Laser Physics Easy Notes

Notes

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typeset with LaTeX

LASER Physics – B

- UNIT 1
  MODULALION OF LIGHT
- UNIT 2
  OPTICAL SOURCE AND DETECTORS
- UNIT 3
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The Electo-optic Effect

#Electro-optic Effect-

Light propagation through Isotropic and Anisotropic Medium. When light propagate through Anisotropic media, we found that, in general, the state of polarization of the light beam may change as it propogates through this medium. If light propagate through crystels in the presence of External electric Field, it alter the refrective index of the crystel and thus byfringence induces. This Effect is known as Electro-optic Effect.

When an $\vec{E}$ is applied across an optical medium, the distribution of e- within it is distorted so that the polirizability and hence the refrective index of the medium changes anisotropically.

The change in refrective index as a function of the applied Field can be obtained from an equation of form

$$\Delta\left(1/n^2\right) = \underbrace{r E}_{\text{Pocket Effect}} + P E^2$$

(r → Linear cofficient; $P E^2$ → Kerr Effect, P ↳ quardratic cofficient)

Pocket effect, the precise effect of the applied $\vec{E}$ depends on the crystel structure and symmetry of the material under consideration.

Thus

$$\Delta\left(\frac{1}{n^2}\right) = -\frac{2\Delta n}{n^3} = r_{63} E_z \qquad \left(\because \begin{array}{l} n_x = n_o + \frac{n_o^3}{2} r_{63} E_z \\ n_y = n_o - \frac{n_o^3}{2} r_{63} E_z \end{array}\right) \quad \ldots\ldots (1)$$

Kerr Constant P was very small where r_{63} is appriciate electro-optic Effect cofficient in KDP

Let us consider a beam of plane polarized light propagating in z direction through a crystal such as KDP with a plane of polarization at 45° to the induced axes x', y' as.

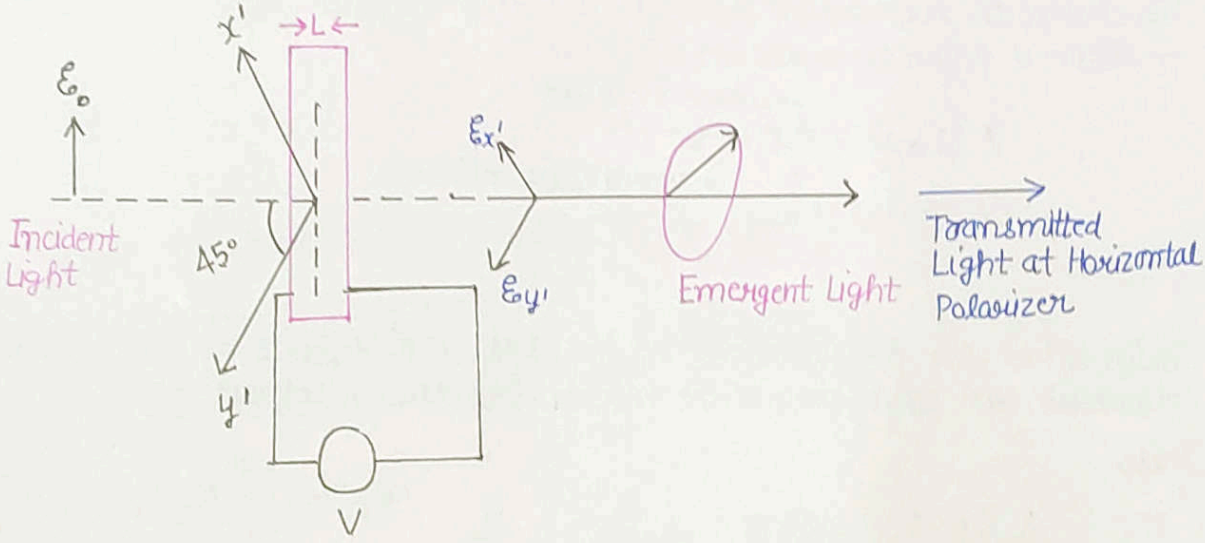
If the incident beam

$$\mathcal{E} = \mathcal{E}_0 \cos(\omega t - Kz)$$

$$\mathcal{E}_x = \frac{\mathcal{E}_0}{\sqrt{2}} \cos(\omega t - Kz)$$

$$\mathcal{E}_y = \frac{\mathcal{E}_0}{\sqrt{2}} \cos(\omega t - Kz) \qquad \ldots\ldots\ldots\ldots (1)a$$

Thus If a crystal of L thickness, the phase change of the two components will be



The induced birefringence occurs in a plane normal to the applied $\vec{E}$.

$$\phi_{x'} = \frac{2\pi}{\lambda_0} n_{x'} L$$

$$\phi_{y'} = \frac{2\pi}{\lambda_0} n_{y'} L$$

use eq^n(1)

$$\phi_{x'} = \frac{2\pi}{\lambda} L n_0 \left(1 + \frac{1}{2} r n_0^2 \mathcal{E}_z\right)$$

$$\phi_{y'} = \frac{2\pi}{\lambda_0} L n_0 \left(1 - \frac{1}{2} r n_0^2 \mathcal{E}_z\right) \qquad \ldots\ldots (1)b$$

$$\phi_{x'} = \phi_0 + \Delta\phi_0$$

$$\phi_{y'} = \phi_0 - \Delta\phi_0$$

Where

$$\Delta\phi_0 = \frac{\pi}{\lambda_0} L r n_0^3 \mathcal{E}_z = \frac{\pi}{\lambda_0} r n_0^3 V \quad \ldots\ldots\ldots (2)$$

In eq^n(2), we have taken $\mathcal{E}_z$ to equal V/L where V is applied voltage.

Net retardation

$$\Phi = \phi_{x'} - \phi_{y'} = 2\Delta\phi_0 = \frac{2\pi}{\lambda_0} r n_0^3 V$$

and the emergent light will be in general elliptically polarized.

From eq^n's 1(a) & 1(b)

$$\mathcal{E}_{x'} = \frac{\mathcal{E}_0}{\sqrt{2}} \cos(\omega t + \Delta\phi)$$

$$\mathcal{E}_{y'} = \frac{\mathcal{E}_0}{\sqrt{2}} \cos(\omega t - \Delta\phi)$$

$\Delta\phi$, Phase shift depends directly on the applied voltage V.

Transmitted Electric Field

$$\mathcal{E} = -\frac{\mathcal{E}_0}{2}[\cos(\omega t + \Delta\phi) - \cos(\omega t - \Delta\phi)]$$

$$\mathcal{E} = -\mathcal{E}_0 \sin\Delta\phi \sin\omega t$$

And

$$I = \frac{\omega}{2\pi} \int_0^{2\pi/\omega} \mathcal{E}^2 dt \quad \left[\because T = \frac{2\pi}{\omega}\right]$$

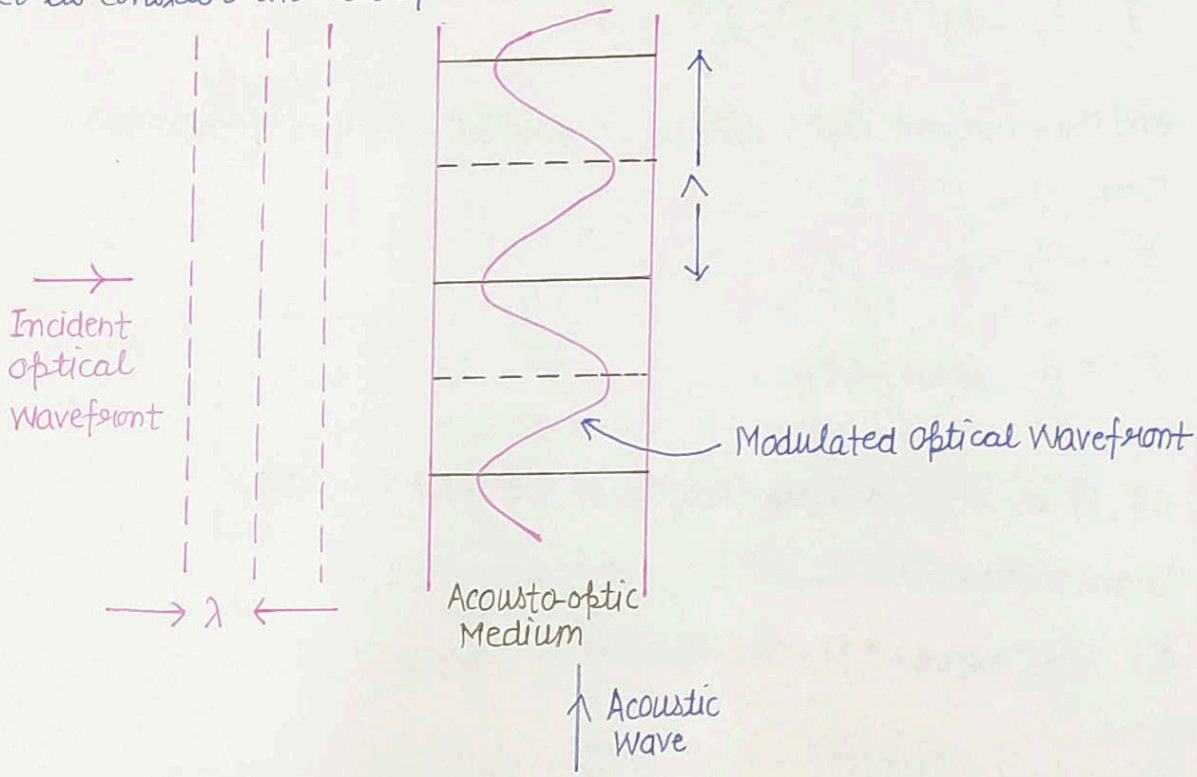
$$I = I_0 \sin^2\Delta\phi = I_0 \sin^2\left(\frac{\Phi}{2}\right)$$

↳ Incident on Electrooptic Crystal

$$\boxed{\frac{I}{I_0} = \sin^2\left(\frac{\pi}{\lambda_0} r n_0^3 V\right)} \Rightarrow \text{Such system is Electrooptic.}$$

#Acousto Optic Effect -

The Acousto optic effect is the change in the refractive Index of a medium caused by the mechanical strains accompanying the passage of a surface acoustic (strain) wave along the medium. The strain and hence the refractive index varies periodically with a wavelength Λ equal to that of a acoustic wave. The refractive index changes are caused by the photo-elastic Effect, which occurs in all materials.
Let us consider the case of a monochromatic Light wave.



The solid horizontal lines represent Acoustic wave peaks and dashed horizontal lines represent acoustic wave troughs. The portions of the wavefront near to a pressure peak will encounter a high refractive index and therefore advance with a lower velocity than those portion of the wavefront which encounters pressure minima. The acoustic wave velocity is much less than the light wave velocity.

As light wave propagates in the direction normal to the local wavefront, almost all the wave element will suffer a change in the direction leading to a redistribution of the light flux, which concentrate near regions of

compression. In effect, the acoustic wave setup a diffraction pattern grating within the medium so that optical energy is diffracted out of the incident beam into the various orders.

There are two main cases of interest.

(A) Raman Nath Regime

(B) Bragg Regime.

(A)

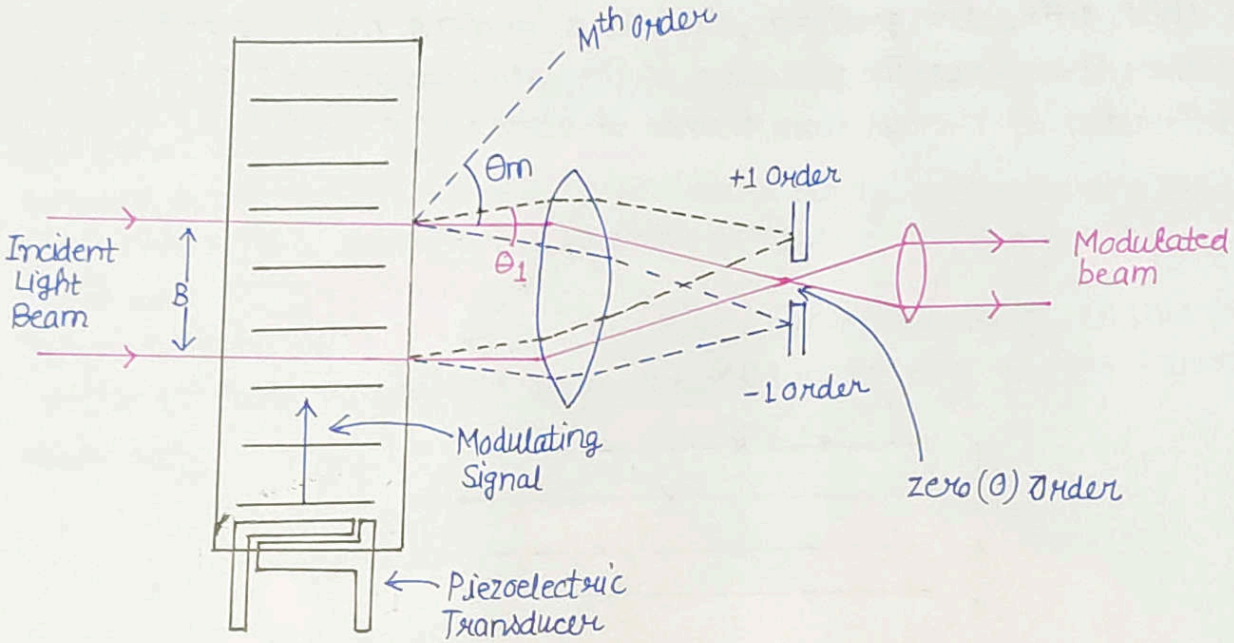


Figure (Acousto Optic Modulator)

In the raman nath regime, the width of the acoustic beam is so small that is diffracted light suffers no further redistribution before leaving the modulator. The light is then diffracted as though from a simple plane grating such that

$$m\lambda = \Lambda \sin\theta_m$$

where $m = 0, \pm 1, \pm 2$

θ_m = Angle of diffraction

The irradiance I of the light in these orders depends on the ruling depth of a acoustic grating which is related to the amplitude of the

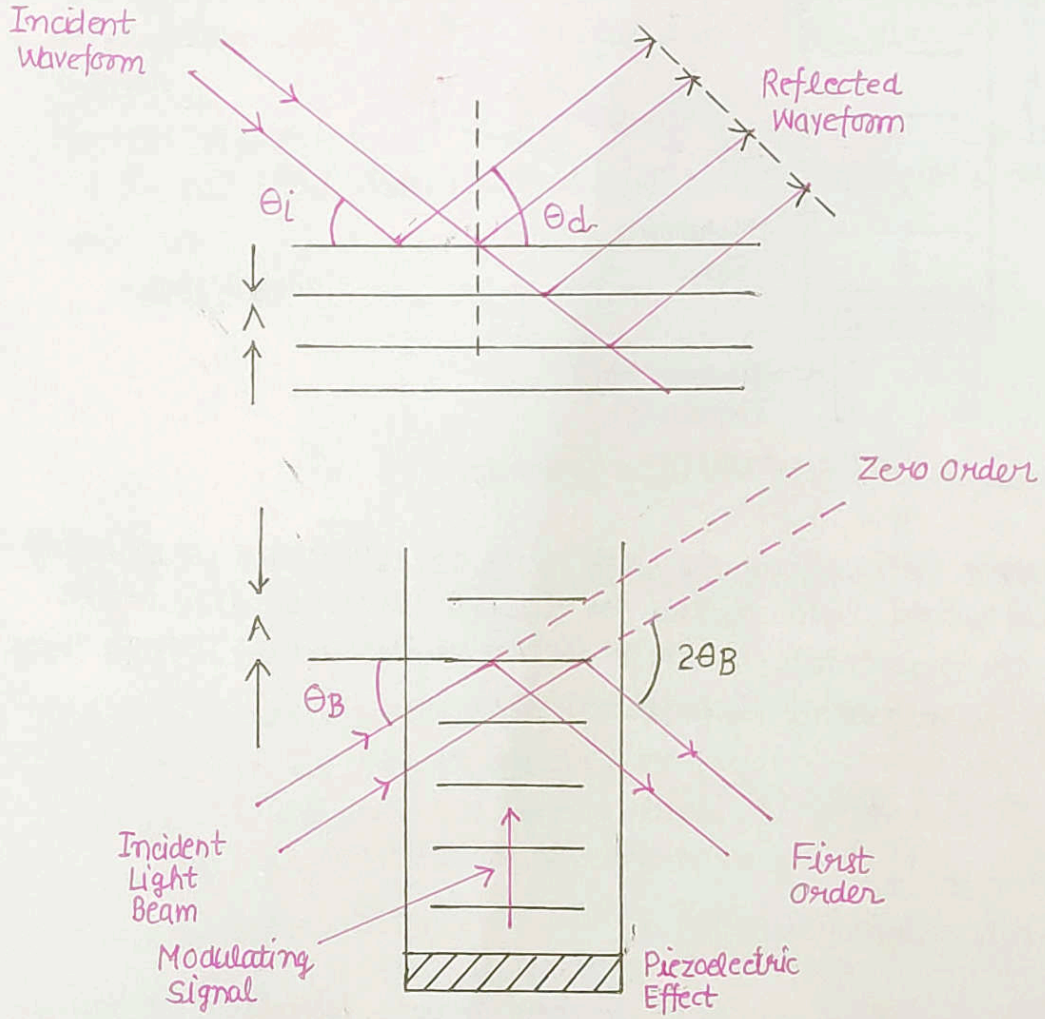
acoustic grating. The fraction of light removed from the zero order beam.

← Transmitted Irradiance.

$$\eta = \frac{I_o - I}{I}$$

(B)

The Physical basis of the Bragg regime is that light diffracted from the incident beam is extensively rediffracted before leaving the acoustic field. Under these conditions, the acoustic field acts very much like a thick diffraction grating, that is a grating made up of planes rather than lines. The situation is then very similar to that of Bragg diffraction of X-rays from planes of atoms in a crystal.



Conditions :

(i) $\theta_i = \theta_d$

(ii) $\sin\theta_i + \sin\theta_d = \frac{m\lambda}{\Lambda}$

$m = 0, 1, 2, \ldots$

$$\sin\theta_i = \sin\theta_d = \frac{m\lambda}{2\Lambda}$$

The diffraction is similar to that obtained with a plane grating, but only for special angles of incident.
Although in the simplified theory given above strong scattering can take place when m is equal to any positive Integer, a more rigorous treatment.
The modulation depth $(I - I_0)/I_0$ or diffraction efficiency η, in this case can theoritically equal 100% in contract to about 34% for the Raman Nath case.

$$\eta = \sin^2\left(\frac{\theta}{2}\right)$$

$$\eta = \frac{\sin^2\phi}{2}$$

where $\phi = \frac{2\pi}{\lambda} \cdot \frac{\Delta n L}{\cos\theta_B}$ (Δn: Amplitude of Refractive Index fluctuation; L: Length of modulator)

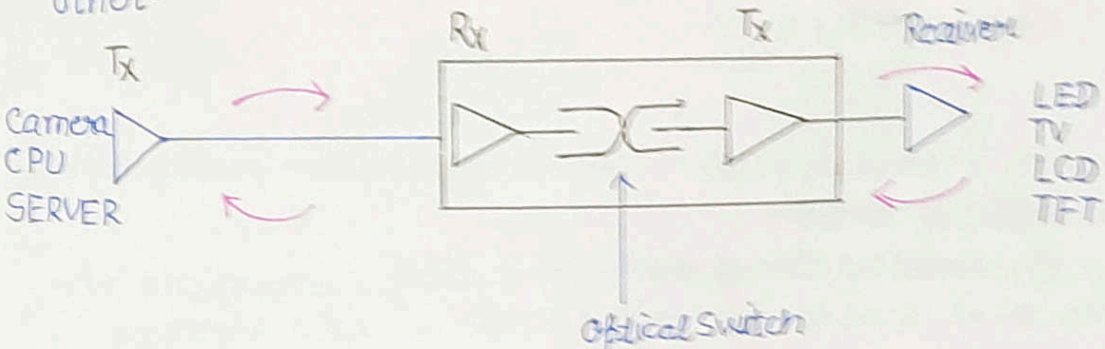
The acoustic waves, which create the diffraction grating, are of course moving through the medium, and, as consequence, the diffracted wave behaves as if it had been reflected from a mirror moving with the same velocity as the grating, and therefore appears to originate from a (mirror) source moving as twice the mirror velocity. Thus the frequency is of reflected beam is changed by the Doppler Effect, is given by

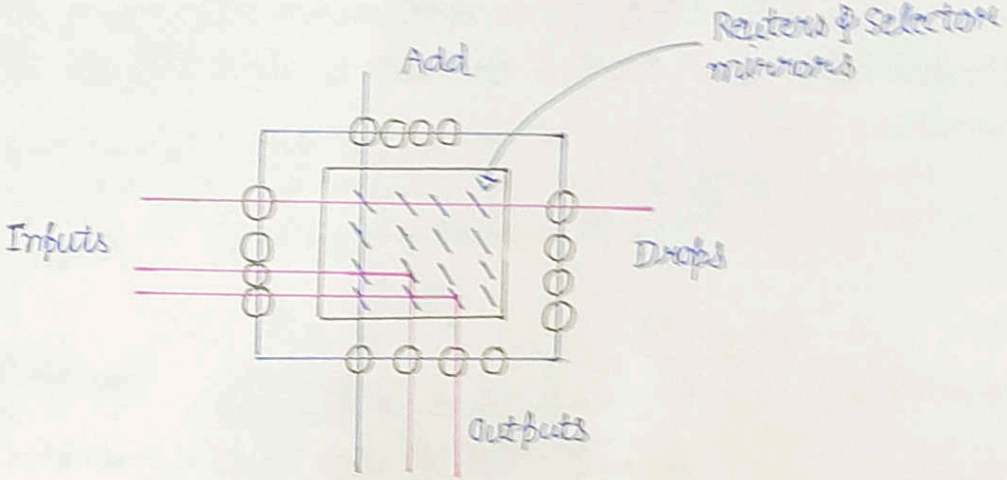
$$\nu' = \nu_0\left[1 \pm 2v_x\left(\frac{c}{n}\right)\right]$$

Frequency shift $\Delta\nu = \nu' - \nu_0 = \pm 2\nu_0 v_x \frac{n}{c}$

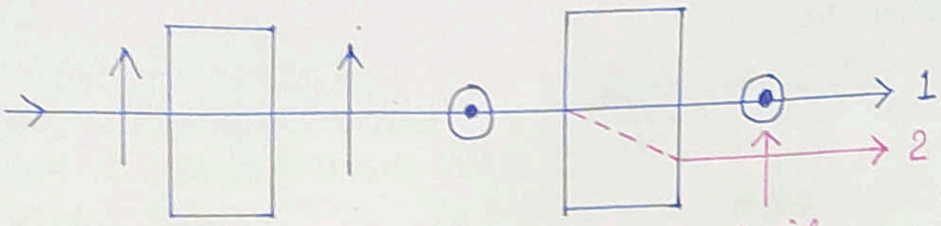
Optical Switches-

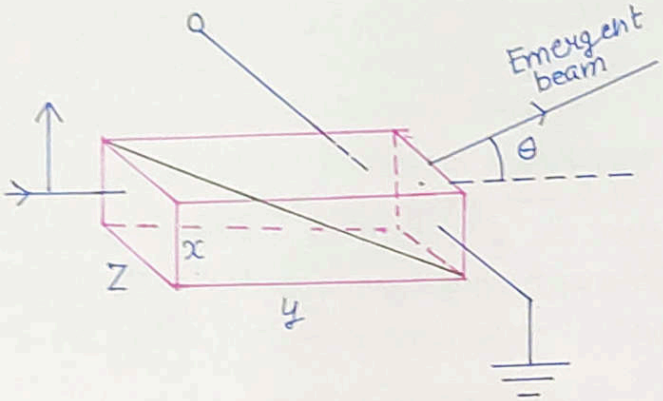
An Optical Switch is a device that selectively switches optical signal from one channel to another. The switching can be temporal or spatial. The former is known as optical switch or optical modulator, while the latter is called an optical space switch or an optical router. In general, optical modulators and routers can be made for each other.





An Optical Switch may operate by mechanical means, such as physically shifting an optical fiber to drive one or more alternative fibers or by Electro-optic effect, Magneto-optic Effect or other methods. Slow optical switches, such as those using for alternate routing of an optical switch transmission path such as routing around a fault. EOE, MOE used for logic operations.





The arrangement shows that it can be used for beam switching. Here we have two similar prism of KDP but with opposite orientations. A ray entirely in the upper prism travels in a medium of refractive index.

$$n_2 = n_0 - \frac{n_0^3}{2} r E_z$$

While a ray entirely in the lower prism travels in a medium where the efforts of the applied field is reversed so that

$$n_1 = n_0 - \frac{n_0^3}{2} r E_z$$

The arrangement leads to a deflection of the beam. The rays 1 and 2 will transverse the crystal in times t_1 and t_2.

$$t_1 = \frac{Ln}{C}$$

$$t_2 = \frac{L(n+\Delta n)}{C}$$

Using snell's Law, the angle of beam diffection θ measured outside the crystal is given by

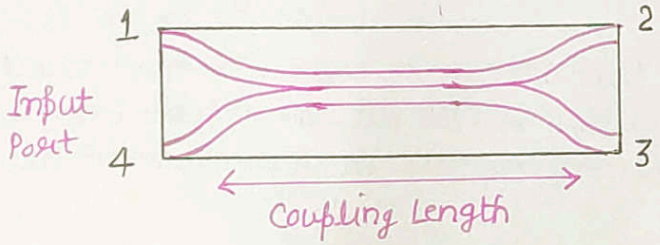
$$\theta = \theta' \times n = \frac{n \Delta y}{W}$$

$$\theta = \frac{L \Delta n}{W}$$

$$\boxed{\theta = \left(\frac{L}{W}\right) n_0^3 r \varepsilon_z}$$

Optical Directional Coupler-

Couplers are devices used to interconnect adjacent waveguides to combine or devide light with very low loss. A directional coupler allows the light to pass through one direction only, In a 1×2 directional coupler,



It devides the input power applied to the port (1) into two outputs at port (2) and (3). In ideal condition no light reaches at port (4). For efficient coupling, it requires that the propagation vectors are the same for each guide. The light coupling can be varied from 0 to 100 percent by suitable choosing the coupling length.

Various coupling Functions :

1. Combiner- Combine a number of Input into one or more outputs.
2. Splitter- Devide input into two or more outputs.
3. Polarizer Splitter- Input devide into two polarized light.
4. Monitor- Couple some portion of light to the monitor port.

Magneto-Optic Effect :

The presence of Magnetic Field may also affect the optical properties of some substances thereby giving rise to a number of useful devices. In general, however, as electric field are easier to generate than magnetic field, electro-optic devices are usually preferred to magneto-optic devices.

- **Faraday Effect –**

This is simplest magneto-optic effect and the only one of the real intrest for optical modulators. It concerns the changes in refractive index of a material subjected to a steady magnetic field $\vec{B}$. Faraday found that when a beam of plane polarized light passes through a substance subjected to a magnetic field, its plane of polarization is observed to rotate by an amount proportional to the $\vec{B}$ component parallel to the direction of propagation. This is very similar to optical activity. In the Faraday effect the sense of rotation of the plane of polarization is independent of the rotation of propagation. Thus the rotation can be doubled by reflecting the light back through the faraday effect device.

The rotation of the plane of polarization is given by

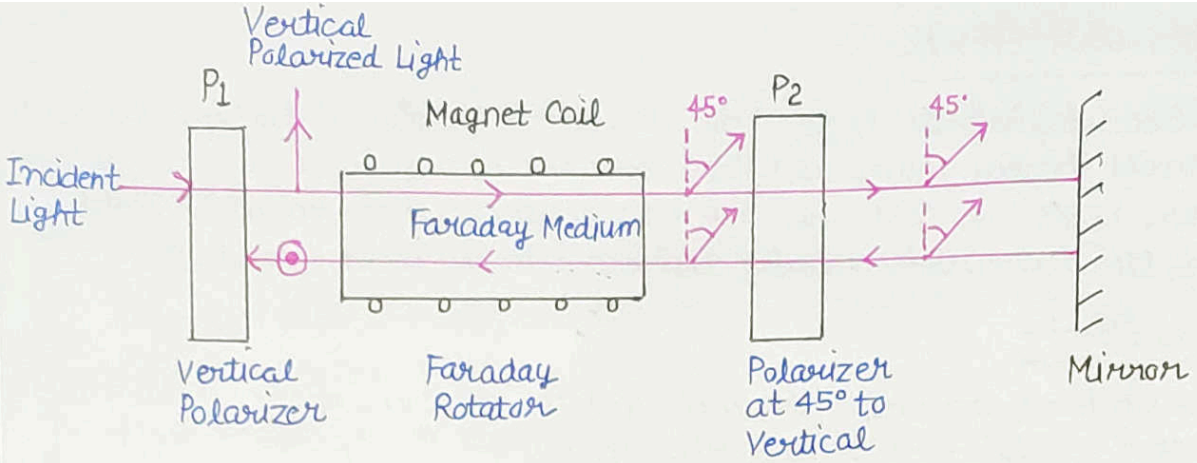
$\theta = VBL$
- L → Path length in the material
- B → Magnetic Flux density ∥ direction of propagation
- V → Verdet constant

The Faraday Effect is small and wavelength dependant.

$$\theta = \frac{\pi}{\lambda_0}(n_T - n_I)L$$

A faraday rotator used in conjunction with a pair of polarizers acts as optical isolator which allows a light beam to travel through it in one direction but not in opposite one.

The construction of a typical isolator is shown below.



Light passing from Left to right is polarized in the verticle plane by polarizer P_1. The faraday rotator is adjusted to produce a rotation of 45° in a clockwise sense. The second polarizer P_2 is set at 45° to P_1 so that it will transmit light emerging from the rotator. However, a beam entering from the right will be plane polarized at 45° to the verticle by P_2 and then have its plane rotation by 45° in the clockwise direction by the rotator. It will therefore be incident on P_1 with its plane of polarization at right angles to a plane of transm. and be eliminated.

One potential application of magneto-optics currently receiving attention is large capacity computer memory. Such memories must be capable of storing very large amount of information in a relatively small 's area. Writing may be achieved by heating the memory elements on the storage medium to a temperature above the curie point using laser beam. To read the information, laser beam is direction to the memory elements.

Systems, incorporating, have enabled information to be stored, read and erased at rate > 1 Mbps.

OPTICAL SOURCES AND DETECTORS

Optical Source :

- Emission of Light can take place in the form of Photon.
- Energy must be supplied to boost the e- from low energy state to a higher energy state.
- The energy can come from many sources : Heat (Incandesent Light), Electrical discharge (D_2, Hg, Na, Lamps), Electrical current (LED, LD), Biolumisence (Fire Fly- Luciferase Engyme).

Optical source requirement for performance-

- Physical dimensions
- Narrow Radiation Pattern
- Linearity
- Ability to be directly modulated by current
- Fast response time
- Adequate output power into fiber
- Line Width
- Efficiency
- Stability
- Driving circuit Issue
- Reliability and Cost.

Optical Sources of Light-

→ Tungustan

→ Deuterium

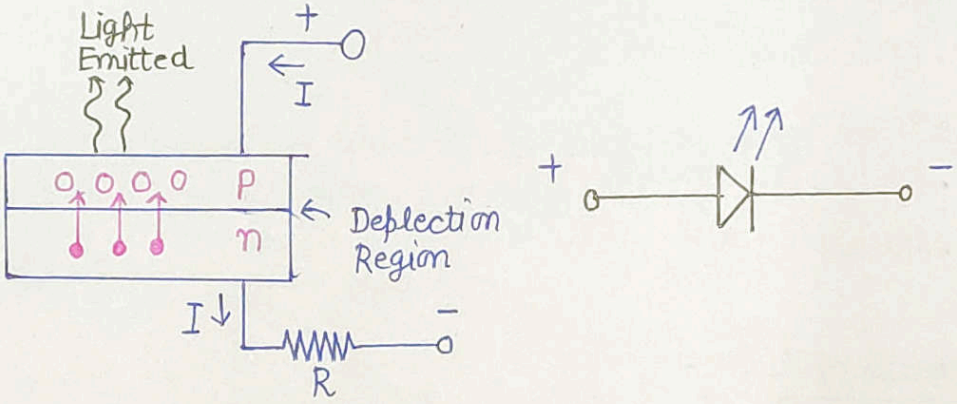
→ Mercury

→ Hollow cathode Lamp

LED Structure & Materials -

A pn junction acts as the active or recombination region. When a pn junction is forward biased, e^- and holes recombine either radiatevely (emitted Photon) or non-radiatevely (emitted heat). This is simple LED operation. Emitted wavelength depends on bandgap energy.

Material	Wavelength Range (um)	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

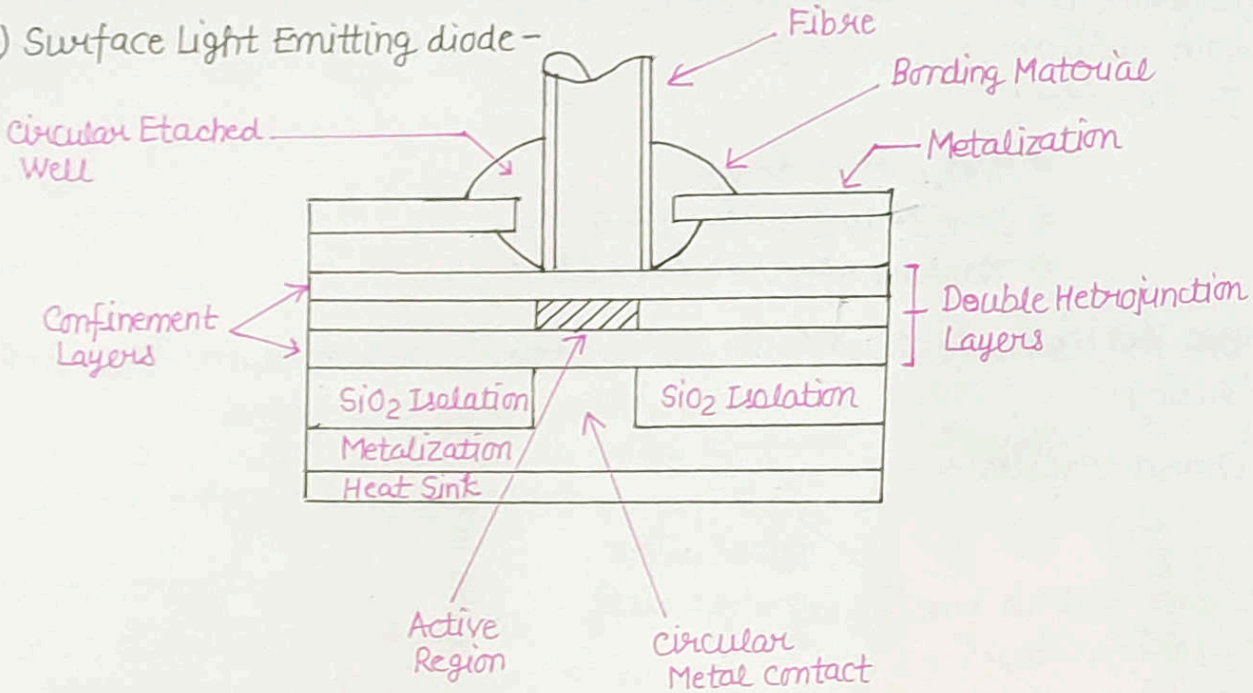


Light is emitted at site of carrir recombination which is primarily close to the junction.
However the amount of radiative recombination and the emission area within the structure is dependant upon the semiconductor material used and the febrication of the devices.
It emits coherent light through spontaneous emission.

Types of the LED structures

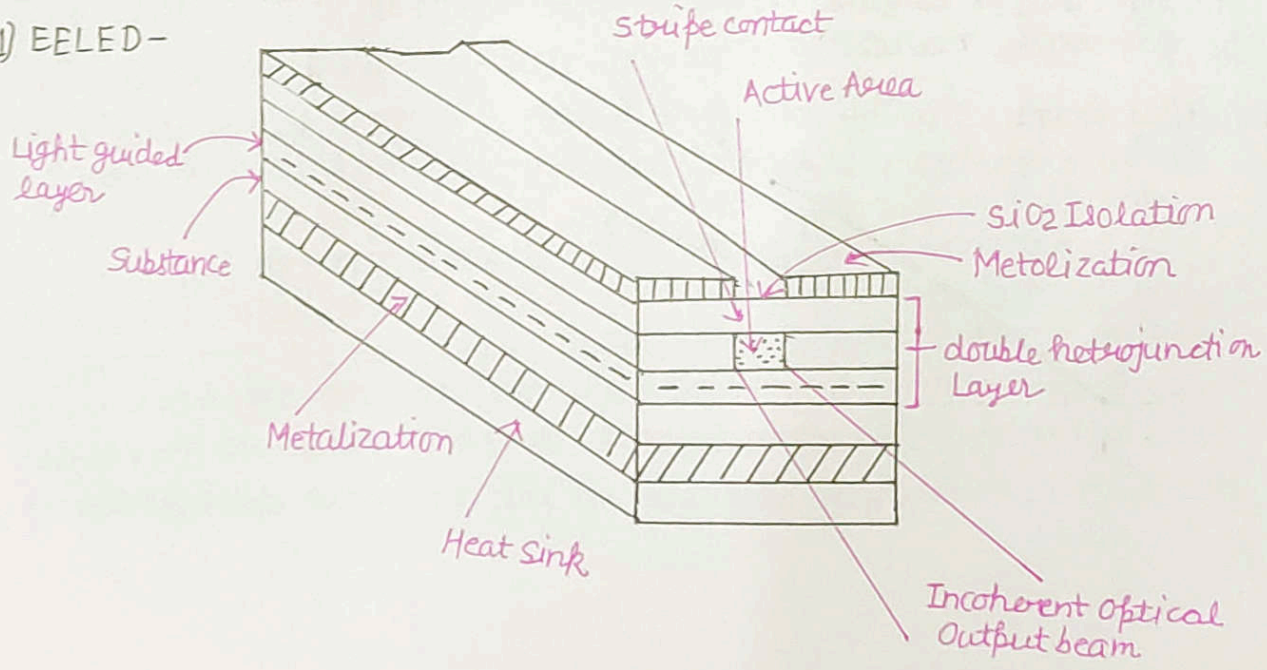
- SLED — Surface Light Emitting Diode
- EELED — Edge Emitting LED
- SLD — Suplumineseent LED

(1) Surface Light Emitting diode –



The active region is limited to a circular section that has an area compatible with a fiber core and face.

(11) EELED –



Edge Emitted double heterojunction LED's the output beam is lambertian in the plane of the pn junction ($\theta_{\parallel}$) and highly directional perpendicular to the pn junction. It has advantage of transparent guiding layers with a very thin active layer (50 to 100 μm). This reduces self absorption and narrow the beam divergence. Light is emitted at one end face only.

(iii) Superluminescent LED-

Diagram is quite similar to EELED. But It has significant benefits over both SLED and ELED for OFS.

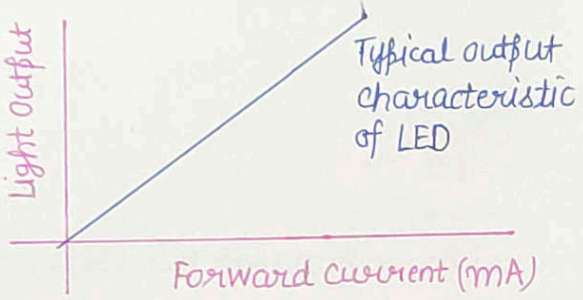
It provides;

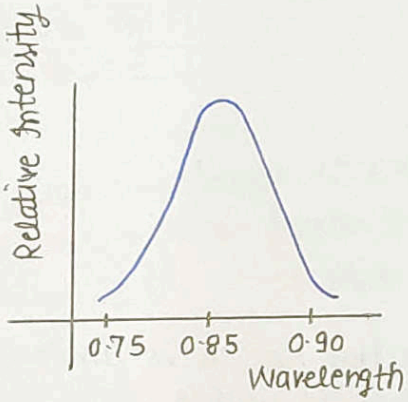
* High output power
* Directional output beam
* Narrow spectral linewidth

or

one end is made optically lossy to prevent reflections and thus suppress lasing.

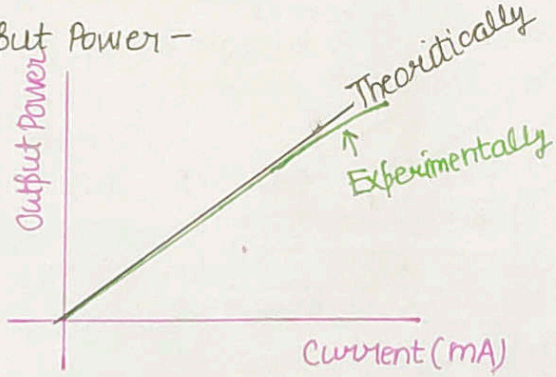
- Characteristics-



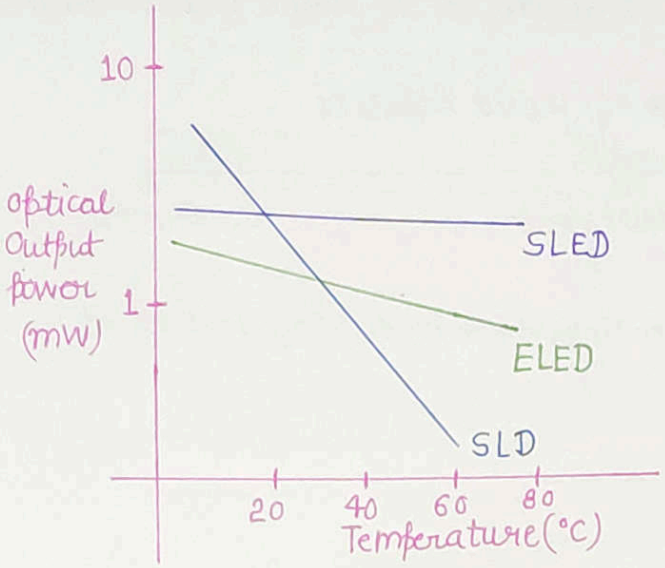


The light output is quite linearly proportional to the current, so it can be preciously modulated.

- Output Power -



• Temperature Dependance-



This characteristic show the variation in output at a specific drive current over the temperature range for all the devices. To utilize the high power potential of such devices at elevated temperature, the use of thermo-electric cooler may be necessary.

Liquid Crystal diode-

It is a passive type of display. LCD is commonly known as liquid crystal display. Here one of the prime requisites is for low power consumption, particularly so for the digital watch because of the necessarity low capacity of the power source.

There two types of basic LCD available. These are -

(a) Reflective - Require front Illumination.

(b) Transmissive - Requires rear Illumination.

The Liquid crystal state is a phase of matter which is exhibited by a large number of organic materials overs a restricted temp. range.

At the end of the temperature range, the material becomes a crystalline solid, whilst at the upper end of the temperature range, it changes into a clear liquid. Within this range it has a milky yellowish appearance and combines some of the optical properties of solids with the fluidity of liquids. A major characteristic of the all liquid crystals commponds are the rod-like shape of their molecules.

When they are in crystal liquid phase, these molecules can take up certain orientations relative both to each other and to the liquid crystal surface.

Ordering of Liquid crystals

(a) Nematic (b) Cholesteric (c) Smectic

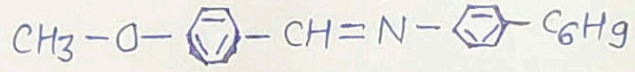
(a)

Nematic and cholesteric are more important in display devices at present and illustrated.



In Nematic Ordering (above figure), the molecules are aligned parallel to each other, but apart from remaining properties. A nematic liquid crystal molcule usually consists of two benzene rings linked with a central group.

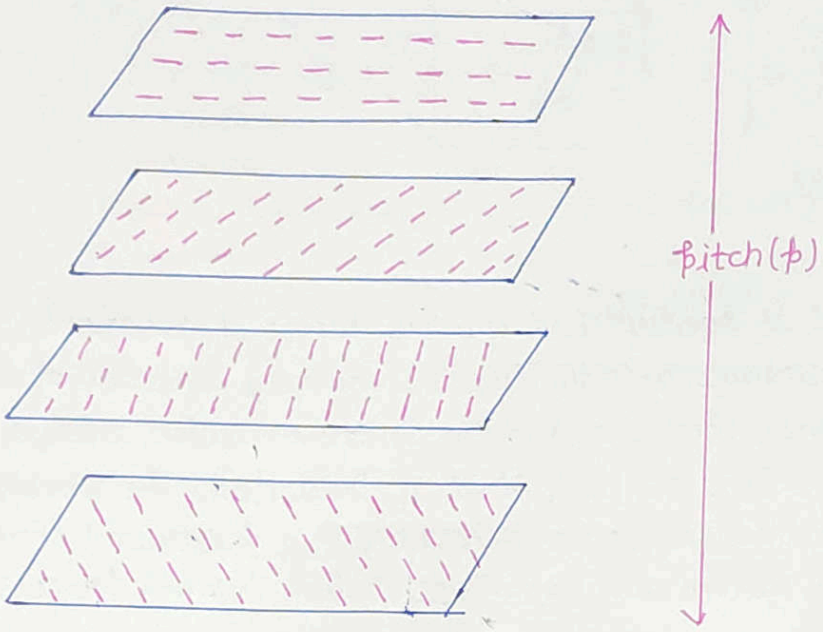
4-methoxybenzylidene-4-butylanaline (MBBA)



It shows liquid crystal behaviour over temperature range 20°C to 47°C.

(b)

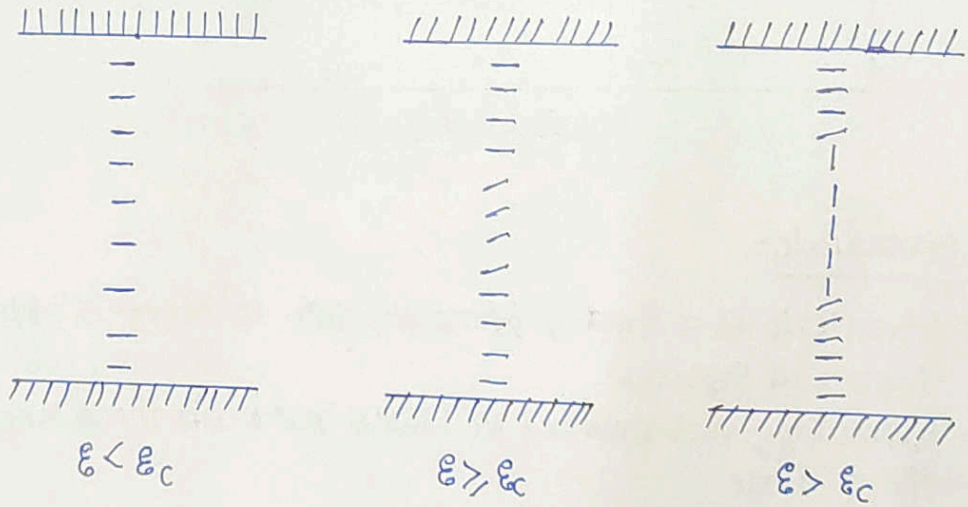
In the Chlesteric phase, we may regard the material as being made up from a large number of planes each having a nematic like structure but each plane showing a progressive change in the director direction from the one below. The distance between planes having the same director direction is called pitch p. This type of displays exhibit some interesting colour effects.

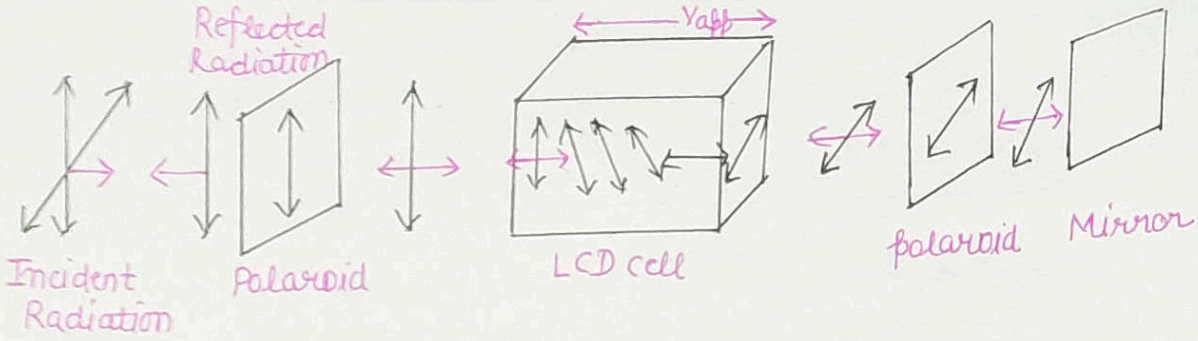


One of the most important electrical characteristic of liquid crystal display material is that they show different dielectric constants $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$.

If $\varepsilon_{\parallel} > \varepsilon_{\perp}$ we refer it as positive material, which tends to make the molecules lie along the $\vec{E}$, since they will tend to minimize their energy.

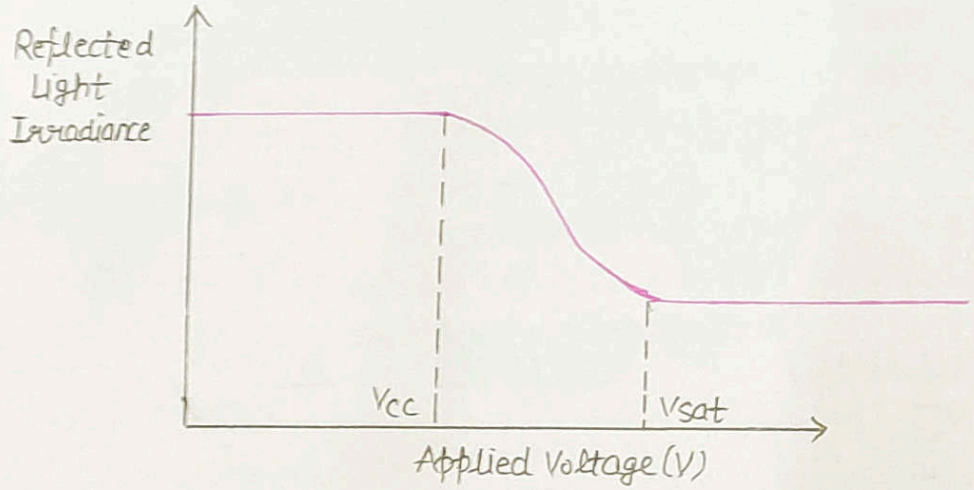
This transition is found to take place above a critical field (ε_c)





In operation, the cell is sandwitched b/w two pieces of polaroid whose polarizing directions corresponds to the director ordering direction of the particular cell surface they are next to. In the reflected mode, a reflector is placed behind the back sheet of polarizod. The arrange--ment has been shown and traces the behaviour of a polarized beam as it transverse the system with no voltage applied. Further process is as shown in figure.

The amount of light reflected from an LCD as a function of applied voltage is shown.



PIN Photodiode-

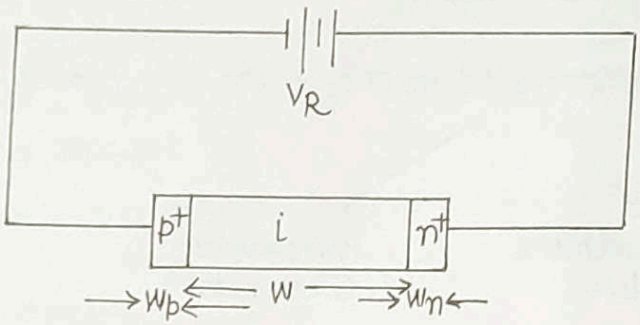
PIN photodiode is a kind of photo detector. It converts optical signal into electrical signals.

This technology was invented in 1950's. There are three regions in this type of diode.

Regions :

1. p-region
2. Intrinstic region
3. n-region

The p-region and n-region are comparatively heavily doped than than the usual p-n diode's p and n-regions. The width of the intrinstic region should be larger than the space width of a normal p-n junction



The p-n photodiode operates with an applied voltage (reverse bias) and when the reverse bias is applied, the space charge region must cover the intrinstic region. Electron hole pairs are generated in space charge region by photo absorption. The switching speed of frequency response of photodiode is inversly proportional to the life time.

The switching speed can be enhanced by a small minority carrier life time. For the photo detector application where the speed of response is important, the depletion region width should be made large as possible as a result the switch speed also increase

Applications :

(1) RF and microwave switches
(2) RF and microwave variable attenuators
(3) photo detector
(4) photovoltaic cell.

Avalanch Photodiode-

An Avalanch photodiode (APD) is a highly sensitive semiconductor photodiode that exploits the photoelectric effect to convert light into electricity.

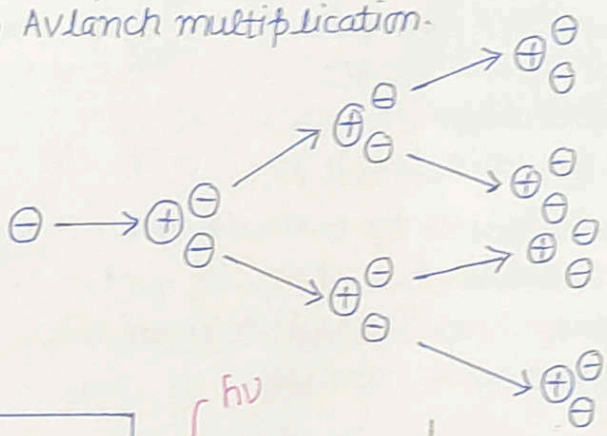
One of the main working parts of any optical receiver is the photodetector. The device that transforms optical signal into electrical signal.

$T_x \longrightarrow R_x$

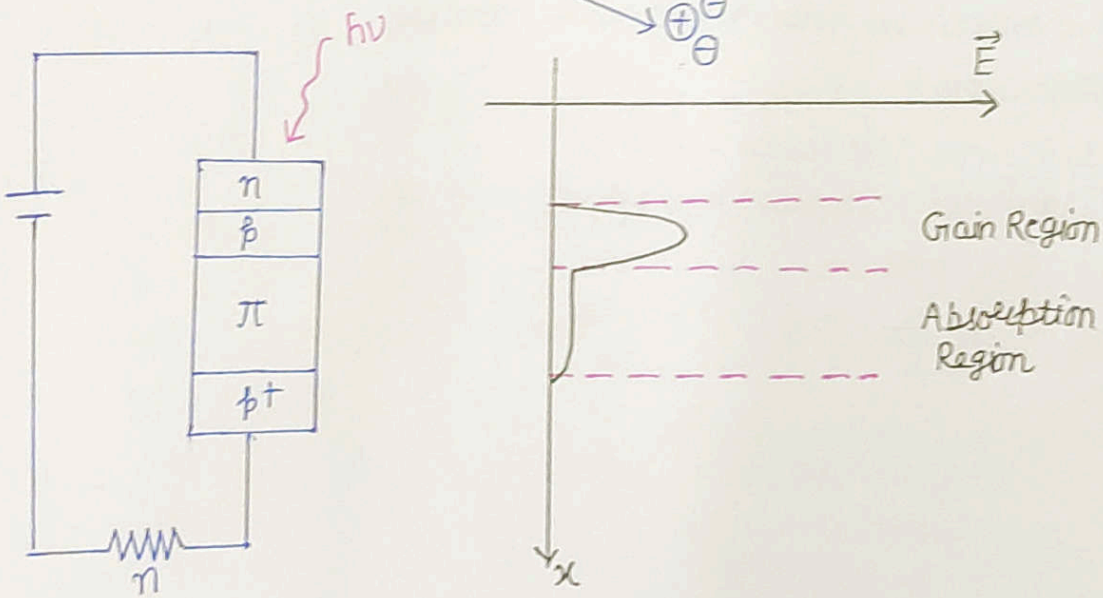
The photodiode can be operated in one of the two modes!

- Photoconductivity (Reverse-bias)
- Photovoltaic (Zero-bias)

They are the photodetectors that provides built in first stage gain through Avlanch multiplication.



→ Generation of free carriers that are created by absorbed photons.



(1) In APD, an extremely high electric field is created around 3×10^5 V/cm

(2) The generation of high field region causes holes ⊕ & electrons ⊖ to aquire sufficient energy to excite new electron-hole pairs. This cause avalance breakdown in ordinary reverse bias condition. This process is known impact ionization.

→ APD are used in optical receiver before the signal is given to the receiver circuitry, the photon is multiplied with photo current and this increase the sensitivity of the receiver.

→ It requires high operating voltage and produces high noise. The O/p is not linear.

→ It is used as counterpart of PIN diode that is often used.

Photomultipliers-

In the photomultipliers, the photoelectrons are accelerated towards a series of electrodes (dynodes) which are maintained at successively higher potential with respect to cathode. On striking a dynode surface, each e^- causes the emission of several other electrons which in turn are accelerated towards the next dynode and continue the multiplication process. Thus if on avarage δ secondary e^- are emitted at each dynode surface for each incident e^- and there are N dynodes overall, then the total current amplification factor between the cathode and Anode is given by

$$G = \delta^N \quad \ldots\ldots\ldots\ldots\ldots (1)$$

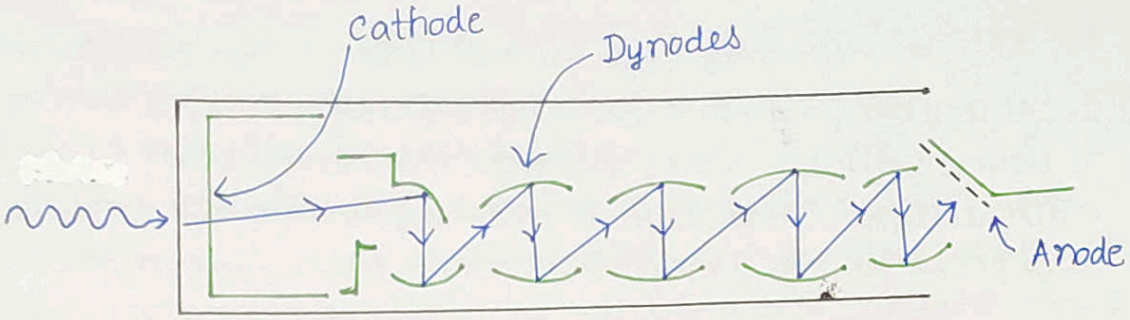
e.g.

$\delta = 5$

$N = 9$

$G = 5^9 = 1953125 = 1.9 \times 10^6$

$Gain \approx 2 \times 10^6$

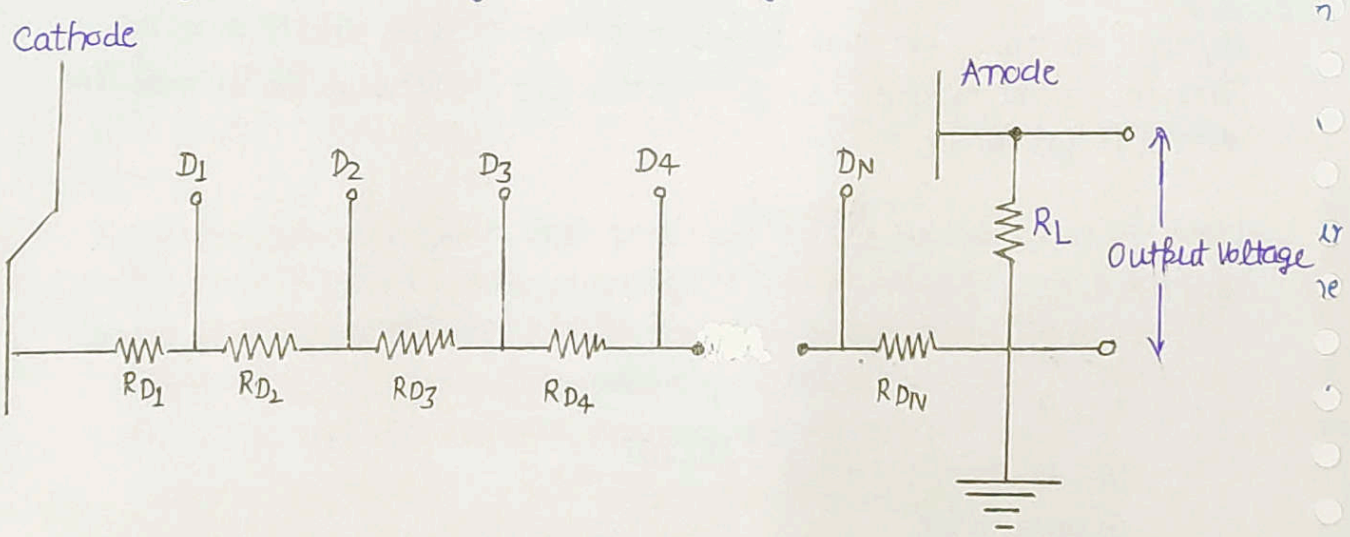


The Photoelectrons are emitted from the opposite side of the cathode layer to that of the incident radiation. Obviously, in this arrangement the thickness of the photocathode is very critical. If It is too thick, few photons will penetrate to the e^- emitting side, whilst if it is too thin few photons will be absorbed.

Types of dynode made PMT

- Venetial blind Type — Inexpensive, Very suitable
- Box and grid type — Similar to VBT
- Linear Focused
- Circular cage focused

In Linear Focused and circular cage, some degree of e^- focusing is obtained by careful shaping and positioning of the dynodes.



The dynode potential are usually provided by means of this circuit. Care must be taken to ensure that the voltage b/w the cathode and the first dynode is large enough to maintain proportionality b/w cathode current and cathode illumination.

The photomultipliers response to light input by delivering the charge to the anode. This charge may be allowed to flow through a resistor R_L or to charge a capacitor. The corresponding voltage signal then provides a measure of the input optical signal. If individual pulses need to be examined then it is important to ensure that the response time of the ext. circuitary is lessthan that of the pulse rise time. This usually implies a low value for the R_L.

Traditionally, Photomultipliers have been relatively bulky device with Cathode diameter of 25 mm or more. Smallest one is 8 mm or so.

- Dark current-

$$i_n = aAT^2 \exp\left(-\frac{e\phi}{KT}\right)$$

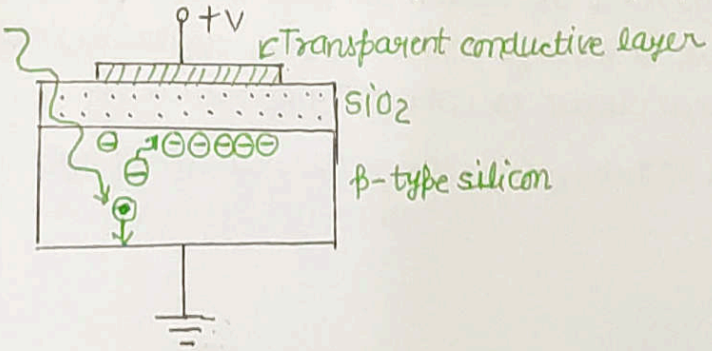
- Shot noise-

$$\Delta i = (2ie\Delta f)^{1/2}$$

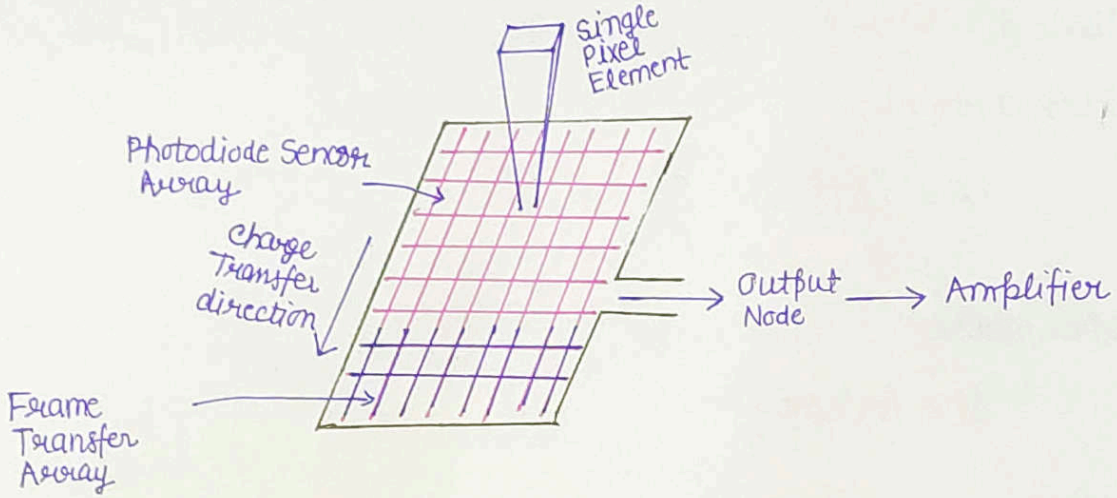
CCD-

We have seen how an optical image may be converted into an electrical signal by using a videocon-type device. An alternative approach is to use an array of discrete detectors. The image may be focused directly onto a 2D array, or alternatively the image may be scanned a 1D array.

An alternative approach was proposed by the researchers of Bell Lab in 1970s. This involved using a charge coupled device (CCD structure). The basic building block of this is the MOS (metal-oxide-semiconductor) capacitor. This is formed by growing a layer of SiO_2, on a p-type silicon substate, a metal electrode is then evaporated on top of the oxide layer.



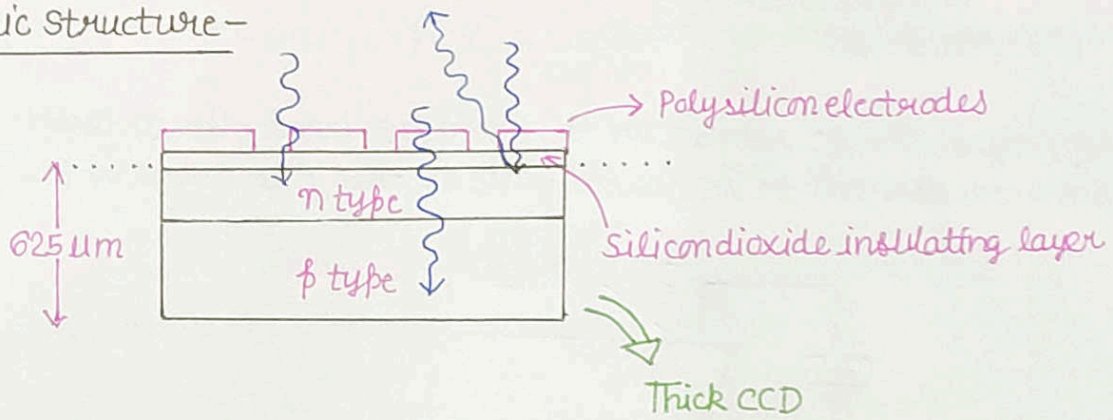
The metal electrode is known as the gate and is biased positively with respect to the silicon. Photogenerated e⁻ - hole pair within the silicon will be separated, with the electrons being attracted to the surface of the silicon under the gate, where they will remain whilst the gate voltage is +ve. The e⁻ are effectively trapped within a potential well formed under the gate contact. The amount of trapped charge will be proportional to the total integral light flux falling onto the device during the measurement period.



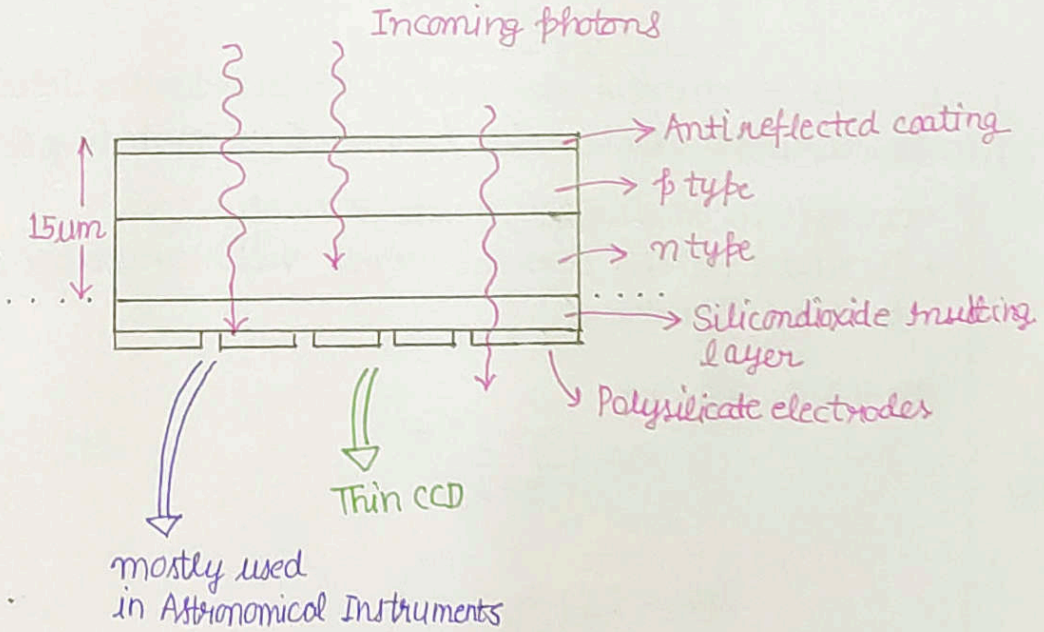
- The Photoelectric effect - turning photons into charge
- Replaces photographic Film and PMT
- Consists of a thin silicon wafer devided an array of thousands of tiny light sensitive squares. Each square corresponds to an individual pixel in the final image.
- Each photosite has tiny capacitors that holds charge.
- Light enters the array, and will liberate electrons from the silicon atom.
- Turns light into electrons - Photoelectric Effect - Analog device.
- Output - The voltage from each photosite - depends on number of photons that penetrated the silicon surface on each photosite.
  - → Output Voltage converted to a digital signal (electronics).
  - → Final output is an array of numbers.
- Instead of taking a picture - record an image.

- most astronomical instruments today use CCDs.
  - # Astronomy
  - # Photometry
  - # Imaging
  - # Spectroscopy
- Developed by Bell's Laboratory.
- CCDs are manufactured on silicon wafers using the same technique used to manufacture computer chips. Scintific CCDs are very big, only a few can be fitted on wafer. This is one reason that they are so costly. Also the wafers are very fragile.

- Basic Structure –



- Thinned Back side Illuminated CCD-



Photoconductive detectors-

An e^- may be raised from the valence band to a conduction band in a semiconductor where the energy gap is Eg by the absorption of a photon of frequency ν provided that

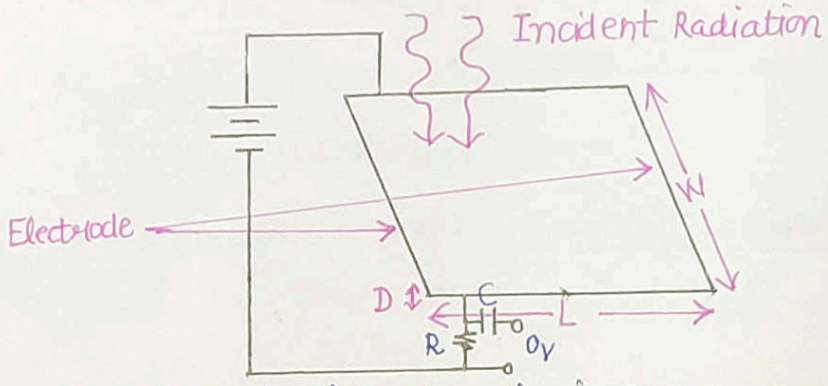
$$h\nu >> Eg$$

in terms of wavelength

$$\lambda \leq \frac{h\nu}{Eg}$$

$$\text{Bandgap wavelength } \lambda_g = \frac{h\nu}{Eg}$$

As long as the e^- remain in the conduction band, the conductivity of the semiconductor will be increased. This is the phenomena of Photoconductivity



It is basic mechanism operative in photoconductive detectors. An external potential across the electrodes is usually provided by the circuit.

- Changes in conductivity of the detector.
- Increase flow of current which will increase the potential across the load Resistor R_L.

Hots only

reflection coefficient

$$\rho = \left(\frac{n-1}{n+1}\right)^2$$

$$I(0) = I_0(1-\rho)$$

This may then be detected using a high impedance voltmeter. If we are only interested in time varying part of the incident Radiation, then a blocking capacitor C may be inserted in the output line to remove any d.c component.

The optimum size of R_L in a particular situation is determined by the fractional change in the resistance of the photodetector when under max. illumination.

We suppose that the radiation falling normally onto the slab is monochromatic and of Irradiance I_0. Not all the incident energy will be available to generate e^- within the semiconductor.

→ Some will reflected
→ Some will pass the semiconductor without any absorption.

Reflection cofficient -

$$r = \left(\frac{n-1}{n+1}\right)^2$$

Irradiance inside the surface -

$$I(0) = I_0(1-r)$$

Now Irradiance at point a distance x into semiconductor

$$I(x) = I(0)e^{-\alpha x}$$

α → Absorption cofficient

Thus the fraction of incident irradiance which is actually absorbed

$$A_I = (1-r)\,\eta_{abs}$$

where

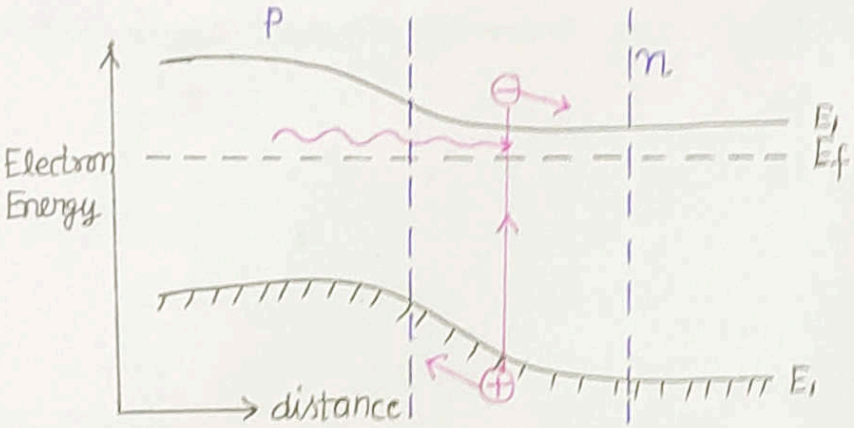
$$\eta_{abs} = 1 - e^{-\alpha D}$$

η_{abs} → The total no. of e⁻ hole pairs generated within the slab per second is $\eta I_0 WL/h\nu$

Photovoltaic method of detection of light -

Photovoltaic is the direct conversion of light into electricity at the atomic level. Some material exhibits a property known as photoelectric effect that cause them to absorb photons of light and release electrons. Where the free electrons are captured, an electric current result that can be used as electricity.

The photovoltaic mode is zero biased. When a p-n junction is formed in a semiconductor material, a region depleted of mobile charge carrier is created which has a high internal $\vec{E}$ across it. If the e^- hole pair is generated by photon absorption within this region. The $\vec{E}$ separates the e^- and hole as shown in figure.



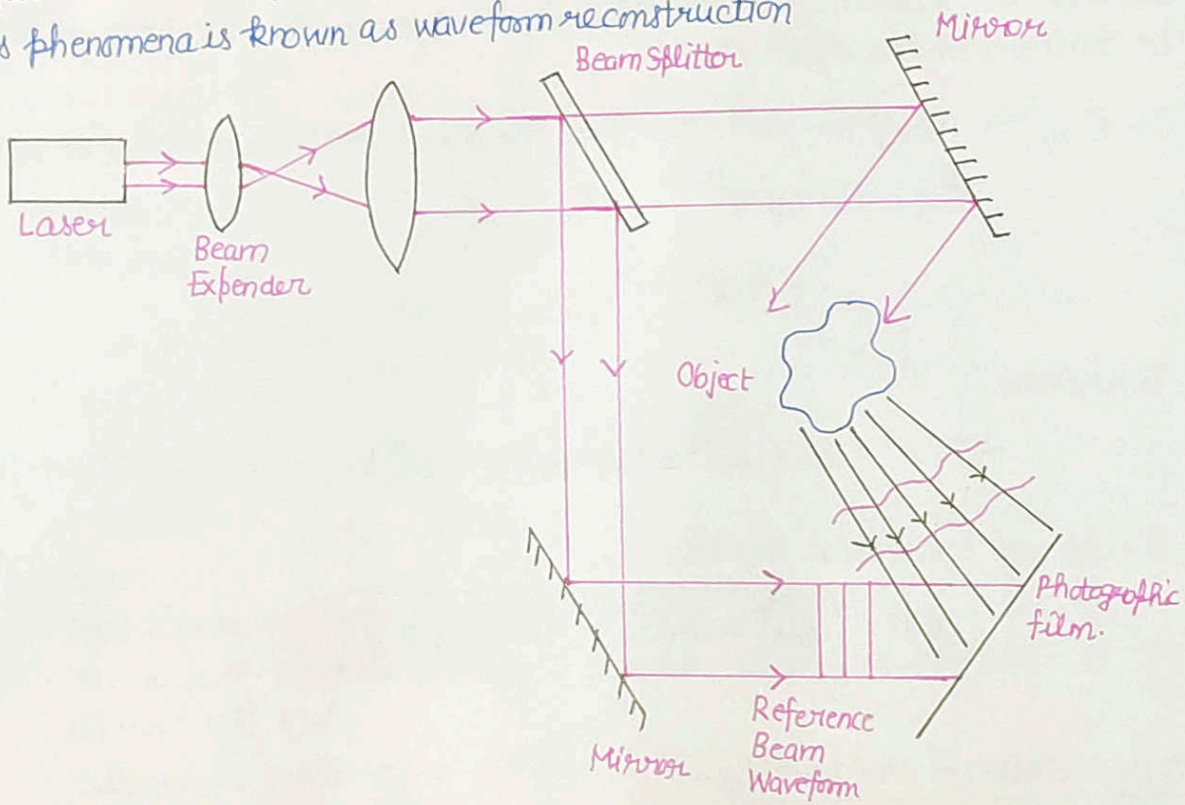
We may detect the charge separation. Firstly, if the device is left on open circuit, an externally measurable potential will appear b/w the p and n regions. This is the photovoltaic mode of operation.

UNIT-4

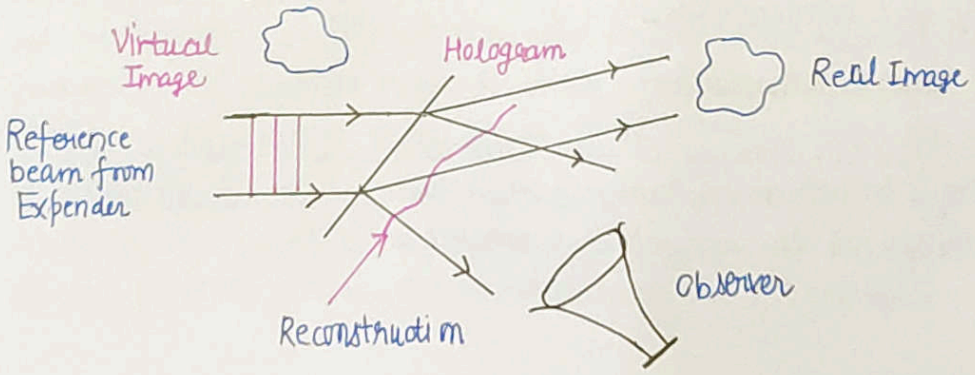
HOLOGRAPHY

Basic Principle, construction and Reconstruction-

Holography was developed prior to laser. The first holography was recorded by Gabor in 1948. The requirement of holography for light with a high degree of spatial and temporal coherence has closely linked with the development of holography. Holography is a method of recording information from a 3D object in such a way that a 3D image may subsequently be reconstructed. This phenomena is known as waveform reconstruction



Because of high degree of mutual coherence of two sets of (object) → wave produce an interference pattern on plate, which is recorded in the photographic emulsion and forms a hologram.



The photographic plate is now processed and illuminated with only the reference beam present. Most of the light from the reference beam passes straight through the hologram.

Constructive Interference $\lambda = d\sin\theta$

↳ Local fridnge Spacing

Thus the construction of interference of these differacted wave reconstructed the original waveform from the object to an observer the waveform appear to be coming from the object itself.

The $\vec{E}$ of the waveform reflected from the object in the (x,y) plane at time t by

$$\vec{E}_{ob} = U_o(x,y)e^{-i\omega t}$$

↳ Amplitude

Irradiance

$$I(x,y) = |U_o + U_R|^2 = (U_o + U_R)(U_o^* + U_R^*)$$

The sum of Individual Irradiance

$$\boxed{I(x,y) = (U_o U_o^* + U_R U_R^*) + (U_o U_R^* + U_o^* U_R)}$$

Application of Holography-

Undoubtebly, the full potential of the holographic technique is still to be realized although a number of application are now firmly estable. We shall discuss one established and one potential application namely holography Interferometry and computer memories.

• Holographic Interferometry-

A variation of the tecchnique is real time technique of holographic interferometry, in which the interference fringes are viewed in real time. A holograph is the subject that recorded as abare.

Techniques -

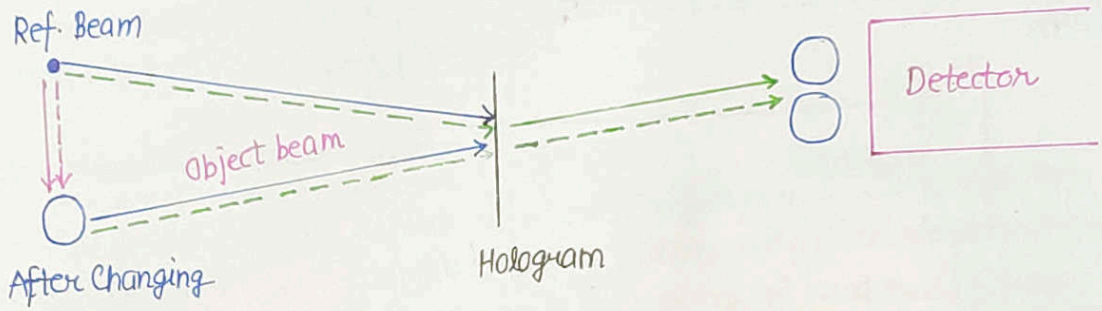
(i) Double exposure holographic interferometry - displacement of object is measured by counting fringes.

(ii) Real time holographic interferometry - time b/w two records.

(iii) Time-avarage holographic interferometry - Examine the spatial characteristic of low amplitude viberations of an object.

* Object move continuesly.

Holographic interferometry is a way to perform interferometry measures. It is a way to trace changes in object without mechanically touching the measured objects.



Applications -

→ Nondestructive testing such as detection of cracks

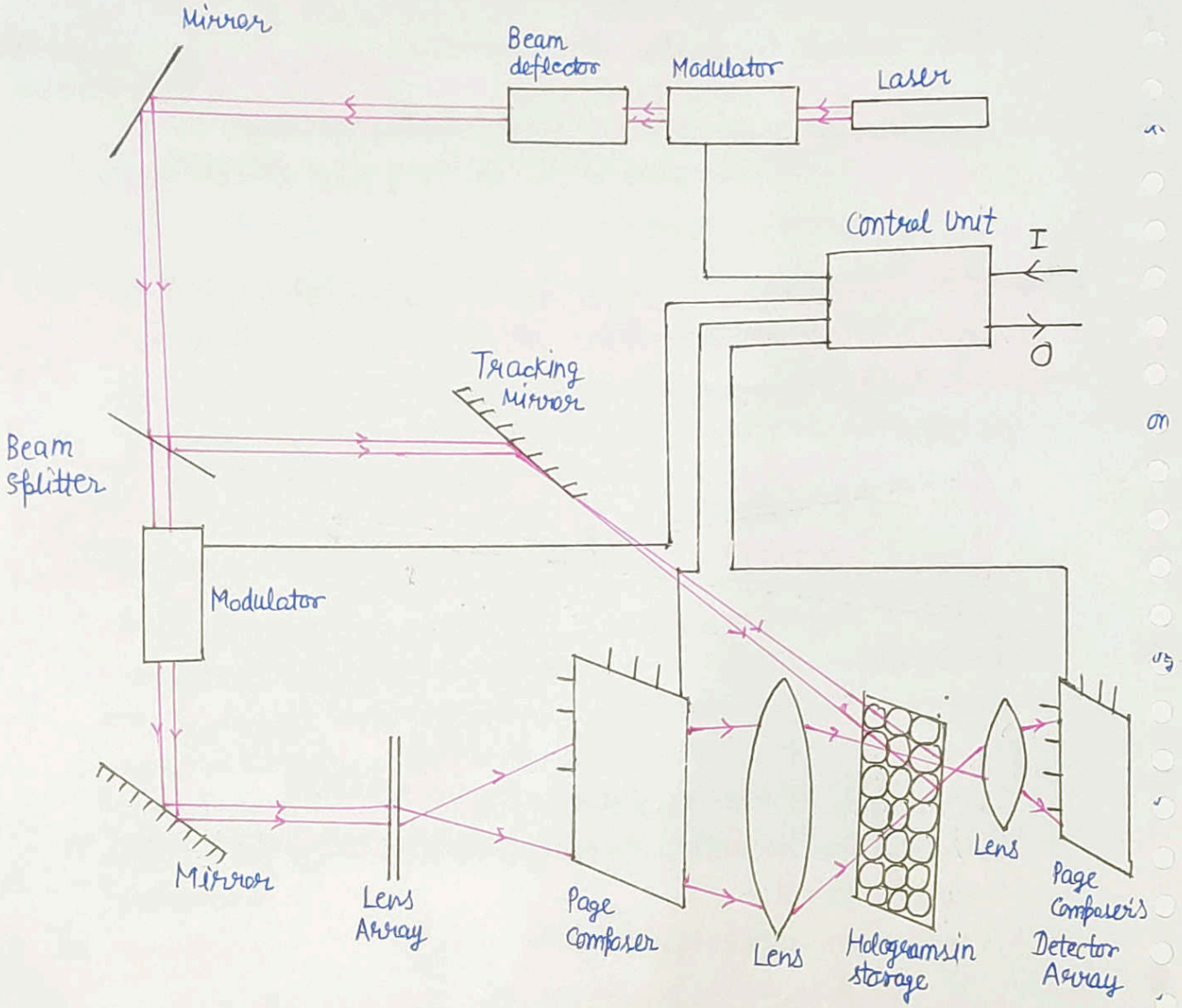
→ Analysis of viberating surfaces such as detecting of resonance of an aircraft tail.

→ Holographic contouring of objects.

• **Holographic computer memories -**

Holographic computer memories are being actively re-developed because they have a very high storage capacity - Theoretically up to 10^{10} bits mm^{-3} with rapid access. Though they are unlikely to replace established technologies such as magnetic disks, tape or optical disk storage, they could be used where very large total storage capacity is required. Holographic storage systems are also very intersting in that they are involved several of the opto electronic devices we have described, such as lasers, photodetectors, optical modulator or optical media.

A holographic memory records and read out a large number of bits simultaniously as we can appriciate by considering the following diagram.



The information to be stored in formed into a 2D array of bits by a device called a page composer. The page composer may be though of as an array of light valves which may be open or closed corresponding to ones, and zeros respectively. The array of up to perhaps 10^5-10^6 bits is then stored at one time in a particular location of the holographic memory. During recording, the light modulators allow maximum irradiance in both the signal and reference beam

Readout of the data is addressed when the hologram is only addressed only by the reference beam. The image is focused by a lens and projected onto the detector array such as a CCD array, which is now available with 2048 X 2048 pixels. The stored information is thus converted into electrical signals.

Advantages -

(i) The information about a particular array is distributed in a holographic fringe pattern across the entire hologram.

(ii) The information is recovered essentially in parallel.

(iii) The holographic recording and construction is insensible to the exact position of the reference or reading beam on the hologram.

(iv) It is possible to record several holograms in different planes of one thick, sensitive material provided that different reference beam directions are used to record each hologram.

High Energy Applications of Laser -

For several years now lasers have been used to perform a large number of materials processing functions such as cutting, drilling, welding, marking, scribing and the surface treatment of a wide range of materials. These include materials such as diamond, ceramics, metals, wood, pliable materials and biological tissues. These technology process have often been successfully undertaken without the need to resort to relatively advances and expensive technologies.

Advantages -

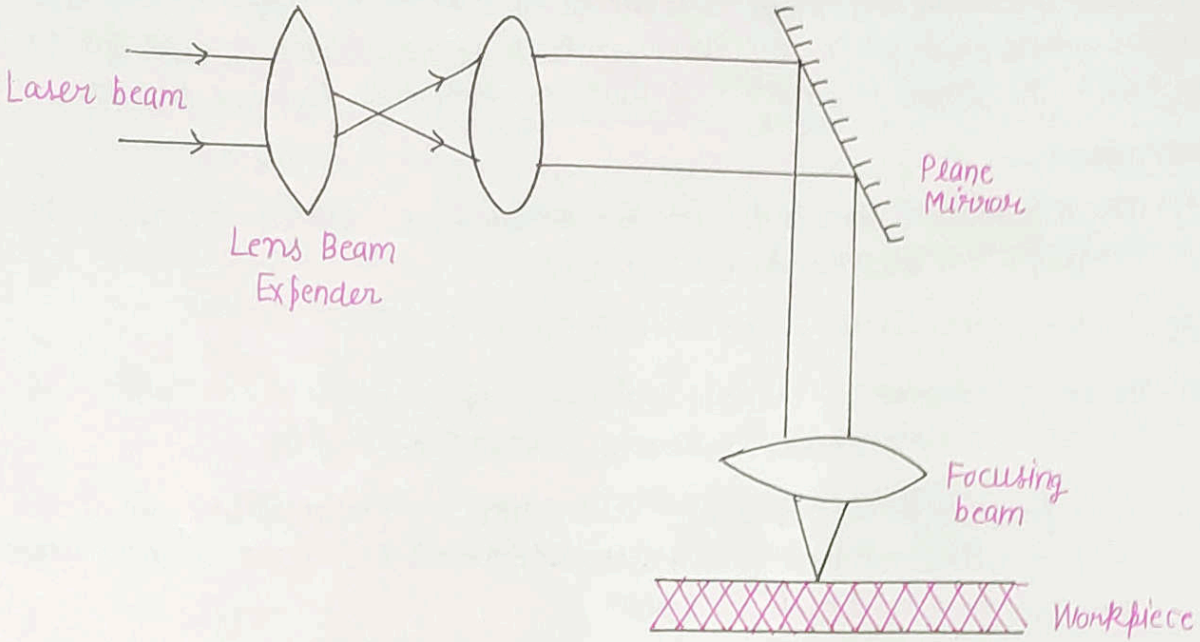
(i) Laser radiation is clean form of energy, in that no contaminating impurities need come into contact with the workpiece. Infact the working atmosphere can often be controlled to suit a particular task.

(ii) As we have seen laser beams, because of their high spatial coherence, may be focused into very small areas.

(iii) It is easy to control the irradiance.

(iv) The beam can be readily directed into relatively inaccessible locations.

The figure shows a basic beam delivery system.

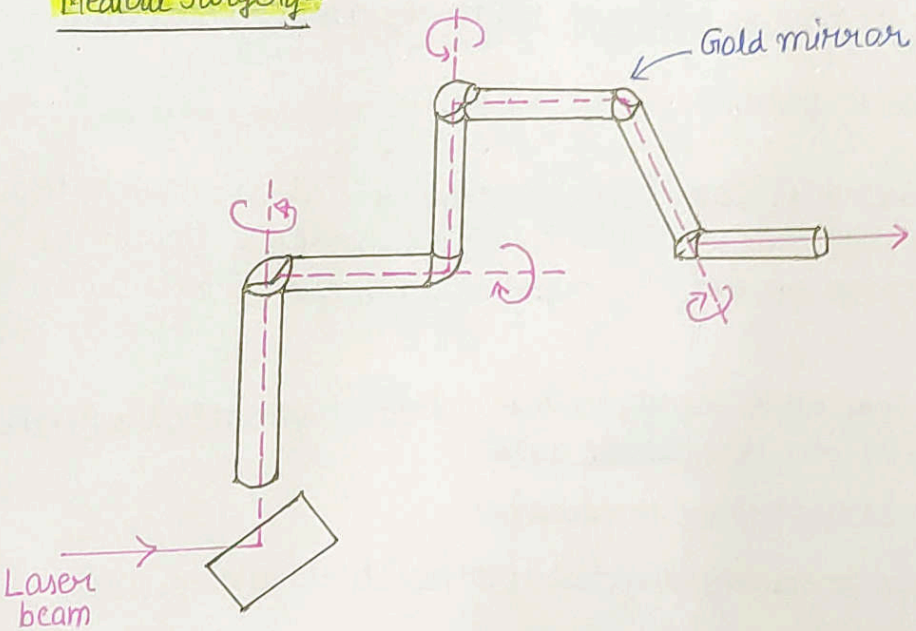


→ Not possible to put workpiece horizontally hence a system layout is designed.

→ Designed for inaccessible locations.

→ Beam delivery system use optical fibers

Medical Surgery –



It is articulated beam delivery system for use with CO_2 Laser in surgery.

This is for very careful control of the focus position on the workpiece, which may require manipulation of beam by an operator or machine vision system.

Industrial Application-

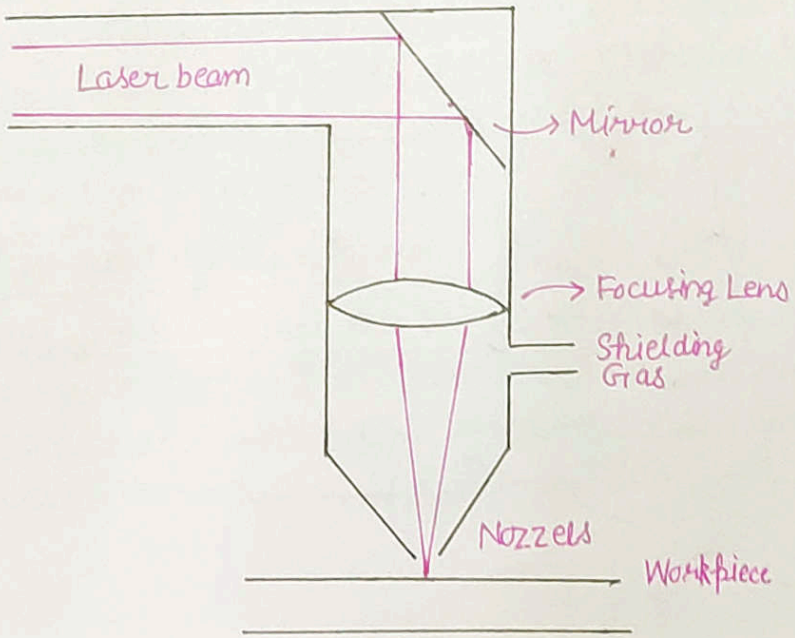
A detailed theoritical analysis of the interaction between a laser beam and a material surface is extremely difficult to carry out. The material parameters which must be taken into account including the reflection, thermal conductivity, Heat capacity, Latent Heat of fusion, Vaporization, melting point, boiling point, and absorption of laser radiation.

Nevertheless the theory enables orders of magnitude calculations to be undertaken to estimate quantities such as the temperature rise and rate of removal of material for given laser power inputs.

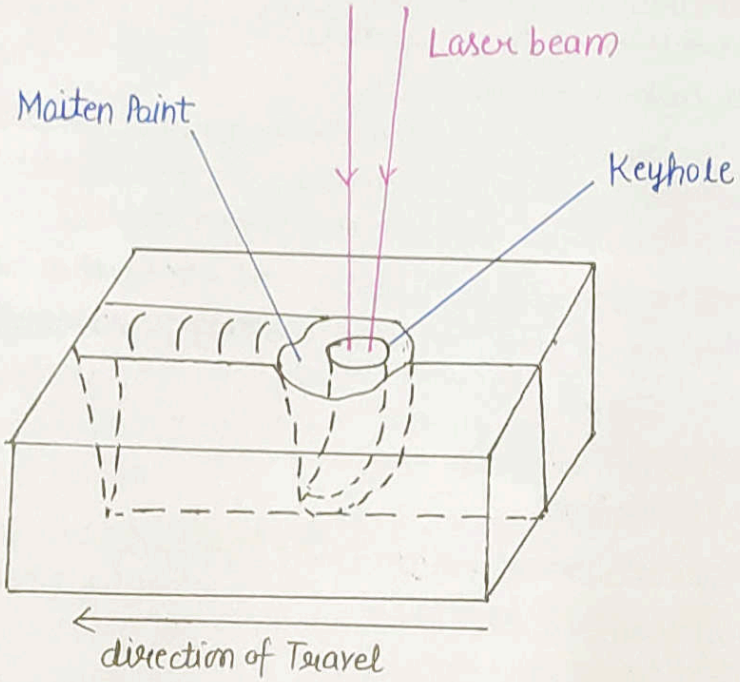
Laser welding has to compete with many well established such as soldering, Arc welding, Resistance welding, e- beam welding, Laser welding has no. of Advantages -

(i) Minimum Heat Input
(ii) Clean Technology
(iii) No physical contact with external components.
(iv) Weld dissimilar metals.
(v) Automated process.
(vi) Faster Weld rate.
(vii) High quality of resulting welds.

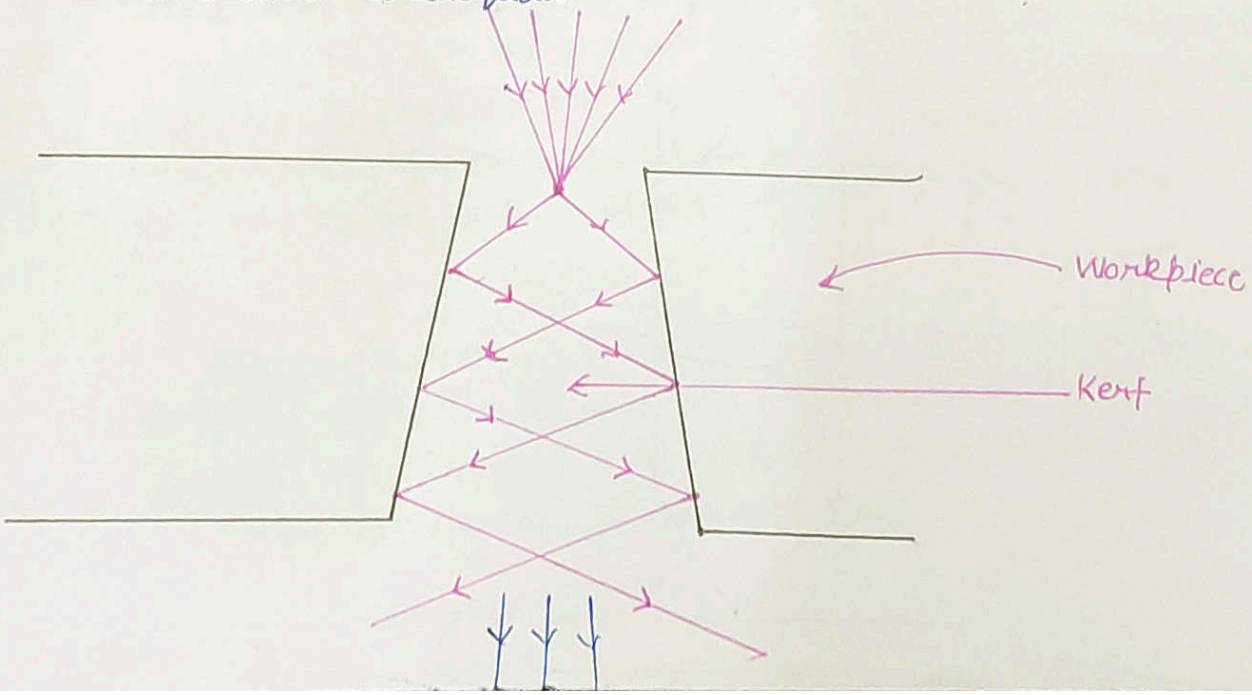
Welding is normally carried out using a shielding inert gas such as Ar or Hi.



When using multikilowatt CO_2 or high energy pulse mode lasers the welding process becomes rather more complicated. In these situations, when the laser beam first strikes the surface significantly amount of material may be vapourized forming a small hole known as a keyhole.



Laser cutting system are frequently essentially numerically method controlled system or robots. In this case of cutting sheet metal, for e.g a two axis numerical contral is adequate.



This was the sketch of Kerf product of Laser beam. The laser beam is channelled through the material by multiple reflections from the wall producing a waveguiding effect. A similar effect occurs in Laser drilling.

Medical Applications-

One of the most rapidly developing areas of laser applications is perhaps in medical. Many medical applications arise directly from the laser materials processing capabilities.

e.g.

CO_2 Laser ——→ General surgry.

Ruby Laser ——→ Detached Retinas

One of the most commonest application of medical is use of CO_2 lasers in general surgery. The 10.6 μm emission wavelength is strongly absorbed by water molecules present in tissues, and the subsequently evaporation of the water leads to the physical removal of tissues.

A resent introduced Er:YAG Laser emits at wavelength of 2.94 μm, which is also strongly absorbed by water molecule, and the laser is consequently particularly useful for precise, localized tissues removal or ablation.

One of the earliest applications in ophthalmology was in treatment of detached retinas using light from a ruby Laser.

The hole drilling capabilities of lasers have been used to drill holes (fistulas) of about 300 μm diameter through the sclera to reduce the increased intraocular pressure in the eye resulting from glucoma.

Laser can also be used in the treatment of cancer, particularly in otherwise inaccessible parts of the body, such as the larynx and neck of the womb. Indeed Laser radiation has been used very successfully for several years in the treatment of early stages of cervical cancer.

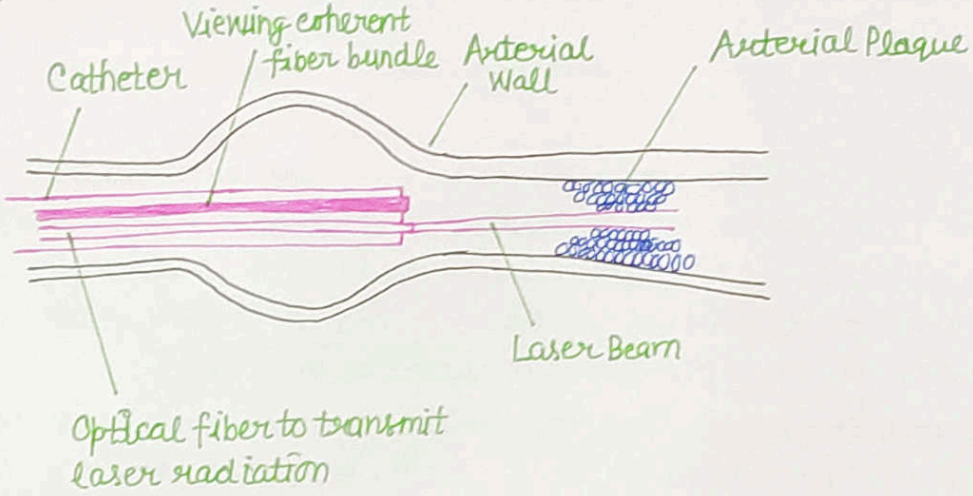
Laser Induced Nuclear Fission-

For many years, research has been directly towards a system for producing controlled their thermonuclear reactions to generate energy. Nuclear Fusion of light elements occurs within a very high temperature plasma such as exist in the sun.

A typical fusion reaction is

$$_{1}^{3}H + _{1}^{2}H \longrightarrow _{2}^{4}He + _{0}^{1}n + 14\,MeV$$

This reaction yields a helium atom and an energetic neutron. This Figure shows the removal of arterial plaque using laser radiation transmitted down a fine optical fiber inserted into the artery. A viewing fiber bundle is also included in the tube inserted into the artery.



UNIT - 3

FIBRE OPTICS

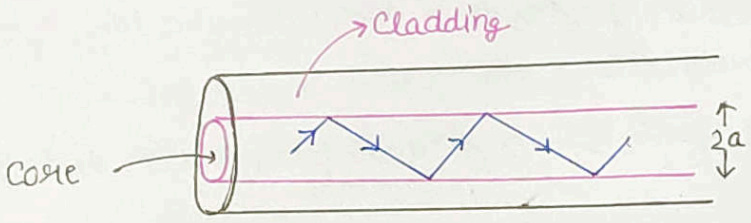
It has been realized that light with its carrier frequency of some 10^{14} Hz has a potential to be modulated at much higher frequency than either radio or microwave and thus opens up the possibilities of a single communication channel with extremely high information content.

difficulties aries -

(i) Need guided medium.

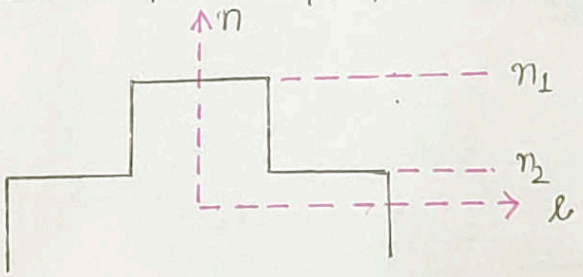
(ii) Atmospheric transmission limited.

Tyndall demonstrated that light could be guided within a water jet as a result of total internal reflection



optical Fibre Waveguide -

In their simplest form fiber optics have a cylindrical geometry with a core region surrounded by a cladding. As In planer waveguide the refractive index of the core is greater than that of cladding. Such fibers are referred to as step index fibers because of the shape of the refractive index profile.



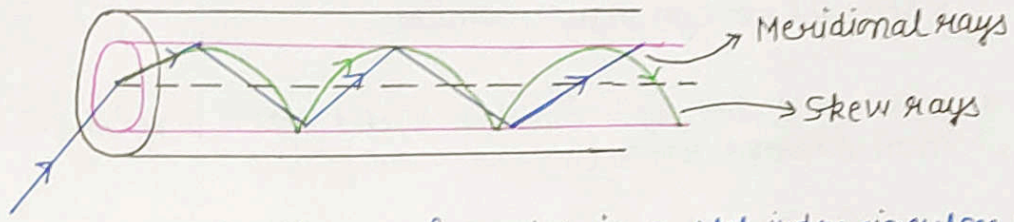
The resulting structure is often covered by an additional coating layer (usually of plastic) which serves to strengthen the fiber and to provide protection against chemical attack. As with the planer waveguide, radiation is restricted to travel down the guide in certain modes. With each mode corresponding to a distinct EMF distribution across the guide.

The equations describing the modes in circular waveguide are much more complicated then their planer waveguide countorparts and we make no attempt to derive them. However, we can take a number of concepts developing for planer waveguide and apply them.

We may devide the rays travelling within the fiber into two parts.

(a) Meridional Rays

(b) Skew Rays



As a planer waveguide the no. of modes in a step index circular waveguide is determined by the V parameter

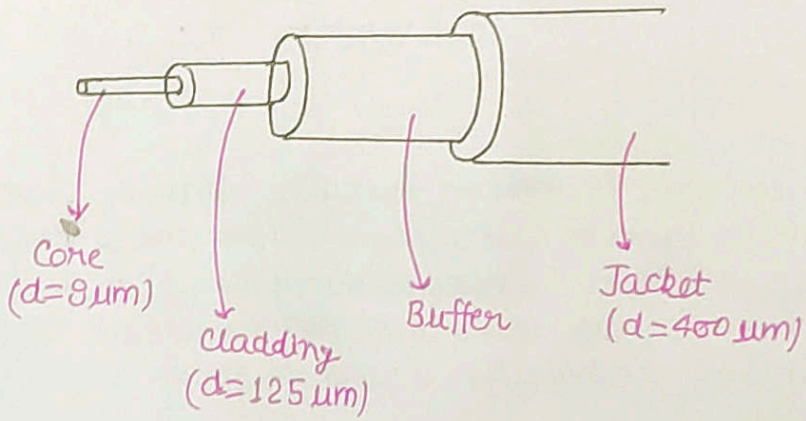
$$V = \frac{2\pi a}{\lambda_0}(n_1^2 - n_2^2)^{1/2}$$ → derived from planer dielectric waveguide

The fiber can support only one mode when $V < 2.504^4$ whilst when $V >> 1$ the number of modes N, than can propagate is given by

$$N \simeq V^2/2$$

Structure of fiber optics-

(II semester notes - linked)



Losses in fibers-

(1) Bending Losses- In multimode fibers, the principal bending loss mechanism arises from mode coupling. From there we conclude that bends in a multimode fiber can lead to the possibility that energy in a particular mode is coupled into a different mode.
When the fiber is bent into an arc of a circle, the loss is found to be strongly dependant on the radius of curvature and a semiempirical expression that is sometimes used to describe the loss is

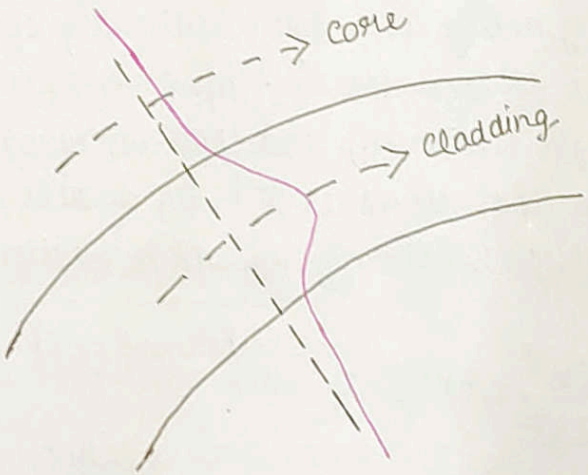
$$\alpha_B = Ce^{-R/R_c}$$

- α_B : absorption coefficient
- C : constant depends on the fiber parameter
- R : bend radius

(2) Intrinstic fiber losses- In this, we examine the losses in silica-based fiber that depend on the fiber material.



Small kinks or microbands can be formed when the fiber is pressed against a surface is not perfectly smooth.



This figure is illustration of the mechanism of radiation loss in fiber at bends. To maintain a plane waveform a part of the mode may have to travel at velocities greater than that of light in the cladding. Since this is not possible, this portion of the mode must be radiated away.

It is useful to consider the unit commonly used to characterize loss in fibers. This is $dB\,Km^{-1}$ and defined as follows: If a beam of optical power P_i is launched into one end of a fiber and if, after a length L of fiber, the power remaining in this fiber is P_f then the loss is given by

$$\text{Attenuation (loss)} = \frac{10\log_{10}(P_i/P_f)}{L} \; dB\,Km^{-1}$$

Losses intrinstic to silica fibers have two main sources;

(a) Scattering Losses

(b) Absorption Losses

(a) Scattering Losses-

Light propagate in fibers that the material is homogenous. Silica is an amorphous material and thus suffers from structural disorder. The same basic molecular units are present throughout the material but these are connected together in an essentially random way. This results in a fluctation in the refractive index through the material with each irregularity acting as a point scattering center. The scale of the fluctuation is of the order of $\lambda/10$ or loss, and the scattering is known as Rayleigh scattering and characterized by an absorption cofficient that varies as λ^{-4}. In details the absorption cofficient due to Rayleigh Scattering α_R can be written

$$\alpha_R = \frac{8\pi^3}{3\lambda^4} n^8 p^2 \beta K T_B$$

- n: Refractive index
- p: Photoelastic cofficient
- β: Isothermal compressibility at temp. T_B.

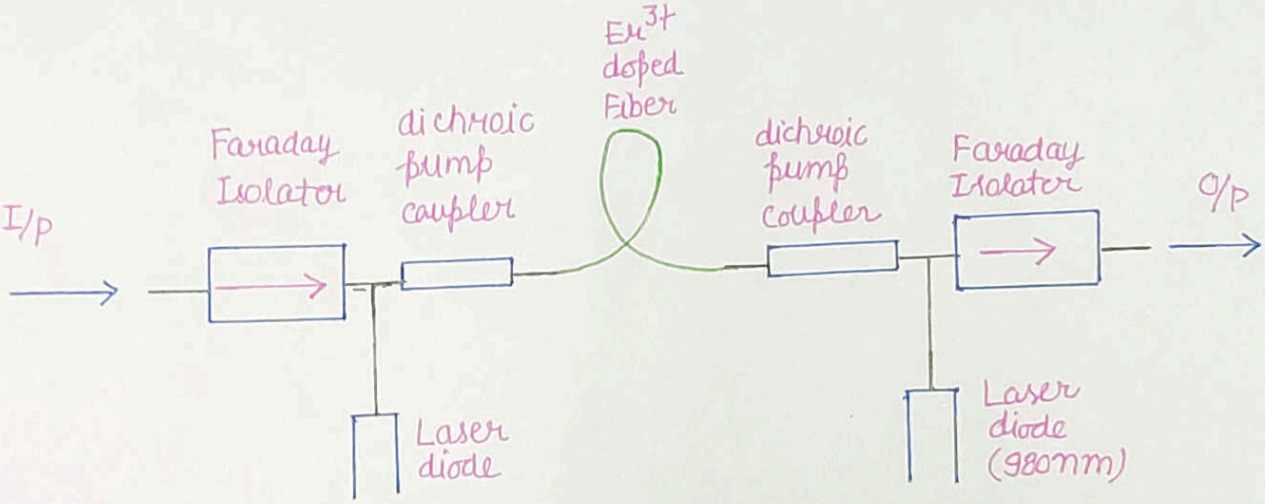
(b) Absorption Losses-

Absorption losses in the visible and IR regions arises mainly from the presence of impurities, trace of transition metal ions (Fe^{3+}, Cu^{2+}) or hydroxyl ions (OH^-).

Optical Fiber Amplifiers-

Optical Fiber amplifier is one of the key instruments for modern optical communication systems. A rare earth doped optical fiber amplifier, in which optical gain is provided by stimulated emission from rare earth elements, is the most widely used type of Amplifier.

Erbium, Praseodymium
Yetterium, Neodymium



Characteristics of fiber optics-

- Attenuation
- Chromatic dispersion
- Polarization dispersion
- Signal to noise ratio
- Self Phase modulation and cross Phase modulation
- Four wave mixing
- Raman and Brillion Scattering