materials GeO_2 or P_2O_5,
  To increase (↑) R.I. dope with GeO_2 or P_2O_5
  To decrease (↓) R.I. dope with B_2O_3.

Classification of Optical fiber



Based on R.I.

1. **Step index**
   In this R.I. changes suddenly like step function between core and cladding



(Step index fiber)

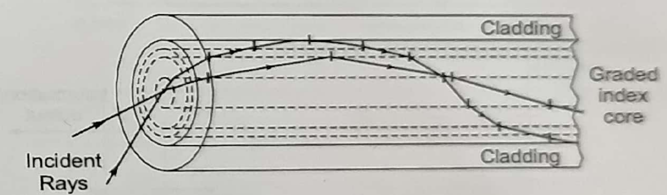
Drawback

- Pulse distortion is more.
- Losses are more.
- Information carrying capacity is less.

2. **Graded Index**
   - R.I. is not uniform within the core.
   - At the axis of core R.I. is maximum.

   From core to cladding RI decreases

   Light propagation through graded index:



- Ray of light is offered a parabolic or the sinusoidal path when passed through a graded index fiber.

Advantages

- Pulse distortion is reduced
- Losses are reduced
- Information carrying capacity is increased

Disadvantages

- Difficult to manufacture
- costly

Based on Mode

1. Single or Monomode optical fiber
   - Narrow core is used (2 μm to 10 μm).
   - $\mu_{core} - \mu_{cladding}$ = Very small.
   - It has only one path for transmission i.e. only a single mode can travel through it.

- It is always step index as core is narrow which cannot be made graded index.
- V-number decides how many mode or path will be there.

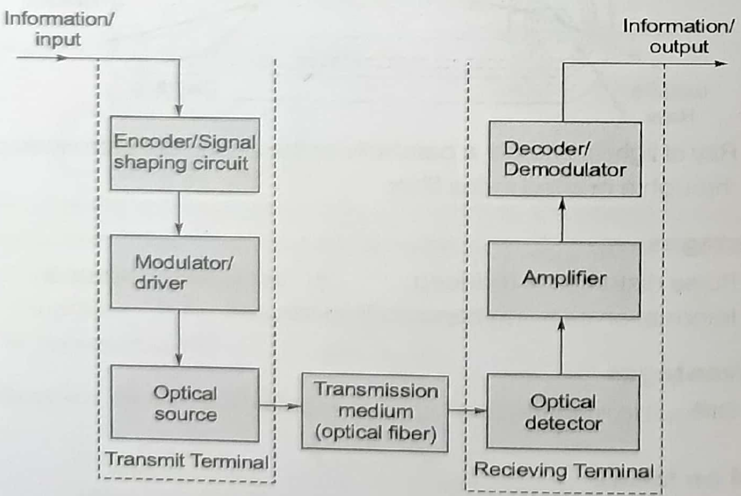
$$\boxed{V = \frac{2\pi r}{\lambda}\sqrt{n_1^2 - n_2^2} \le 2.4045}$$

r = radius
λ = wavelength
n_1 = RI of the core
n_2 = RI of the cladding

2. Multimode optical fiber
   - Wide core is used (> 50 μm)
   - More than one mode can travel through it

$$\text{No. modes or path} = \frac{V^2}{2}\left(\begin{matrix}\text{for step}\\ \text{index fiber}\end{matrix}\right)$$
$$= \frac{V^2}{4}\left(\begin{matrix}\text{for graded}\\ \text{index fiber}\end{matrix}\right)$$

Optical Fiber Communication System



Characteristics of Optical Communications

1. Attenuation loss must be low.
2. Pulse distortion must be low.
3. Bandwidth (information carrying capacity) must be high.

1. Attenuation Losses
   - The output at the output end of the fiber is found reduced in power as compared to the input due to absorption, scattering, reflection etc.

$$\boxed{\text{Attenuation (db/km)} = \frac{10}{L}\log\frac{P_o}{P_i}}$$

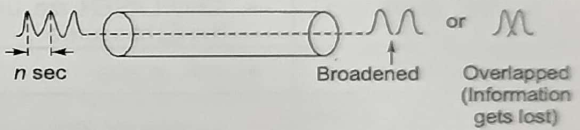
Where, P_0 = output power; P_i = input power
L = length of the optical fiber

Ideally attenuation losses in the fiber must be 0 dB/km, but it is not practically feasible.

Attenuation Losses Occur Due to

(i) Absorption (ii) Scattering losses (iii) Radiation losses

2. Pulse Distortion or Dispersion
   - The broadening of the light pulses at the output of the optical fiber cable is called as the dispersion. Its unit is (n sec/km).



$$\Delta T = \frac{n_1 L}{c}\Delta \quad \text{(For step index)}$$
$$\Delta T = \frac{n_2 L}{2c}\Delta^2 \quad \text{(For graded index)}$$

$$\Delta = \frac{n_1}{n_2} - 1$$

where, c = speed of light

$\boxed{\Delta T \text{ for graded index} > \Delta T \text{ for step index}}$

3. Bandwidth
   - Bandwidth of an optical fiber is the maximum number of pulses that can be sent and received without overlapping.
   - The maximum number of pulses are to be limited by the distortion, as we have to keep some time gap between two successive pulses ΔT which reduces the number of pulses and hence the bandwidth.

Preferable Characteristic of Optical Fiber are

- High Bandwidth
- Low losses
- Low core diameter
- Low pulse distortion
- Low numerical aperture (Low N.A.)

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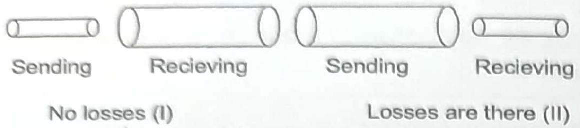
Coupling Losses of the Fiber



- Losses will occur in case (II) and no losses will be there in case (I)

$$\boxed{\text{Loses} = 20 \log \frac{(NA)_{\text{sending}}}{(NA)_{\text{Reciever}}}}$$

Comparison of Optical Fibers

Modewise Comparison

Multimode	Singlemode
• Core diameter is large so easy to launch the multiple modes	• Core diameter is less, it carries only a single mode
• Light source used LED, LASER	• Only LASER are used as the light source
• They have more N.A.	• N.A. is less
• Losses are high, since number of modes are more	• Losses are less
• Bandwidth is low	• Bandwidth is high
• Cost is low	• Cost is high

Material wise Comparison

All glass	Plastic silica	All plastic
Losses are less	Medium losses	High losses
Low mechanical strength	Medium mechanical strength	High mechanical strength
Low N.A.	Medium N.A.	Low N.A.
Long distance application (∵ of low losses)	Medium distance application	Short distance application

Applications of Optical Fibers

1. Industrial applications
2. Medical
3. Military operations
4. Telecommunication

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3 LASERS

Lasers

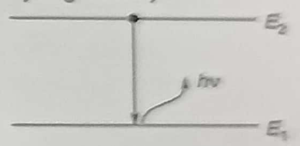
- LASER is an acronym of Light Amplification By stimulated Emission of Radiation.
- A laser is a device that emits light through a process of optical amplification based on the stimulated emission of photons. The light beam obtained by LASER is highly directional and intense.

Principle of Laser

- Consider the case when an atom or the molecule in an excited state with energy E_2 and makes a transition to lower energy state E_1. It emits electromagnetic radiation of frequency n given by

$$h\nu = E_2 - E_1$$

$$\nu = \frac{E_2 - E_1}{h}$$



where h = Plank's constant

- The transition of electron in an atom can take place by three process

(i) **Absorption**

atom + photon ⟶ atom* ; atom = atom in ground state

atom* = atom in the excited state

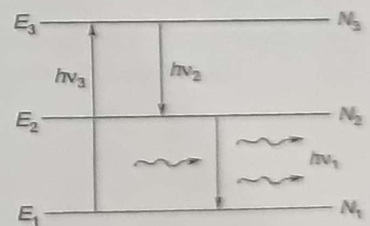
(ii) **Spontaneous Emission**

atom* ⟶ atom + photon

(iii) **Stimulated Emission**

atom*+photon ⟶ atom+2 photon

Population Inversion



- Let N_1 and N_2 be the number of atoms in the lower and upper levels respectively.
- When the photon of energy $h\nu$ is incident on it may lead to transition from E_2 to E_1 or from E_1 to E_2.
- If $N_2 < N_1$ = Absorption of light is dominant.
- If $N_2 > N_1$ = Stimulated emission will dominate.
- When this happens, the population inversion, takes place. To start population inversion some starting external energy must be supplied to the atoms of the material. Population inversion constitutes the basic principle of the LASER action.

Characteristics of Laser Beam

(i) Very high directionality (ii) high intensity
(iii) Monochromatic (iv) Coherent

Directionality

(a) Angle of divergence or angular spread

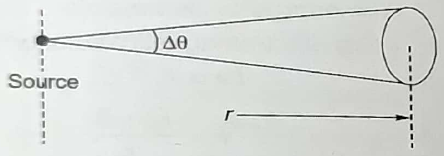
$$\boxed{\Delta\theta = \frac{1.22\,\lambda}{d}}$$

d = aperture diameter of light source from where the light is comming.
λ = wavelength of the light comming from the laser source.
$\Delta\theta$ = angular spread of the laser beam.

(b) Areal Spread

$$\boxed{\text{Areal spread} = \pi(r\theta)^2}$$

r = distance of the surface from the laser source (m).



Remember:

- The spread must be low for a better and efficient laser beam.

Intensity

$$\boxed{\text{Intensity } (I) = \frac{\text{Power}}{\text{Area}}}$$

Monochromaticity

- A laser beam is highly monochromatic i.e. it has only a single wavelength or the single colour.
- The degree of non-monochromaticity is defined by ($\in$)

$$\in = \frac{\Delta\nu}{\nu_0} \qquad \nu_0 \Rightarrow \text{Central frequency}$$

$\Delta\nu$ = width of spread in frequency

- Consider a case of large number of modes travelling into a laser cavity of length (L).

The difference in frequencies between consecutive modes is $\Delta\nu$ and the length of the cavity is L

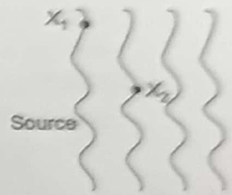
$$\therefore \quad \boxed{\Delta\nu = \frac{c}{2L}} \qquad \boxed{\text{No. of modes} = \frac{\text{Bandwidth}}{\Delta\nu}}$$

Coherence

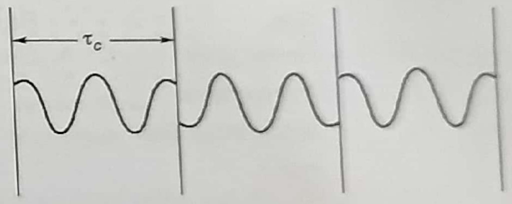
- Coherence is a measure of the degree of phase correlation that exists in the radiation field of light source at different locations & at different times.
- Light from a conventional source is a jumble of tiny seperate waves that cancel each other in a random order. The wavefront so produced changes from one point to other and varies from instant to instant. Hence there are two seperate concepts of coherence:
  (i) Spatial coherence (ii) Temporal coherence

Spatial Coherence

- If two fields at two different points on a wavefront of a electromagnetic, wave has a constant phase difference over any time 't', they possess spatial coherence.



Temporal Coherence



(Electromagnetic wave with coherence time τ_c)

- Temporal coherence refers to the correlation between the field at a point and the field at the same point at a later time.
- The time for which the wave remain sinusoidal and do not break in phase is called as the coherence time (τ_c).
  The distance travelled by the wave in the time interval τ_c is called as the length of coherence (l)

$$\boxed{l = c\tau_c}$$

Bandwidth ($\Delta\nu$) is related to τ_c as

$$\boxed{\Delta\nu = \frac{1}{\tau_c}}$$

Basic Parts in Laser

1. Active Material
   - It is the material kept inside the cavity.
   - It participate in the laser generation process.

2. Excitation/Pumping Mechanism

- The process by which the atoms are raised from the lower level to the upper level so that neccessary population inversion is obtained is called as the pumping.

  It is classified as:

  (a) **Optical Pumping:** In this method the population inversion is attained by means of strong source of light such as gas discharge, flash lamp or arc lamp.

  (b) **Chemical Pumping:** In this method population inversion is obtained by suitable chemical reaction without any need of other source of energy.

  (c) **Electrical Pumping:** In this method population inversion is obtained by means of an intense electric discharge in the medium and is suited to gas medium.

Classification of Lasers

Solid	Gas	Semiconductor
• Ruby laser (made of Ruby crystal)	• He-Ne laser Atomic laser	• Ga As laser
• Nd-YAG laser	• Argon laser (Ion laser)	
	• CO_2 laser (molecular laser)	

Gas Laser

- Highly monochromatic light
- Most pure spectrum
- Continuous and pulsed output
- Power variation can be from low value to high value (i.e. mW to MW)

Semiconductor Diode Laser

- Its output is slightly broad.
- Most widely used laser due to low cost and simple to design and operate.

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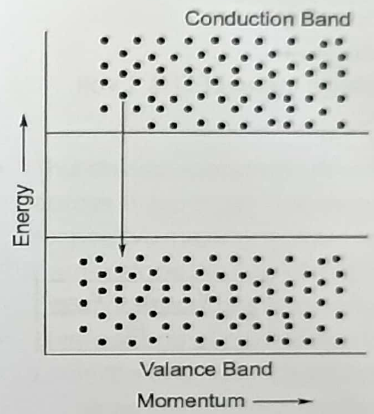
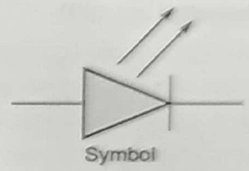
LIGHT EMITTING DIODE (LED)

4

LIGHT EMITTING DIODE (LED)

- An LED is a forward Biased p-n junction which emits visible light when ON current is made to flow through it.





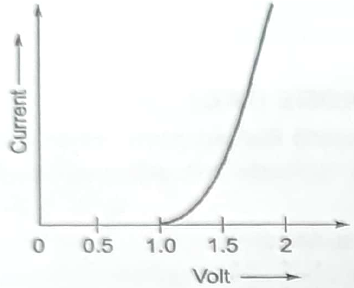
- The light is emitted when electrons from the N-side cross the junction and recombine with the holes on the P-side.
- The electrons on the N-side are in heigher level (i.e. conduction band) whereas the holes on the P-side are in lower level (i.e. valence band), whenever the electron falls from conduction to valance band the recombination takes place and the energy is released, this released energy is in the from of either heat or light. The maximum energy released in case of Si, and Ge is in the from of heat whereas in case of Ga As, GaP, Ga, AsP energy released is in the form of light.

Note:
- GaAs has very high efficiency in terms of photons emitted per carries.

- Different materials give different energy gap and hence have different colour emission.

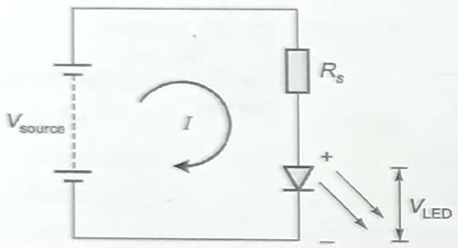
  GaAs ⟶ infrared radiation
  GaP ⟶ red or green light
  GaAsP ⟶ red or yellow light

Characteristics of LED



Unlike an ordinary diode, the cut-off voltage for an LED is 1 volt.

Current Through an LED



$$\boxed{I = \frac{V_{source} - V_{LED}}{R_s}}$$

Remember:

- Never connect an LED with a battery or a power supply directly.
- Led must have a resister in series to limit the current to a safe value.

$$\boxed{R_s = \frac{(V_{source}) - (V_{LED})}{I}}$$

Internal Quantum Efficiency

$$\eta = \frac{\text{Light energy emitter}}{\text{Light energy emitter + Heat energy emitter}}$$

$$\boxed{\eta = \frac{R_r}{R_r + R_{nr}} \times 100\%}$$

where

R_e = Radioactive Recombination (light)

R_{nr} = Non-Radioactive Recombination (heat)

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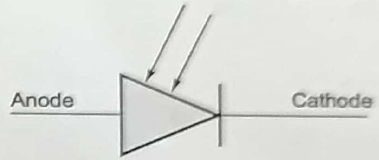
PHOTO DIODE

5

Photodiode

- A photodiode is a type of photodetector capable of converting light into either current or voltage.



- This device operates in **reverse bias** and the electic field developed across the p-n junction sweeps the mobile charge carriers to their respective majority sides. Hence a deplection region is formed. This barrier stops the flow of majority carrier and supports the flow of only the minority carries and hence the leakage current flows.
- This leakage current is due to both the effects:
  1. In the absence of light falling on the reverse biased photodiode, some leakage current flows called the dark current.
  2. Another leakage current is due to the incidence of light or photons on the diode.
  3. This leakage current is proportional to the current or light faling on the photo diode.

Sensitivity

- Sensitivity of a photodiode is the amount of current flow per unit light irradiance.

$$S = \frac{I}{H};\qquad \text{where} = I = \text{Current flowing; } H = \text{Irradiance}$$

Note:

- Dark current must be minimised to enhance the sensitivity of the photodiode. The dark current doubles for every 10°C increase in temperature for silicon and this decrease the signal to noise ratio.

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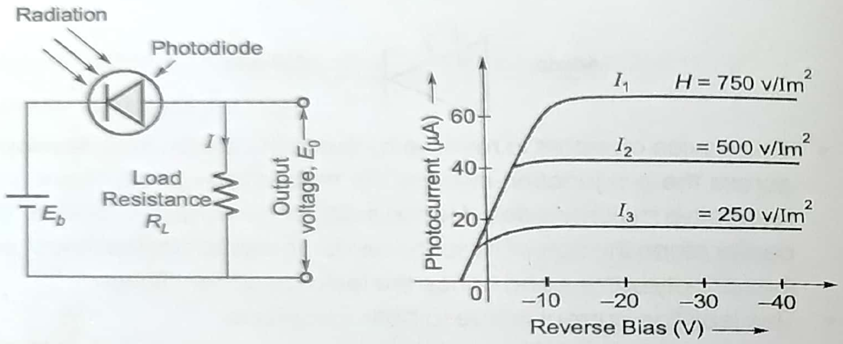
Advantages of photodiode over photoconductors

- Better frequency response
- Linear
- Less Noisy

Disadvantages of Photodiode

- Small active area
- Rapid increase in dark current
- Require amplification at low illumination level

Characteristics of Photodiode



$I_1 > I_2 > I_3$

Photodiode always operates in reverse Bias.

Quantum Efficiency

- The quantum efficiency (η) is defined as the fraction of incident photons which are absorbed by the photoconductor and generate electron which are collected at the detector terminal.

$$\eta = \frac{\text{Number of electrons collected}}{\text{Number of incident photons}} = \frac{R_e}{R_p}$$

where

R_p = incident photon rate (photons/sec)

R_e = electron rate (electron/sec)

Responsivity

$$\boxed{R = \frac{I_p}{P_o}\ (\text{AW}^{-1})}$$

where

R = Responsivity

I_p = Output photocurrent in Amperes

P_o = Incident optical power (W)

$$\boxed{R = \frac{\eta e}{hf} = \frac{\eta e \lambda}{hc}}$$

Current flow through photo dioide (I_p)

$$\boxed{I_p = R \times A \times I}$$

where A = area of photo diode (mm^2)

I = light intensity (mW/mm^2)

Long Wavelength Cut-off

- To built up the leakage current in the photodiode, the energy of the photon must be taken greater than or equal to the energy gap between the valance and the conduction band called band gap (E_g).

$$\therefore \quad h\nu \geq E_g$$

$$\frac{hc}{\lambda} \geq E_g$$

or

$$\lambda \leq \frac{hc}{E_g}$$

So the threshold for the conduction or detection, in commonly called as the long wavelength cut-off point λ_c.

$$\boxed{\lambda_c = \frac{hc}{E_g}}$$

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PHOTO RESISTOR

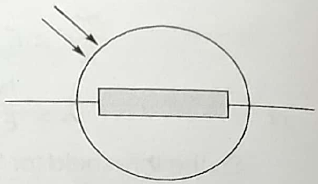
6

Photo-Resistor

- Photo-resistor also called as the LDR (Light Dependent Resistor) is a resistor whose resistance decreases with the increasing incident light. It can also be reffered to as the photoconductor.

Symbol

- In case of photo-resistor the current flow increases with the increase in the irradience. When the light falling on its surface increases, its resistance decrease leading to the increase in the current flow in the circuit.



Dark Resistance

- When the cell is kept in the darkness the resistance is called as the Dark Resistance

$$\boxed{R_t = R_i + (R_f - R_i)\left[1 - \exp\left(-\frac{t}{\tau}\right)\right]}$$

where

R_t = resistance at any time 't' (Ω)

R_i = final resistance after the light is incident (Ω).

R_f = dark resistance (Ω)

Remember:

- The resistance of the photoresistor decreases exponentially with the increase in the illumination on its surface.

Materials used to make Photoresistors are

CdS, CdSe, PbS, PbSe

Sensitivity

- The sensitivity of a photoresistor is defined as: $\boxed{S = \frac{\Delta R}{\Delta H}\ \Omega/\text{W-m}^{-2}}$

  where

  ΔR = Change in resistance (Ω); ΔH = Change in irradiation (W/m^2)

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INTERFERENCE

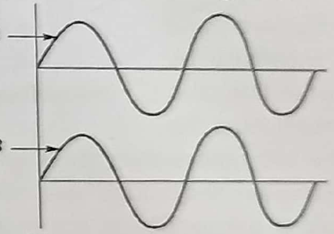
7

Interference

- When two or more light waves superimpose on each other, the resultant wave is produced by adding the two waves algebraically keeping their phase difference into consideration.
- This kind of interaction of the waves in the space leads to the phenomenon called as the intereference.
- The phenomenon of interference leads to the formation of the dark and the bright bands.

Constructive Interference

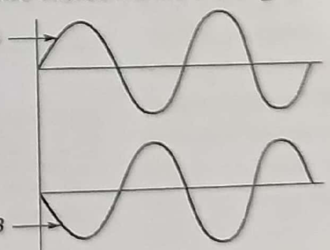
- When the creast of one wave falls on the creast of the other wave and the trough of one wave fall on the trough of the other, the resulting wave well get added up, and hence its brightness will get increased.



$Y = Y_A + Y_B$

Destructive Interference

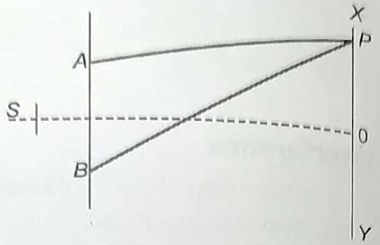
- When the creast one wave fall on the trough of the other and its trough falls on the creast of the other the resulting wave is obtained by the subtraction of two waves hence the brightness gets reduced.



$Y = Y_A - Y_B$

Brightness of the wave is reduced in case of destructive interference.

Path Difference



For maximum intensity at point P.

$\Delta = BP - AP = 2n(\lambda/2) = n\lambda$

For minimum intensity at point P

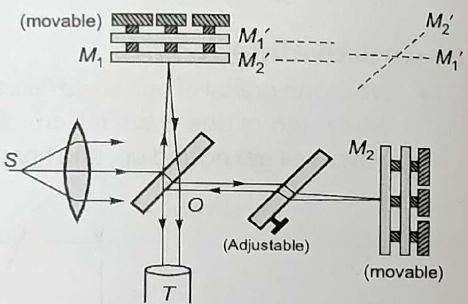
$\Delta = PB - AP = (2n + 1)\,\lambda/2$

where, $n = 0, 1, 2, 3.....$ etc.

Interferometer

- It is a device which is used to produce interference. The device seperate a light beam into two beams and bring them together to produce interference.

Michelson Interferometor



- In michelson interferometer, the amplitude of a light beam comming from an extended source is divided into two parts of equal intensity by partial reflection and transmittance through the mirrors, the two beams then obtained are sent at right angles to each other and are than brough together by reflection through mirrors and focused on a telescope for observation.

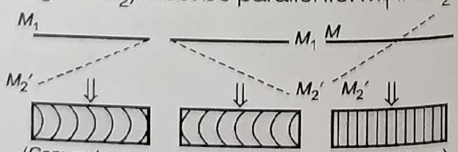
Basic Parts:

1. Monochromatic light source 2. Beam Splitter 3. Two Mirrors

Type of Fringes

(i) **Circular fringes :** For circular fringes to be formed the mirror M_1 and the virtual mirror M'_2 (which is the image of M_2) must be parallel i.e. $M_1 \parallel M'_2$.

(ii) **Localised fringes :** When the M_1 and M'_2 are seperated by distance d, the fringes are as shown in Figure (a), when $d = 0$, the fringes become straight as shown in Figure (c) and beyond this they will become convex to the other side as is shown in Figure (b) These fringes produced can be viewed by a telescope.



(Convex towards thin edge) Figure (a)

(Convex towards thin edge) Figure (b)

(Straight lines) Figure (c)

Application of Michelson Interferometer

(i) Finding the wavelength of monochromatic light

$$n\lambda = 2(\Delta x) = 2(x_2 - x_1)$$

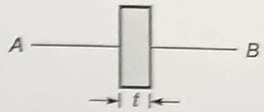
where, n = No. of fringes; λ = Wavelength of monochromatic light

Δx = Micrometer screw movement; x_2 = Final position

x_1 = Initial position

(ii) Calculation of thickness and the refractive index (μ) of any transparent sheet.

(a) 

(b) 

$$n\lambda = 2(\Delta x) = 2t(\mu - 1)$$

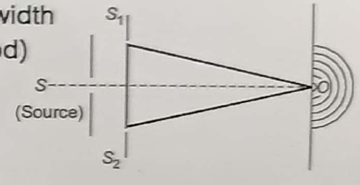
(iii) Resolution of Spectral lines

$$\therefore \quad \boxed{\Delta\lambda = \lambda_1 - \lambda_2 = \frac{\lambda_1\lambda_2}{2x} = \frac{(\lambda_{av})^2}{2x}}$$

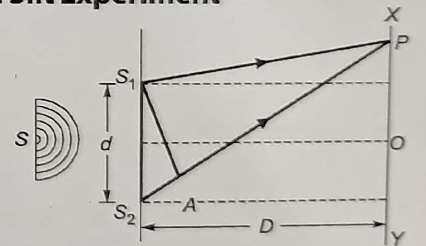
(iv) Calculation of thickness of sheet width by other method. (Young's Method)

$$n\lambda = t(\mu - 1)$$

$$\boxed{t = \frac{n\lambda}{(\mu - 1)}}$$



Young's Double Slit Experiment



Bright fringe

Distance of n^{th} bright fringe from the contral position 'O' is $\boxed{x_n = \frac{D}{d} n\lambda}$

Dark fringe

Distance of n^{th} dark fringe from the contral position 'O' is $\boxed{x_n = \frac{D}{d}(2n+1)\frac{\lambda}{2}}$

Fringe width

- It is denoted by (β). The distance between only two successive bright or dark fringes is called as the fringe width. $\boxed{\beta = \frac{D}{d}\lambda}$

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