* Basic Introduction
* Shannon Channel Capa..
* ~~B~~ Block Diagram of Optical Fib
* ~~Basic~~ Advantage of optical Fibs
* Concepts of Acceptance, critical, ~~NA~~
* Problems of Acceptance, Critical, NA.

* Light propagating in Fiber depends on
  - Mode of propagation
    - Single mode
    - multi mod
  - Index profile of fiber
    - step Index Fiber
    - Graded Index fiber

* Optical Fiber classification
  - SMSI
  - MMSI
  - MMGI

* Comparison of SMSI, MMSI, MMGI
* Problems of MMSI, MMGI, SMSI

* Losses in Fiber
  - Attenuation
    - Intrinsic los
    - Fresnel los
    - Rayleigh scatter
  - Absorption losses
    - material Absorption loss
      - Intrinsic Abso
      - Extrinsic Absorp
  - Scattering losses
    - linear
    - Non-linear
  - Coupling losses
    - lateral alignment
    - Gap misalignment
    - Angular misalignment
    - Imperfect Surface finish
  - fiber bending losses
    - Macroscopic bending
    - microscopic bending loss

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* Shannon's channel capacity:

- In commn network, Imp Factor is channel capacity.

- Channel capacity is the max. rate at which data can b sent across a channel from source to destination

- Shannon - Hartley Theorem : gives the limit to information carrying capacity in bits per secon If channel has bandwidth (B) then the max- info carrying capacity (C) of channel is given by:

$$C = B.W \log_2 (1 + SNR) \text{ bits/sec}$$

SNR is signal to noise ratio.

Effect of S/N on C: If $\frac{S}{N}$ ($N \to 0$) then then $C \to$

Noiseless cha

i.e. capacity will be infinite.

Effect of Bandwidth on C:

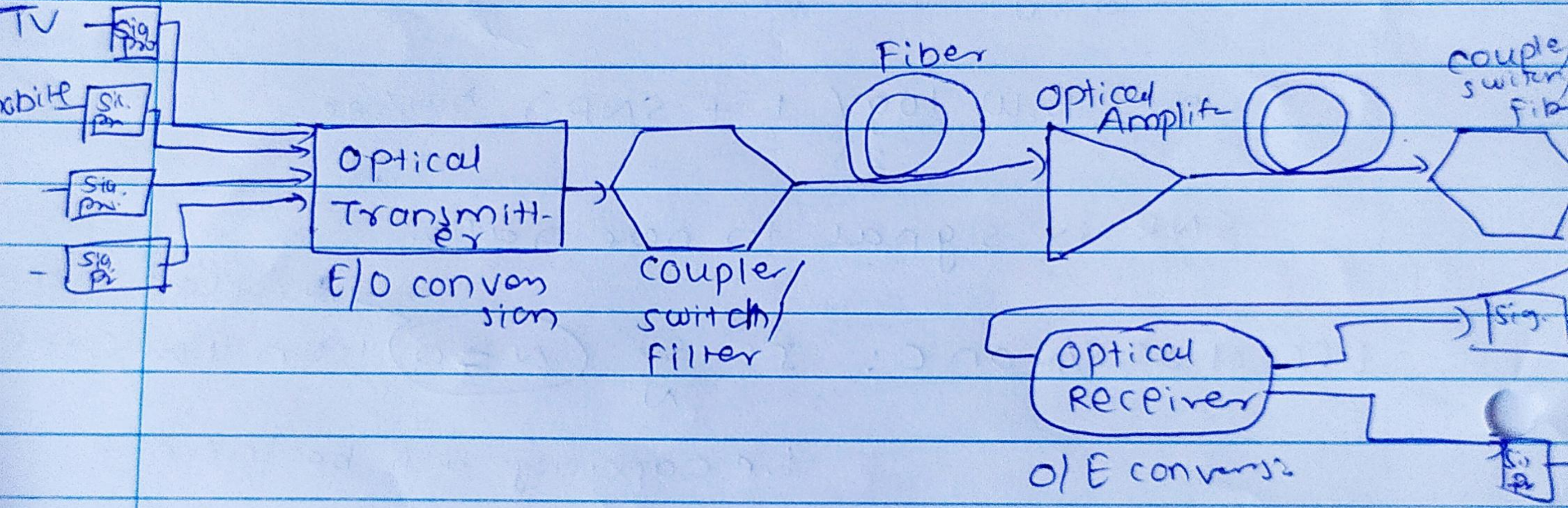
Increasing Bandwith, decreases SNR

Since wider the bandwidth the more noise is introdu

Units:

Peta	Tera	Giga	mega	kilo	Milli	micro	Nano	Pico	Fem
10^{15}	10^{12}	10^{9}	10^{6}	10^{3}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-1}

* Block Diagram For Optical Fiber Communication Link:



E/O conversion → E/O Transducer : LED/ Laser Diodes

O/E conversion → O/E Transducer : Photodiodes.

optical Amplifer → semiconductor/ Doped Fiber/ Raman

coupler/ switch/ Filter : All-optical, depends on net$^{\omega}$.

1. Source :
- source generates the info to send towards receiver
- output is a electrical signal.

2. Optical Transmitter :
- The info. fed to transmitter is electrical in nature But optic cable can only transmit optical signals.
- Therefore it is necessary to convert electrical to optical signal.
- This conversion done by electrical to optical ~~transducers~~ transducers like LED and LASER

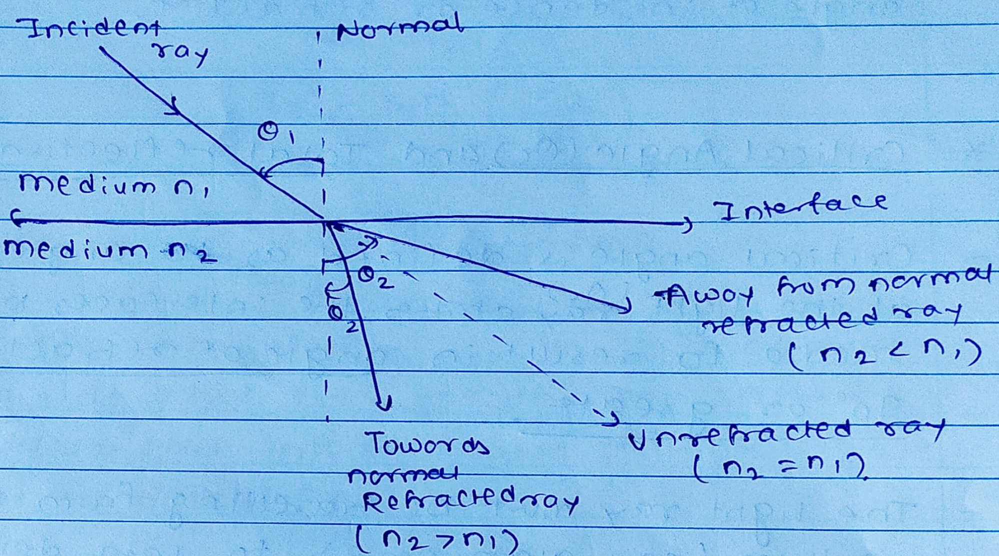
3. Filters :
- Filters are used to route the some of signal to the some of the networks.

4. Fiber :
- The optical fiber cable is used to transmit the information from transmitter to receiver
- The cable generally consists of several cylindrical glass fibers.
- installed under sea or underground
- 0.2 dB/km attenuation.

5. Amplifier :
- To boost the power to transmit information to long distances, amplifier are used.
- semiconductor / Doped fiber / Raman Amplifiers are used ~~to~~ to amplify the optical signal.

* Snell's law:

- Let 'n_1' and 'n_2' be the refractive indices of two mediums and let θ_1 and θ_2 be the angle of incidence and refraction resp.



- Snell's law explains the behavior of light rays striking the interface of two materials with diff. refractive indexes.

- The statement of Snell's law tells that the product refractive index by sine angle of incidence is constant for any ray of light striking the ~~sepo~~ surface of two media.

- $$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

- As ~~refractive index is equal to sqaure root of di~~ constant, the snell's law can be.

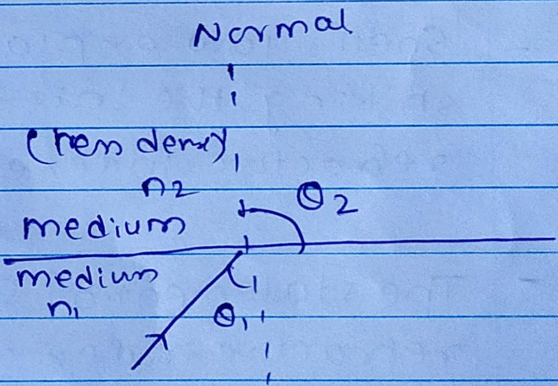
$$\frac{\sin \theta_1}{\sin \theta_2} = \sqrt{\frac{\varepsilon_{r_2}}{\varepsilon_{r_1}}}$$

- This law is used in ray tracing to compute angle of incidence or refraction.

Critical Angle (θ_c) and Total reflection:

- Critical angle (θ_c) is defined as the angle of incidence at the light ray strikes the interfaces betw two media to result in angle of refraction θ_2 of 90° or greater.

- The light ray must be travelling from more dense medium (say glass core) to less dense medium (glass cladding).



Total reflection:

If the angle of incidence is greater than or equal to the critical angle, the angle of refraction will be 90° or greater. Hence the light ray cannot penetrate the less dense medium (cladding). Therefore, total reflection takes place at interface of glass core and cladding with the angle of refraction equal to angle of incidence.

Snell's law :

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

when $\theta_2 = 90^\circ$.

$$n_1 \sin\theta_c = n_2 \sin 90^\circ$$

$$\therefore \sin\theta_c = \frac{n_2}{n_1}$$

$$\boxed{\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)}$$

* Acceptance angle ($\theta_{in(max)}$):

- Acceptance angle $\theta_{in(max)}$ is the maximum angle at which the light ray can strike the air/glass core interface and still propagate down the optical fiber.

- It is the maximum value of external angle of incidence.

- The external angle of incidence θ_{in} must be less than the acceptance angle for successful travel down the optical fibre.

$$\theta_{in(max)} = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$$

• Relationship betw $\theta_{in(max)}$ and θ_c :

Critical angle θ_c – minimum value of angle of incidence.

Acceptance angle $\theta_{in(max)}$ – maximum value of angle of incidence.

If the light ray strike the glass core / cladding interface at an angle θ_{in} which is greater than the acceptane angle, then ray will be refracted into claddinge.

Numerical Aperture (N.A):

- It is defined as the sine of the acceptance angle $\theta_{in(max)}$ and it is unit less quantity. Its value ranges betw -1 to +1.

$$N.A = \sin \theta_{in(max)}$$

Expression for N.A:

$$N.A. = \sqrt{n_1^2 - n_2^2}$$

$$N.A. = \sqrt{(n_1 - n_2)(n_1 + n_2)}.$$

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

Let the diff betw n_1 and n_2 be very small.

Then, $n_1 + n_2 = 2n_1$.

$$\therefore N.A. = \sqrt{(\Delta n_1)(2n_1)}$$

$$= (\Delta 2 n_1^2)^{1/2}$$

$$\therefore N.A = n_1 (2\Delta)^{1/2}$$

$\Downarrow$

Tells us that N.A is dependent only on refractive index of core and cladding.

Expression for Δ:

$\therefore \sqrt{n_1^2 - n_2^2} = n_1 (2\Delta)^{1/2}$

$\therefore n_1^2 - n_2^2 = n_1^2 (2\Delta)$

$\therefore \Delta = \dfrac{n_1^2 - n_2^2}{2 n_1^2}$.

Imp. of NA:

1. It is figure merit of N.A.
2. Used to measure the magnitude of accept. angle.
   $\theta_{in(max)} = \sin^{-1}(N.A)$
3. Describes the light collecting ability of ~~fibre~~ optical fibe.
4. The amount of light can be accepted by optical fiber increases with increase in N.A
5. N.A does not depend on diameter of fiber core but in practice, the large core fibers tend to have larger value of N.A.

1. $n_1 = 1.56$, $n_2 = 1.35$, $\theta_c = ?$, $\Delta = ?$, $N.A. = ?$, Accep = ?

$\Rightarrow$ $\theta_c = \sin^{-1}\left(\dfrac{1.35}{1.56}\right) = 59.93^\circ$

$\Delta = \dfrac{(1.56)^2 - (1.35)^2}{2 \times (1.56)^2} = 0.125 = 12.5\%$.

$N.A = \sqrt{1.56^2 - 1.35^2} \doteq 0.78$

$\theta_{in(max)} = \sin^{-1}(N.A) = \underline{51.26^\circ}$

* Types of modes in optical fiber:

1. Cladding modes: modes corresponding to light rays passing through cladding layer.

2. Bottom modes: modes travelling through the core layers of waveguide.

3. Refracted modes: modes generated because of refraction of light at core-cladding surface.

4. Leaky modes:
While passing through core layer some of the modes continuously loose their energies. These modes are leaky modes.

Condⁿ for optical mode:

- To remain a mode as guided mode, following condition should be satisfied:

$$n_2 k < \beta < n_1 k.$$

β = propagation factor
k = propagation constant $= 2\pi/\lambda$.

- Cut-off condⁿ is boundary betʷ guided and leaky mode. ($\beta = n_2 k$).

- Leaky modes starts when β becomes less than $n_2 k$.

mode	cond^n
Guided	$n_2 k < \beta < n_1 k$
cutoff	$\beta = n_2 k$
Leaky	$\beta < n_2 k$

* Light propagating in fiber depends on

mode of propagation

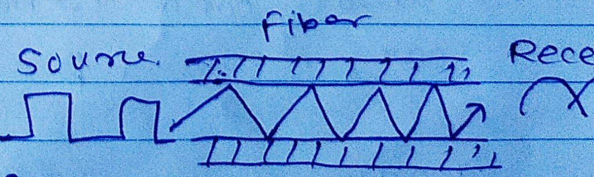
Index profile of fiber

1. Mode of propagation:
- path followed by light rays inside the fiber
- Two types: Single mode and multimode fibers

• Single Mode Fibers:

- The optical signal entering from one end of fiber has only one path to follow, that is along the centre of fiber
- A highly focused light beam is produced, and it travels almost horizontally as shown in fig.
  The critical angle is close to 90°.
- Delays are negligible, reconstruction is easier

• Multimode Fibers:



- The optical signal entering from one end of fiber has more than one path to follow.

- multiple beam will follow diff. zigzag path as shown in Fig.
- no. of reflection depends on angle of incidence of beam.
- all beam do not reach simultaneously.

* IMP Formula:

The no. of modes supported by multimode fiber

$$M = \left(\frac{\pi d}{\lambda}\sqrt{n_1^2 - n_2^2}\right)^2$$

d = diameter (in meters)

λ = wavelength of light ray

m = no. of modes.

* Comparision of ~~rous~~ Single and Multi mode fiber

		Single Mode	Multimode
1.	No. of modes	only one	more than one
2.	Shape of path	straight along axis of core	zigzag.
3.	Distortion	less than multi mode	more than single mode
4.	Bandwidth	High	Low.
5.	Data rate	Higher than multimode	lower than single mode
6.	Application	wideband long haul transmission	For narrowband short distance transmission

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2. Index profile of Fiber :

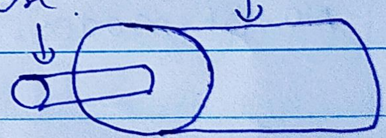
- Index profile is graphical representation of magnitude of refractive index on X-axis and radial distance from core axis on Y-axis.
- It tells us about the change in refractive index and nature of variation in refractive index with respect to radial distance.

- Types : Step Index and Graded Index.

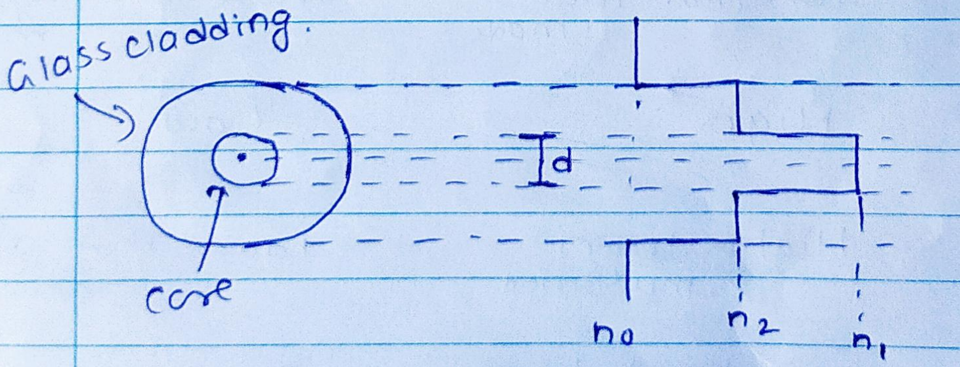
a. Step Index Fibers :
- The optical fibers in which there is an abrupt change in refractive index at the core-cladding interface

- Types : Single mode step Index, Multimode step Index.

• Single mode step Index :
- The construction of SMSI is shown.

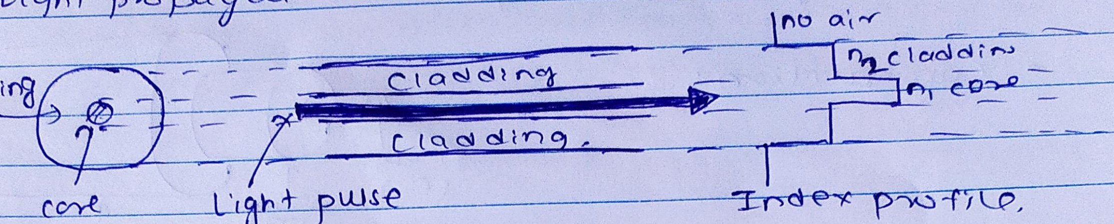


- Index profile :



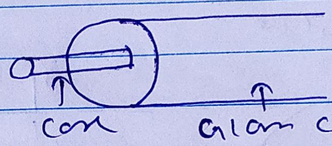
refractive index of core — n_1
refractive index of cladding — n_2
$\therefore n_1 > n_2$

Light propagation in SMSI is shown below:



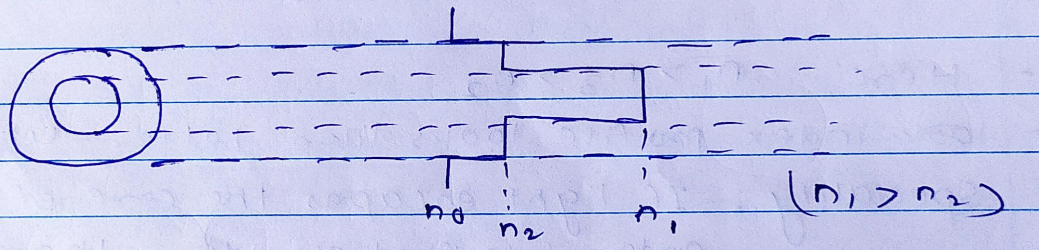
Multimode step Index Fibers:

Construction:



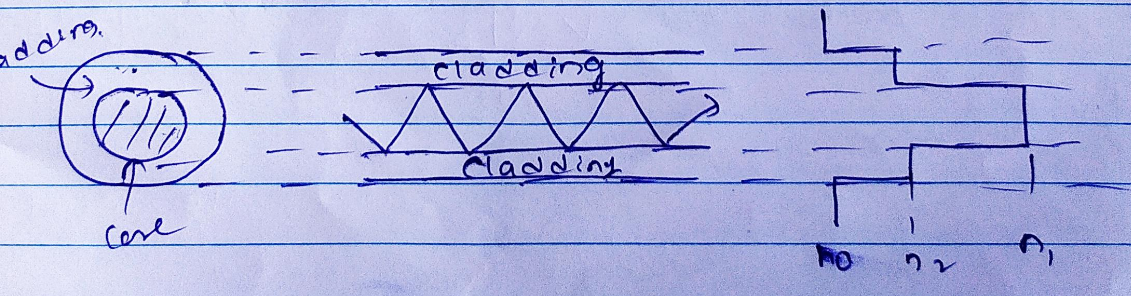
consists of glass core and cladding.
The diameter of core is much larger than ~~to~~ compared to single mode step index fibe.

Index profile:



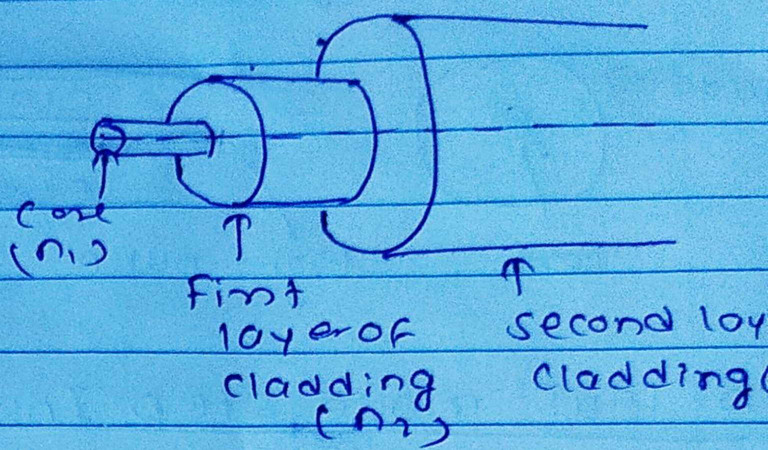
$(n_1 > n_2)$.

Propagation of ligh.

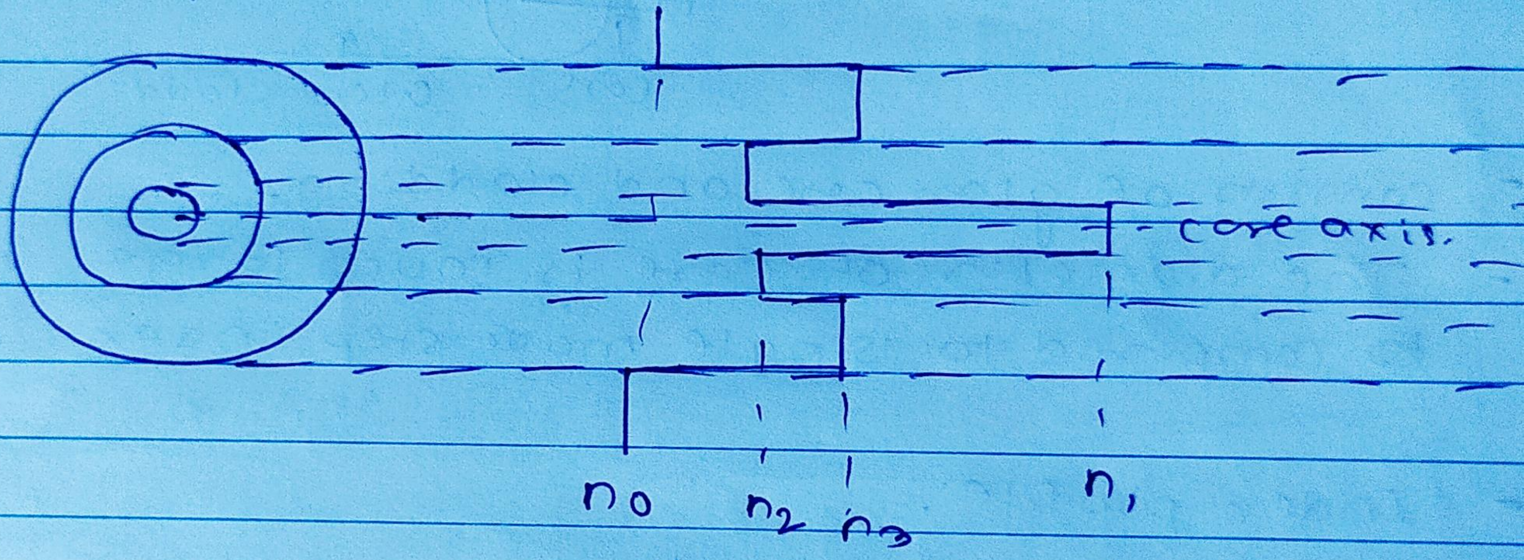


c. Index profile of W-profile fibe:

- Construction:



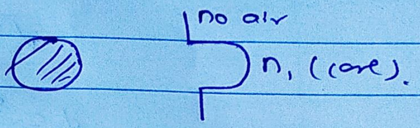
- Index profile



- Here, $n_1 > n_3 > n_2$.
- ~~look~~ index profile looks like letter - W.
- Speciality: If light escapes the core of fibe enters into first cladding then it is completely absorbed in second cla
  This is become $(n_3 > n_2)$.

2. Graded Index Fibers:

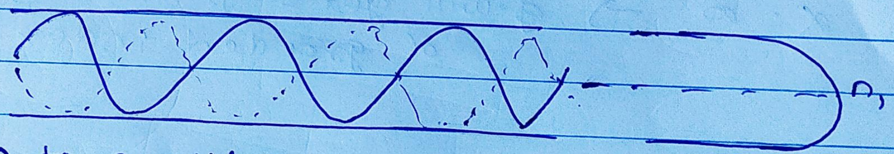
- In this type, the refractive index of fiber core does not remain constant throughout its bulk. But it's non-uniform.



- The refractive index of core is max. at the center of core and reduces gradually towards the walls of core.

- To get this type of index profile, the material in fiber core is modified.

- Propagation of light:



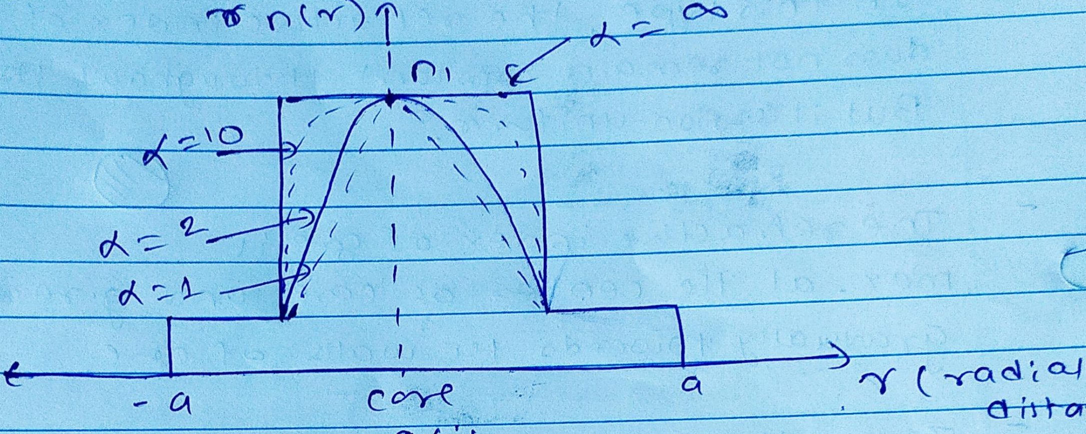
- Due to modification in index profile, the light gets refracted inside fiber core and does not travel in straight line.
- The rays are curved towards the center.

- The refractive index variation in core is,

$$n(r) = \begin{cases} n_1 \sqrt{1 - 2\Delta \left(\frac{r}{a}\right)^{\alpha}} & \text{when } r \le a \text{ (co} \\ n_1 \sqrt{1 - 2\Delta}, \approx n_2 & \text{when } r > a \text{ (cla} \end{cases}$$

α = Shape of index profile, a = Radius of core
r = Radial distance from fiber axis.

Shape of refractive index profile changes with change in value of α.



$\alpha = 1 \rightarrow$ refractive index profile is triangular.

$\alpha = 2 \rightarrow$ It is parabolic

$\alpha = \infty \rightarrow$ will get step index profile in of graded index profile.

	Parameter	Step Index	Graded Index
1.	Change in refractive index	refractive index changes abruptly.	refractive index changes gradually from centre to edge.
2.	Path travelled by light rays	Straight line or zigzag path	Curved paths.
3.	Phenomenon resp for light pro.	Reflection	Refraction.
4.	Size of acceptan. cone.	Smaller than graded index.	Larger than step index fiber.
5.	Index profile.		

* Optical Fiber classification:
1. Single Mode Step index.
2. Multimode step Index.
3. Multimode graded Index.

1. SMSI Fiber:
   - with air cladding
   - with glass cladding

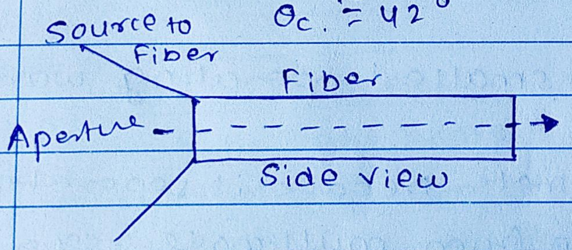
• SMSI fiber with air cladding:
- type of single mode step index fiber, there is no glass clading used.
- outside cladding is air, with ($n_2 = 1$) and refractive index of glass core is ($n_1 = 1.5$).

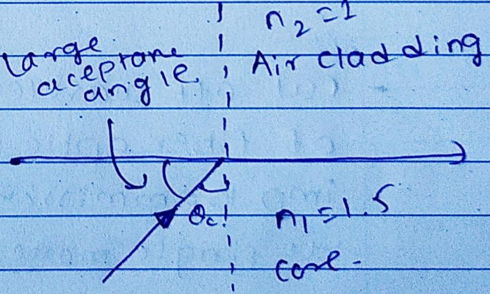
- Critical angle θ_c is defined as,

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

$$= \sin^{-1}\left(\frac{1}{1.5}\right)$$

$\theta_c \simeq 42^\circ$

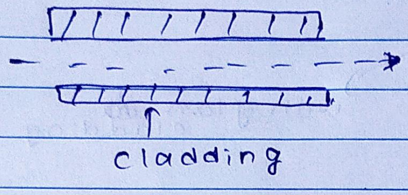


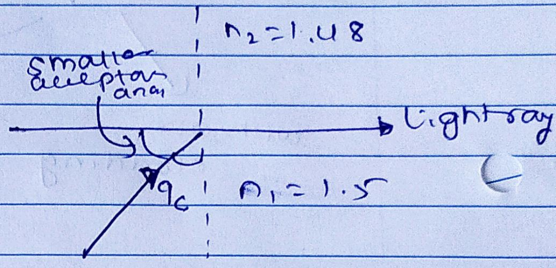


- The large acceptance angle makes easy for the light source to couple light into optical fiber.
- very weak.

SMSI fiber with glass clading:

Here, glass clading is present.
The refractive index of core is $n_1 = 1.5$ and that of $n_2 = 1.48$. (glass cladding).





$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) = \sin^{-1}\left(\frac{1.48}{1.5}\right) = 80.63^\circ.$$

Critical angle (θ_c) is higher than that of single mode air cladding.

~~no~~ difficult to couple light source.

Propagation modes in single mode step Index Fiber:

Cut-off wavelength (λ_c):

cut-off wavelength is smallest operating wavelength of fiber optic cable.
Imp transmission parameter because it separates the single mode region from multimode region

V-number is given as,

$$V = \frac{2\pi a}{\lambda}\left(\sqrt{n_1^2 - n_2^2}\right)$$

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$$V = \frac{2\pi}{\lambda} a \left(n_1 (2\Delta)^{1/2}\right) \quad -(1)$$

$$\lambda = \frac{2\pi}{V} a \left(n_1 (2\Delta)^{1/2}\right) \quad -(2)$$

cut-off wavelength is,

$$\lambda_c = \frac{2\pi}{V_c} a \left(n_1 (2\Delta)^{1/2}\right) \quad -(3)$$

$V_c \rightarrow$ cut-off normalized freq.
[$\therefore V_c = 2.405$]

Dividing (3) and (2)

$$\frac{\lambda_c}{V} = \frac{\lambda}{V_c}$$

$$\lambda_c = \frac{V\lambda}{V_c}$$

$$\boxed{\lambda_c = \frac{V\lambda}{2.405}} \quad (V_c = 2.405)$$

$\Downarrow$

Expression for cut-off wavelength of SMSI fi

2. Mode Field Diameter (MFD):

- Mode Field diameter is section of fiber where the most of the light energy travels.
- Value of MFD is larger than actual diameter of co
This happens because some of light rays travels thr cladding.
-

Multimode Step Index (MMSI) Fiber:

Relation betʷ No. of modes (m) and 'V' number

$$\sin \theta_{in(max)} = \sqrt{n_1^2 - n_2^2}$$

$\theta_{in\,max}$ is small,

$$\sin \theta_{in\,max} = \theta_{in(max)}$$

$$\varepsilon = \pi \sin^2 \theta_{in(max)}$$

$$\varepsilon = \pi \theta^2_{in\,max}$$

$$\theta_{in\,max} = \sqrt{n_1^2 - n_2^2}$$

$$\varepsilon = \pi (n_1^2 - n_2^2)$$

$$A = \pi a^2$$

$$\cancel{m = \left[\frac{\pi a}{\lambda}\right]^2 (n_1^2 - n_2^2)}$$

no. of mode per unit solid angle is

$$m = \frac{2A}{\lambda^2} \varepsilon$$

$$m = \frac{2A}{\lambda^2} \pi (n_1^2 - n_2^2)$$

$$m = \frac{2 \cdot \pi^2 a^2}{\lambda^2} (n_1^2 - n_2^2)$$

$$n_1^2 - n_2^2 = (NA)^2$$

$$m = \frac{2\pi^2 a^2 (NA)^2}{\lambda^2} \qquad v = \frac{2\pi}{\lambda} a (NA)$$

$$\boxed{m = \frac{v^2}{2}}$$

Adv.

1. less expensive.
2. easy to manufacture.
3. easy to couple light

Disadv.

1. received light pulse is distorted.
2. ~~less~~ less bandwidth.
3. lower data rate.

Graded Index:

Due to non-uniform density of core, the light ray with $\theta_i > \theta_c$ will progressively refracted towards the centre of core, and does not travel in straight line

$v \propto \frac{1}{n}$ ⟹ velocity of light max at farthest from ce
min at travel close to center.

rays take same amount of time to reach at end, received light pulse is replica, small amount of distortion.

no. of guided modes is given by

$$m = \left(\frac{\alpha}{\alpha+2}\right)(n_1 k a)^2 \Delta$$

$$k = \frac{2\pi}{\lambda}, \quad V = \frac{2\pi}{\lambda} a n_1 \sqrt{2\Delta}$$

$$\therefore m = \left(\frac{\alpha}{\alpha+2}\right)\left(\frac{V^2}{2}\right)$$

at $\alpha = 2$

$$\boxed{m = \frac{V^2}{4}}$$

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Adv :-
1. less expensive.
2. easy to man.
3. easier to couple light than MMSI, difficult than SMSI.

Disadv :-
1. Distortion more than SMSI, less than MMSI.
2. MMGI fiber cable offer less bandwidth than SMSI
3. support lower data rates than SMSI cable.

* Comparsion :

	SMSI	MMSI	MMGI
no. of. paths	one	many	many
Distortion	less than both	more than SMSI, MMGI	less than MMSI.
Bandwidth	High	Low	lower than SMSI
Data rate	High	low than SMSI	low than SMSI
cost	High	less	less
phen. resp for propagat	Reflect	Reflect	Refracti
Ease of manufact	Difficult	Easy	Easy
	Wideband	Narrow band	Narrowband

DD.

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* Transmission Characteristics of Optical Fibers *

Attenuation.

- power loss taking place inside the fiber optic cable.
- amplitude gets reduced.

Attenuation → Intrinsic, Fresnel, Rayleigh scattering loss.

1. Intrinsic loss:
- scattering takes place at boundary of core and cladding layer.
- This scattering reduces power of signal.

2. Fresnel loss:
- due to change in refractive index at interface of core and cladding layer, Fresnel loss takes place

3. Rayleigh scattering loss:
- causes due to submicroscopic variation in density of glass while manufacturing process.
- The impurities inside the glass act as reflecting and refracting centers.
- This power loss resulting due to scattering is called "Rayleigh Scattering loss".
- Improved manufacturing techniques can reduce loss.

- Expression for power loss:

$$\boxed{A(dB) = 10 \log_{10}\left(\frac{P_{in}}{P_{out}}\right)}$$

- attenuation in multimode fibers tends to be higher than single mode fibers

- Att. coefficient in dB per km is given by,

$$\boxed{A = \frac{10}{D} \log\left[\frac{P(0)}{P(D)}\right]}$$

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* Material absorption loss:

- cause :- defects in fabrication process of fiber optic cable.
- Transmitted light is dissipated as heat. This is called material absorption loss.

Factors contributing:

1. Intrinsic absorption due to atoms of fiber mater
2. Extrinsic absorption due to impurity atoms.
3. Absorption due to atomic defects in glass material.

Intrinsic absorption

Ultraviolet absorp. | Infrared absorp. | Ion resonance absorp.

1. Ultraviolet absorp:

- energy of light rays is given out to valence electrons of silica material used for manufac. of glass.
- The absorption of silica material increases in ultraviolet region. ∴ called as ultraviolet absorption.
- The absorption is of order of 0.1 dB/km.

2. Infrared absorp.:-

- If wavelength of light rays in infrared region, then phot of light are absorbed by atoms in glass.
- The energy is converted to mechanical vibrations. Called as infrared absorption.

3. Ion resonance absorption:

- During manufacturing, the water molecule are trapped in the glass. This molecules produce OH^- ions in material.
- The absorption associated with ~~water~~ water molecules is called Ion resonance absorption.

formulae

① $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$.

② $N.A. = \sin\theta_{in(max)} = \sqrt{n_1^2 - n_2^2}$
$= n_1(2\Delta)^{1/2}$

③ $\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$

④ $\theta_{in(max)} = \sin^{-1}(N.A) = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$
$= \sin^{-1}\left(n_1(2\Delta)^{1/2}\right)$.

⑤ Solid Acceptance angle.
$\mathcal{E} = \pi \sin^2\theta_{in(max)}$.
$\mathcal{E} = \pi\,(N.A)^2$.

⑥ $U = \sqrt{k_0^2 n_1^2 - \beta^2}\, a$, $\omega = \sqrt{(\beta^2 - k_0^2 n_2^2)}\, a$

$V = \sqrt{U^2 + \omega^2} = \frac{2\pi}{\lambda}\, a\, \sqrt{n_1^2 - n_2^2}$

Normalised waveguide parameter / V-number

$= \frac{2\pi}{\lambda}\, a\, (N.A) = \frac{2\pi}{\lambda}\, a\, n_1(2$

As V-number increases, the modes supported by fiber increases.

Single mode Fiber : $V_c = 2.4048$
$\therefore (0 < V < 2.4048)$

(7) No. of. modes in MMSI :

$$m = \left(\frac{\pi d}{\lambda}\right)^2 (n_1^2 - n_2^2)$$

$$m = \frac{V^2}{2}$$

(8) No. of. modes in MMGI :

$$m = \left(\frac{\alpha}{\alpha+2}\right)(n_1 k a)^2 \Delta, \quad \left(k = \frac{2\pi}{\lambda}\right)$$

$$m = \frac{V^2}{4}$$

(9) Step index mode :

$$m = \frac{V^2}{2}$$

(10) Optical power that flows in cladding is,
(Total percent of power flowing through cladding)

$$\frac{P_{clad}}{P} = \frac{4}{3\sqrt{m}}$$

P_{clad} = power in cladding
P = Total power
m = no. of. modes

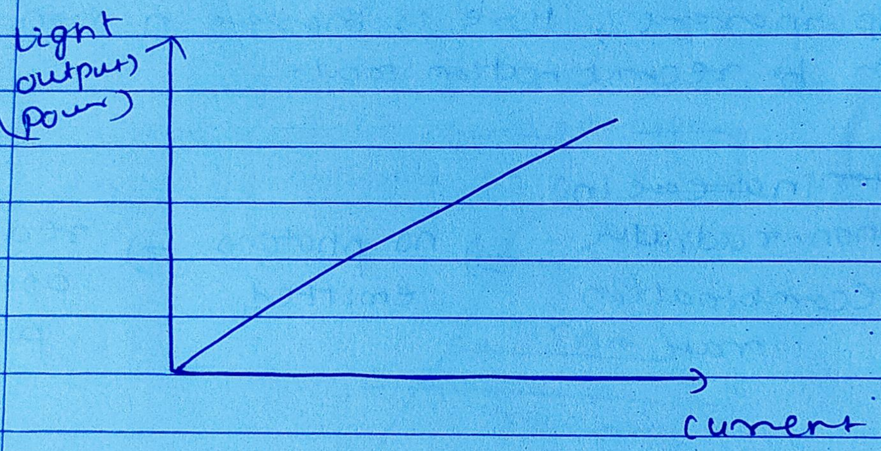
$$\eta_{ext} \approx \frac{1}{n(n+1)^2}$$

Power emmit from LED.

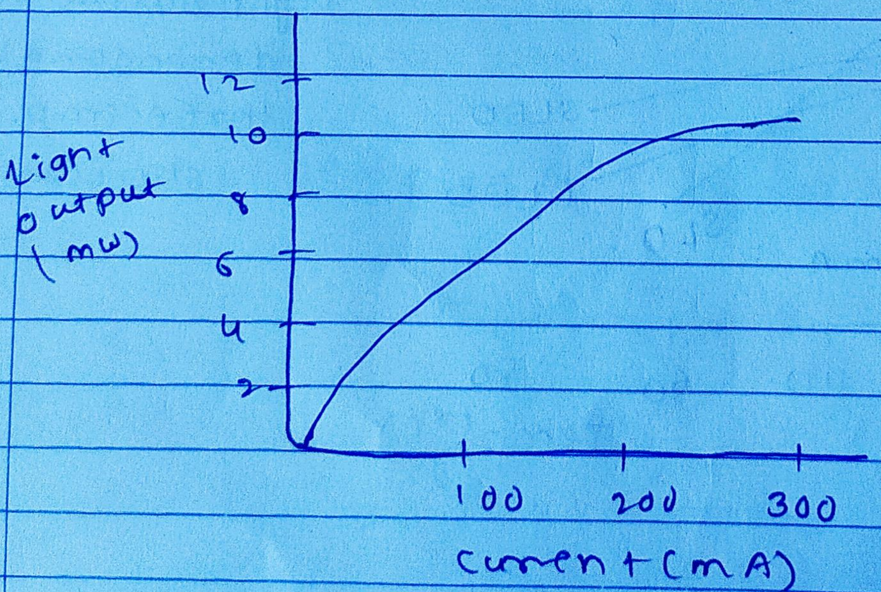
$$P = \eta_{ext} P_{int} = \frac{P_{int}}{n(n+1)^2}$$

* Power characteist

Ideal:

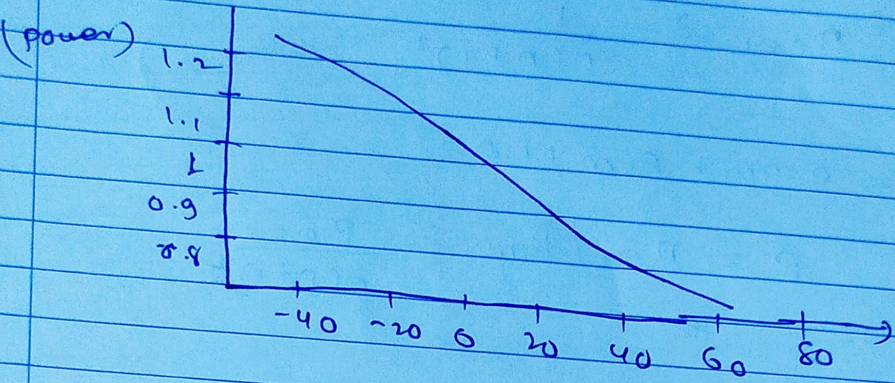


- The ideal output against current characteristics for



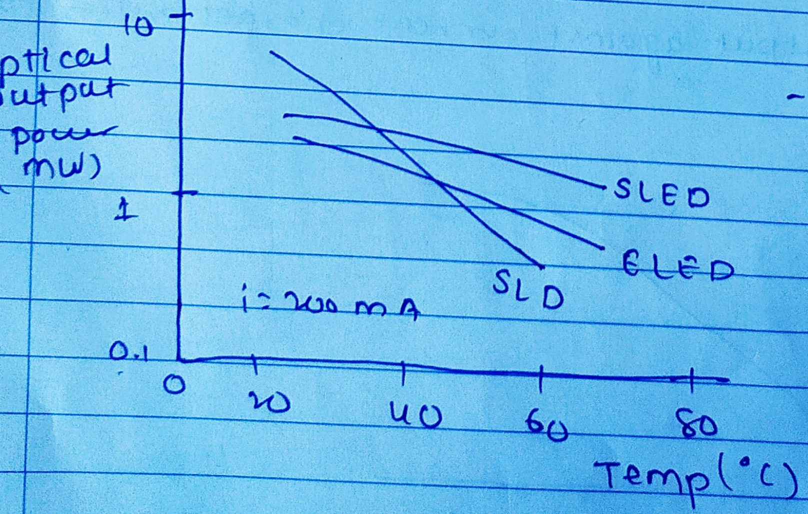
(A I Ga As surface emitter characteristic)

P vs Temp characterstics



- Power is inversely prop. to temp.
- decreases with increase in temp.
- As temp increases, there is increase in non-radiative recombination rate.

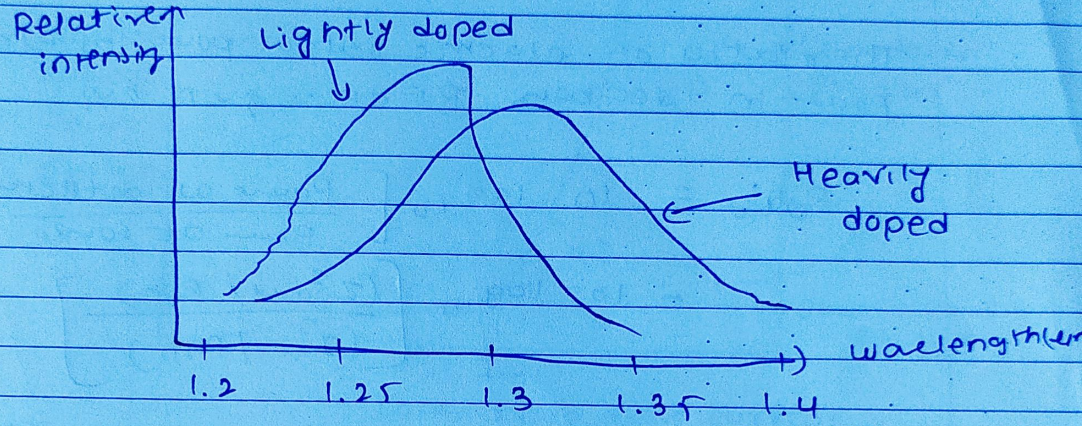
~~reduction~~ increase in non-radiative recombination rate ⟹ no photons emitted ⟹ reduce optical power



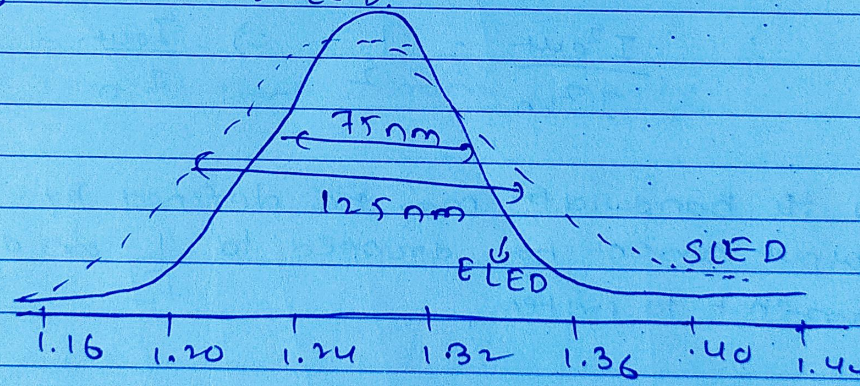
- Light output-temp dependence is three imp. LED structures.

* Spectral width:

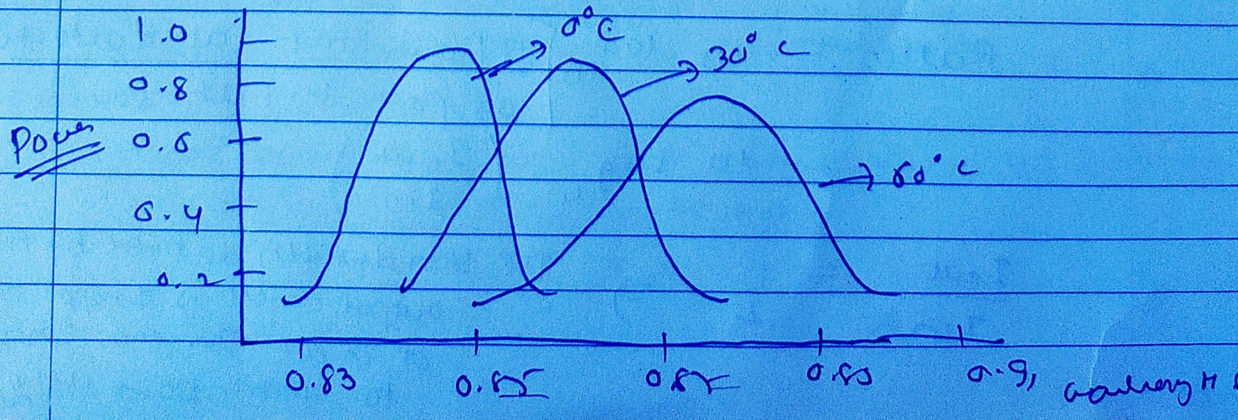
- output spectra for InGaAsP for both lightly doped and heavily doped.



- Spectral output characteristics for InGaAsP surface-edge-emitting LED.



- Effect of temp. on AlGaAs surface-emitting LED



* Modulation Bandwidth:

1. Electrical Bandwidth: Freq. at which the output power is reduced by 3 dB w.r.to. input electric power.

- The ratio of electric output power to electric input power in decibels R_{EdB} is given by:

$$Ratio = 10 \log_{10}\left[\frac{\text{Power at detector}}{\text{Power at source}}\right]$$

$$= 10 \log_{10}\left[\frac{(I^2_{out}/R_{in})}{(I^2_{in}/R_{in})}\right]$$

electrical dB point occurs when ratio of power is $\frac{1}{2}$.

$$\therefore \frac{I^2_{out}}{I^2_{in}} = \frac{1}{2} \Rightarrow \frac{I_{out}}{I_{in}} = \frac{1}{\sqrt{2}}.$$

So the bandwidth may be defined by freq. when output current has dropped to $\frac{1}{\sqrt{2}}$ or 0.707 of input current to system.

2. Optical Bandwidth: The freq where detected power becomes half of its low freq. value.

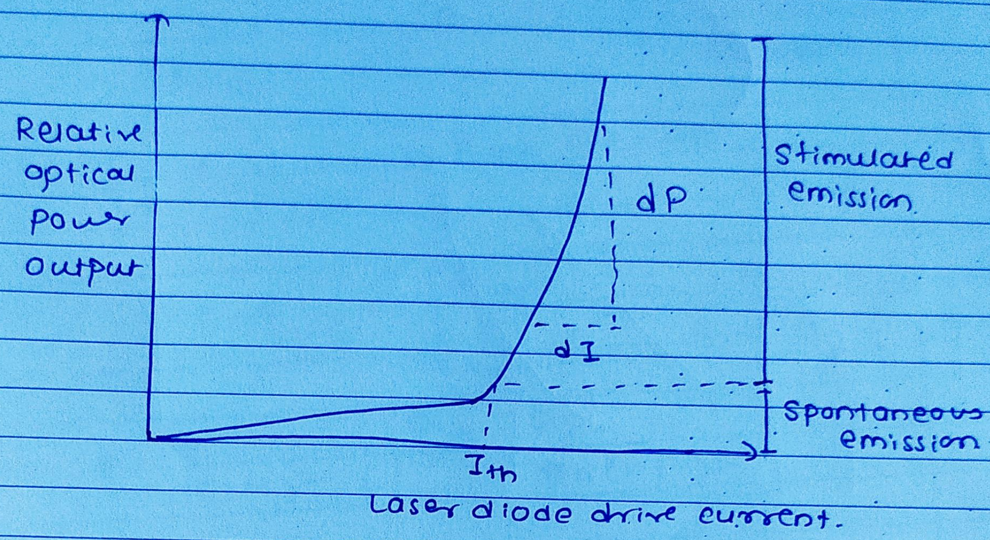
$$Ratio = 10 \log_{10}\left[\frac{\text{op. Power out (at detector)}}{\text{op. power in (at source)}}\right]$$

$$= 10 \log_{10}\left(\frac{I_{out}}{I_{in}}\right)$$

$$\frac{I_{out}}{I_{in}} = \frac{1}{2} \Rightarrow$$ The Bandwidth defined by freq w[illegible] output current is dropped to [illegible] of input ~~current~~ corresp[illegible] to electric power att of [illegible]

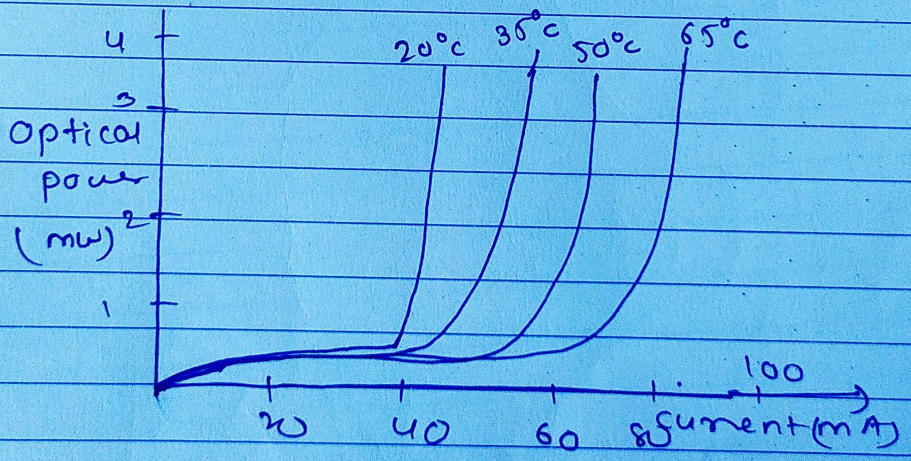
~~LED along transmitter.~~

* Power characteristics of LASER.



- ~~As show~~ The fig. above shows relationship between optical output power and laser diode drive current.

- After I_{th}, the power increases lineerly.



- Optical power of laser at const value of cu varies with change in temp.

Unit 2 - Formulas

* Efficiency of LED:

$$\eta_{int} = \frac{R_r}{R_r + R_{nr}} \quad , \quad \eta_{int} = \frac{\tau}{\tau_r}$$

$$\frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_{nr}} \Rightarrow \text{Bulk lifetime.}$$

$$\boxed{R_r = \eta_{int} \frac{I}{q}} \qquad \boxed{P_{int} = \frac{\eta_{int} \times h \times c \times I}{q \times \lambda}}$$

$$\boxed{\eta_{ext} = \frac{1}{n(n+1)^2}} \qquad \boxed{P = \frac{P_{int}}{n(n+1)^2}}$$