Wave polarization

Polarization is a property applying to transverse waves that specifies the geometrical orientation of the oscillations. In a transverse wave, the direction of the oscillation is perpendicular to the direction of motion of the wave. A simple example of a polarized transverse wave is vibrations traveling along a taut string,for example, in a musical instrument like a guitar .The vibrations can be in a vertical direction, horizontal direction, or at any angle perpendicular to the string. In contrast, in longitudinal waves, such as sound waves in a liquid or gas, the displacement of the particles in the oscillation is always in the direction of propagation, so these waves do not exhibit polarization. Transverse waves that exhibit polarization include electromagnetic waves such as light and radio waves, gravitational waves, and transverse sound waves (shear waves) in solids.

An electromagnetic wave such as light consists of a coupled oscillating electric field and magnetic field which are always perpendicular to each other; by convention, the "polarization" of electromagnetic waves refers to the direction of the electric field. In linear polarization, the fields oscillate in a single direction. In circular or elliptical polarization, the fields rotate at a constant rate in a plane as the wave travels. The rotation can have two possible directions; if the fields rotate in a right hand sense with respect to the direction of wave travel, it .

Types of Polarization

Following are the three types of polarization depending on the transverse and longitudinal wave motion:

Linear polarization

Circular polarization

Elliptical polarization

Linear Polarization

In linear polarization, the electric field of light is limited to a single plane along the direction of propagation.

Circular Polarization

There are two linear components in the electric field of light that are perpendicular to each other such that their amplitudes are equal, but the phase difference is $\pi/2$. The propagation of occurring electric field will be in a circular motion.

Elliptical Polarization

The electric field of light follows an elliptical propagation. The amplitude and phase difference between the two linear components are not equal.

Refraction of light

When the light rays either bend or change their direction while passing from one medium to another it is called refraction of light. The refraction of light takes place when light travels from air into glass, from glass into air, from air into water or from water into air.

The example of optical instruments that work on the basis of refraction of light are camera, microscope etc.

Incident ray: The light rays passing from air into glass or water are called incident rays.

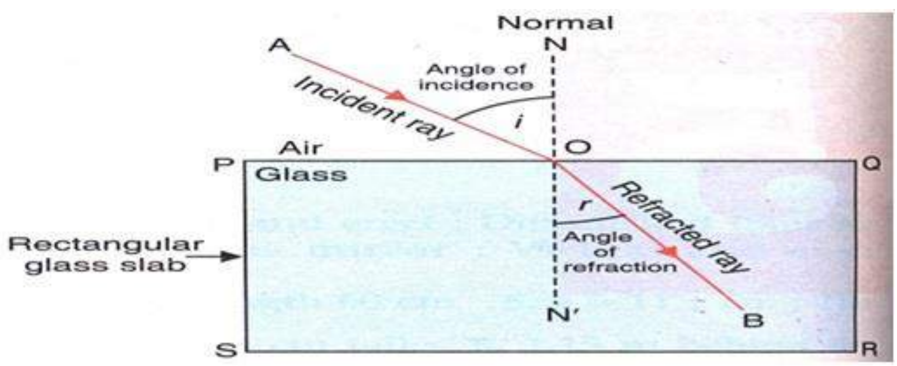
Refracted ray: When the light rays bend after passing into another medium, they are called refracted rays.

Normal: The point of incidence is called normal.

Angle of incidence: The angel between incident ray and normal is called angel of incidence.

Angle of refraction: The angel between refracted ray and normal is called angle of refraction.

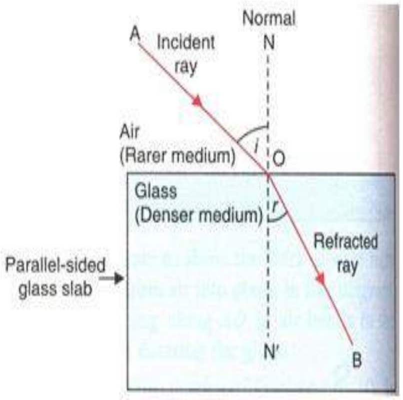
The angle of refraction is either smaller or greater than angle of incidence.



Rules for refraction of light

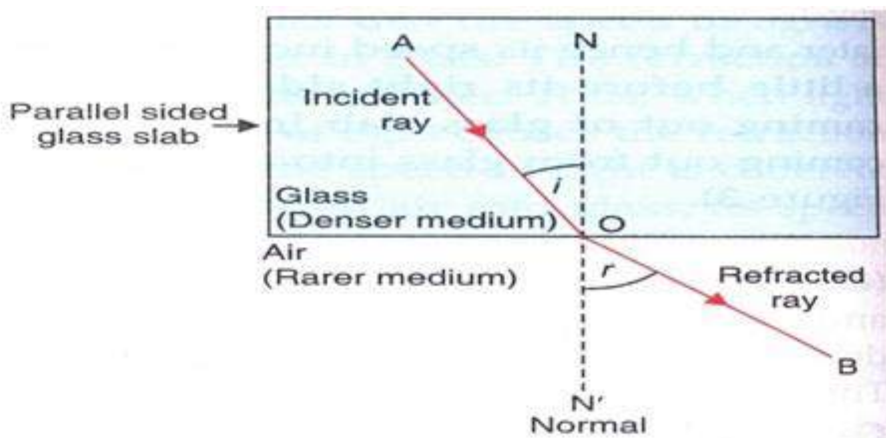
Case 1: When light rays travel from optically rarer medium to denser medium then they bend towards normal. In this case angle of refraction is smaller than angel of incidence.

When light rays travel from air into glass or from air into water, it bends towards normal. This is because the speed of light rays decrease while travelling from air into glass or water.



Case 2: When light rays travel from optically denser medium to rarer medium then they bend away from the normal. In this case the angle of refraction is greater than angle of incidence.

When light rays travel from glass into air or from water into air they bend away from the normal. The speed of light rays increase while travelling from glass or water into air.

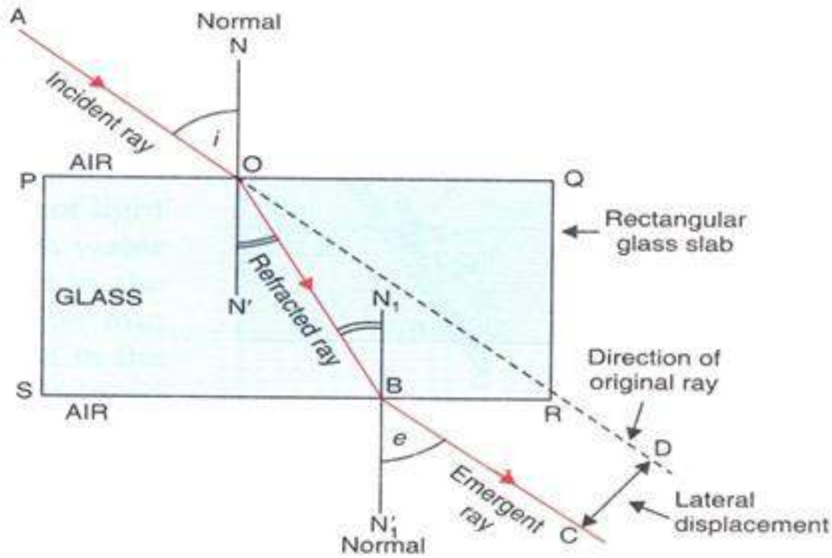


Case of light going from air into glass and again into air

In this case refraction of light takes place two times. One when it enters the glass slab from air and second time when it enters the air through glass slab.

When light rays travelling through air enters glass slab, they get refracted and bend towards the normal. Now the direction of refracted ray changes again when it comes out of the glass slab into air. Since the ray of light I know travelling from denser medium to rarer medium, it bends away from the normal.

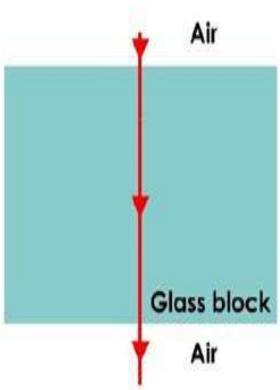
In this case incident ray and the emergent ray are parallel to each other. The perpendicular distance between the original path of incident ray and the emergent ray coming out of the glass slab is called *lateral displacement of the emergent ray of light* and the angle which the emergent ray makes with the normal is called the *angle of emergence*.



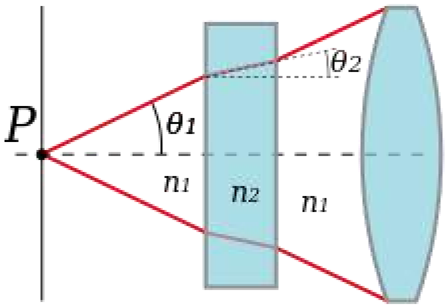
Light falling perpendicularly on glass slab

When light falls perpendicularly or normally on the surface of a glass slab, it goes straight. There is no bending of ray of light on entering the glass slab or coming out of it. In this case angle of incidence and angle of refraction is zero.

The same happens if the ray of light falls perpendicularly on the surface of water.



In optics, the **numerical aperture** (**NA**) of an optical system is a dimensionless number that characterizes the range of angles over which the system can accept or emit light. By incorporating index of refraction in its definition, NA has the property that it is constant for a beam as it goes from one material to another, provided there is no refractive power at the interface. The exact definition of the term varies slightly between different areas of optics. Numerical aperture is commonly used in microscopy to describe the acceptance cone of an objective (and hence its light-gathering ability and resolution), and in fiber optics, in which it describes the range of angles within which light that is incident on the fiber will be transmitted along it.



The numerical aperture with respect to a point P depends on the half-angle, θ_1, of the maximum cone of light that can enter or exit the lens and the ambient index of refraction. As a pencil of light goes through a flat plane of glass, its half-angle changes to θ_2. Due to Snell's law, the numerical aperture remains the same:

$$\mathrm{NA} = n_1 \sin\theta_1 = n_2 \sin\theta_2 .$$

Different modes in optical fiber

Basically optical fibers can be classified according to the number of modes they can propagate. Single mode fibers will propagate only the fundamental mode. Multimode fibers will propagate many number of modes say hundreds of modes. Though this is the case, classification of optical fibers depends on more than the number of modes that a fiber can propagate.

Refractive index profile and core size of an optical fiber are used to distinguish single mode and multimode fibers. The refractive index profile of an optical fiber describes the numerical value of refractive index as a function of radial distance at any fiber diameter. By using the refractive index profiles the classification of single mode and multimode fibers can be done as shown below:

Single mode step-index fibers

Single mode graded-index fibers

Multimode step-index fibers

Multimode graded-index fibers

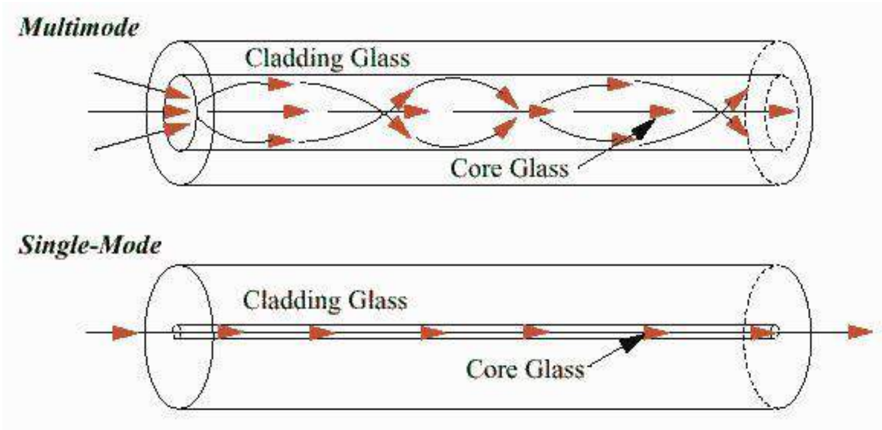
For a step-index fiber (both single mode and multimode optical fibers), the refractive index of the core is uniform throughout the cladding region and undergoes an abrupt change at the core-cladding boundary. Step-index fibers obtain their name from this abrupt change called the step change in refractive index. If we look at the profile drawn from the measured data of a step index fiber, it looks like a step up and step down on a staircase as shown below:

For a graded-index fiber, if we draw the refractive index from the cladding region to the core, we can see it varies gradually as a function of radial distance from the fiber center as shown in the diagram below:

Both Single mode and multimode optical fibers can have a step-index or graded-index refractive index profile. For a multimode fiber, the performance of graded-index fibers is superior compared to the step index multimode fibers.

Anyway, depending on the intended application, both type of multimode fibers improve system design and operation Performance. As far as single mode fibers are concerned, advantages for single mode graded-index fibers compared to single mode step-index fibers are relatively small. Almost all Single mode fibers have step index profile. Step index single mode fibers are denoted by SM MC or Single mode matched clad optical fiber.

Difference between single mode fiber and multi mode fiber



Single Mode cable is a single stand of glass fiber with a diameter of 8.3 to 10 microns that has one mode of transmission. Single Mode Fiber with a relatively narrow diameter, through which only one mode will propagate typically 1310nm or 1550nm. Carries higher bandwidth than multimode fiber, but requires a light source with a narrow spectral width. Synonyms mono-mode optical fiber, single-mode fiber, single-mode optical waveguide, uni-mode fiber.

Single-mode fiber gives you a higher transmission rate and up to 50 times more distance than multimode, but it also costs more. Single-mode fiber has a much smaller core than multimode. The small core and single light-wave virtually eliminate any distortion that could result from overlapping light pulses, providing the least signal attenuation and the highest transmission speeds of any fiber cable type.

Single-mode optical fiber is an optical fiber in which only the lowest order bound mode can propagate at the wavelength of interest typically 1300 to 1320nm.

Multimode cable is made of of glass fibers, with a common diameters in the 50-to-100 micron range for the light carry component (the most common size is 62.5). POF is a newer plastic-based cable which promises performance similar to glass cable on very short runs, but at a lower cost.

Multimode fiber gives you high bandwidth at high speeds over medium distances. Light waves are dispersed into numerous paths, or modes, as they travel through the cable's core typically 850 or 1300nm. Typical multimode fiber core diameters are 50, 62.5, and 100 micrometers.

However, in long cable runs (greater than 3000 feet [914.4 ml), multiple paths of light can cause signal distortion at the receiving end, resulting in an unclear and incomplete data transmission.

Optical Components

Sources-

LED

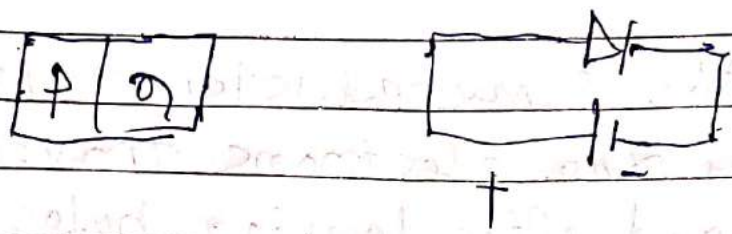
When the semiconductor materials are energised the electrons travel to the conduction band after leaving holes behind them. After some time the return to the valence band. and recombine with the holes In this proces they release some energy in the form of heat and photons. In some materials the most energy realeased are in the form of Photons (light energy).

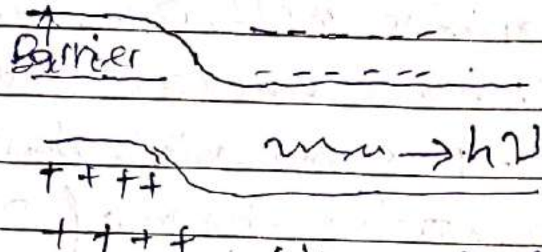
Materials used for led

Good LED materials should have the following specialities-

(a) Materials have the good injection and luminance efficiencies.
(b) Materials have the ability of fabricating a p-n junction.
(c) they should have the ability of exctracting most of the energy in the form of light. (photon)
(d) Materials used for LED is GaP, GaAsP, ZnSe, etc.

A pn junction semiconductor diode emits light when it is forward biased.





with applied forward voltage.

The led emits lights i.e. photons are generated in the ~~f~~ few area of pn junction. The emitted light is to be passed through the semiconductor for reaching the surface from where light is finally emitted to reach the eye of the observer.

The light reached to the observer's eye is less than the actual amount. Because

(a) The light available at the surface depends on the absorption coefficient of the semiconductor.

(b) The light faces another layer of medium (air) to reach the human eye.

To get max^m light to be extracted from the material the losses to be minimized.

Scanned with

Different types of LEDS designed.

The basic structures of LEDs are:-

(i) Surface emitting LEDS (SLEDS)
(ii) Edge emitting LEDS (ELED)

Configurations based on GaAs/GaAlAs have been used in short-haul applications while those based on InGaAsP/InP have been employed in medium-large fibre links.

Relatively large amount of (SLD) superluminance diode has also been used in nowadays optical communication systems.

(i) SURFACE-Emitting LED (SLED)

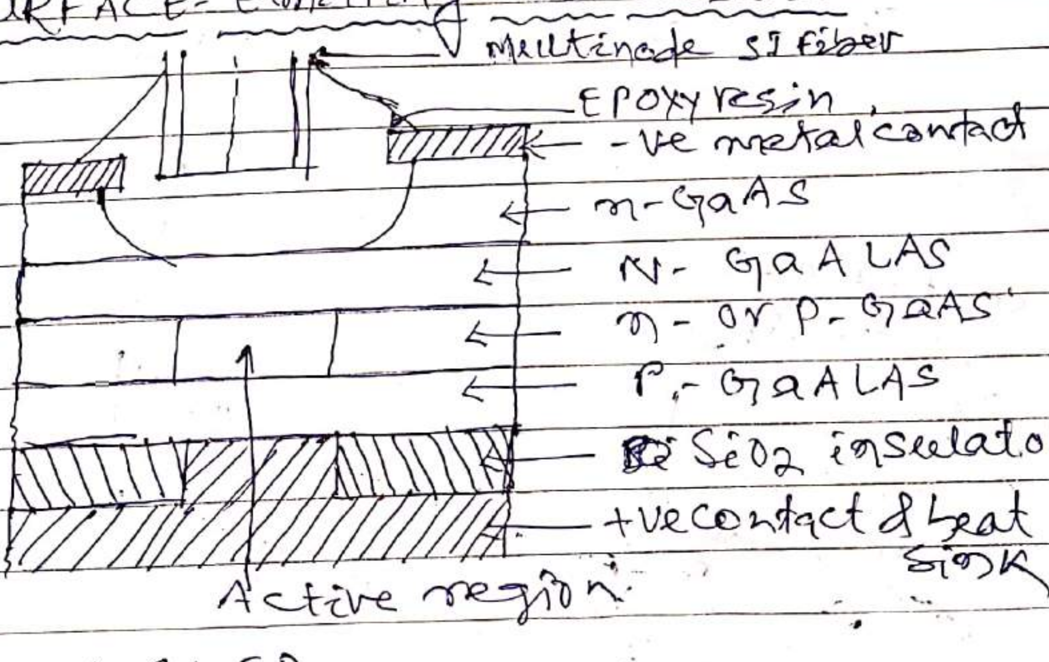


fig. A SLED.

When optical radiation is emitted in the active layer is taken out from the surface as shown in the above fig.

A well is etched to the GaAs substrate layer to avoide re-absorption of light emitted. It is called Burrus-type structure after the name of the scientist.

To increase the carrier density and hence recombination rate inside the active region the light-emitting area is restricted to a small region.

This is achieved by confining the injected current to this region through the electrical isolation of the rest of the area by a dielectric layer.

The heat generated by the device is conducted ~~by~~ away by mounting a heat sink near the hot region.

(ii) Edge-Emitting LEDs (ELED)

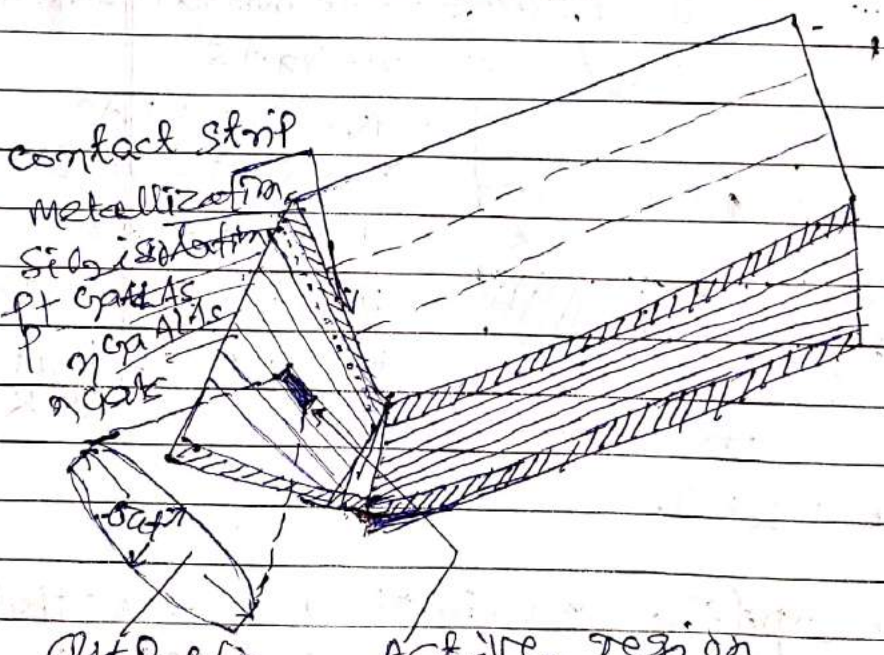


Fig. Stripe geometry DH ELED based on GaAs / GaAlAs.

DH-ELED is the basic structure of the high radiance for fiber-optic communi--cation.

The structure consists of 5 epitaxial layers of GaAs/GaAlAs. The active layer consists of smaller band gap. The positive contact is in the form of strip.

The recombination radiation generated in the active region is guided by internal reflection at the ~~the~~ heterojunction.

The rear end facet is made reflecting & and front end facet is coated antireflecting to avoid the laser action.

Advantages.

(a) Low working voltages.
(b) fast action
(c) Less power consumption.
(d) Small size and weight.
(e) Long life.

Applications.

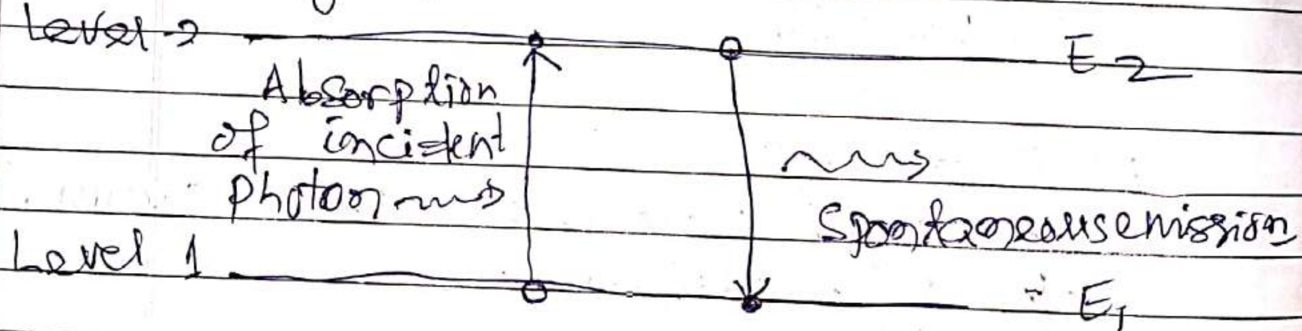
(a) Light source in optical comm.
(b) in Military use
(c) Narrow band light sensors
(d)

LASER

The word LASER stands for light amplification by stimulated emission of radiation.

Let us consider that the atom have only two energy levels. When a photon of energy $E_2 - E_1 = h\nu$; where h is plank's constant and ν is the frequency, interacts with an atom of such a system, there exists two possibilities.

(i) If the atom is in the ground state, with the energy E_1, the photon may be absorbed so that it is excited to the upper level of energy E_2. Subsequent de-excitation give rise to the emission of radiation in a random manner. This is called the spontaneous emission and is given



(ii) if the atom is already in the excited state, than the incident photon may stimulate a downward transition with the emission of radiation. photons emitted in such a manner have been found to be coherent with the stimulating photon i.e. both the stimulating.

The radiation in the form of electromagnetic waves emitted along the axis of the cavity form a standing wave pattern between the two mirrors. Hence all the waves which satisfy the condition given below will form standing wave pattern

$$L = \frac{m\lambda}{2n} = \frac{mc}{2nv}$$

λ = wave length in vacuum.

oscillations are sustained only for those modes which lie within the gain curve or the laser ~~to~~ transition line.

LASER Action in Semiconductor

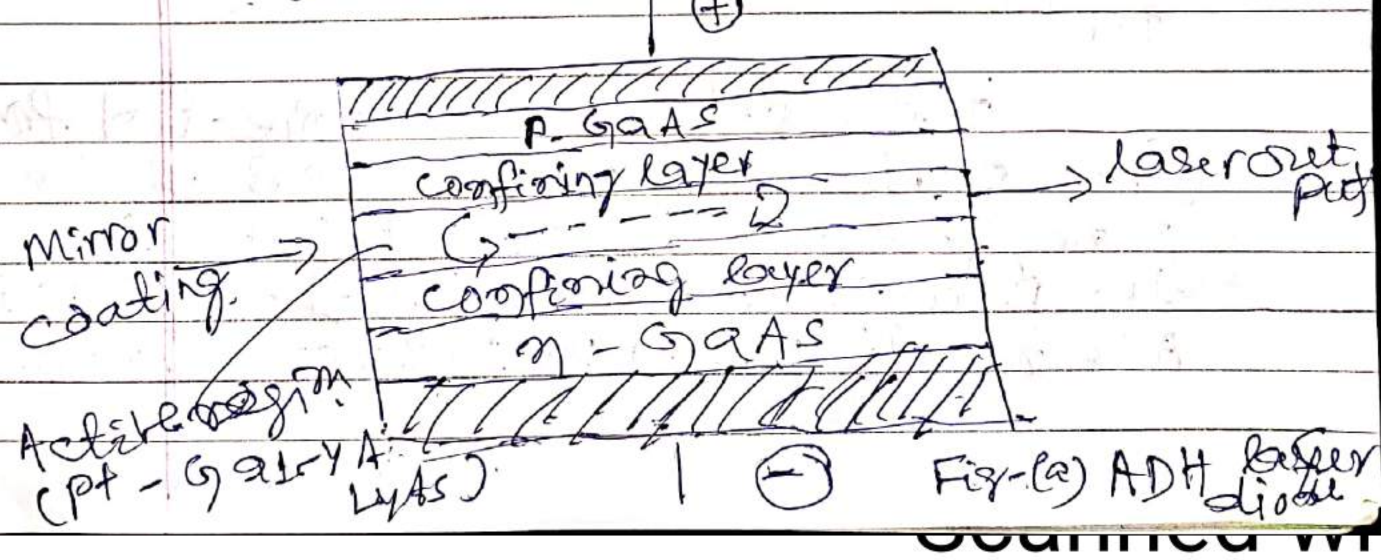
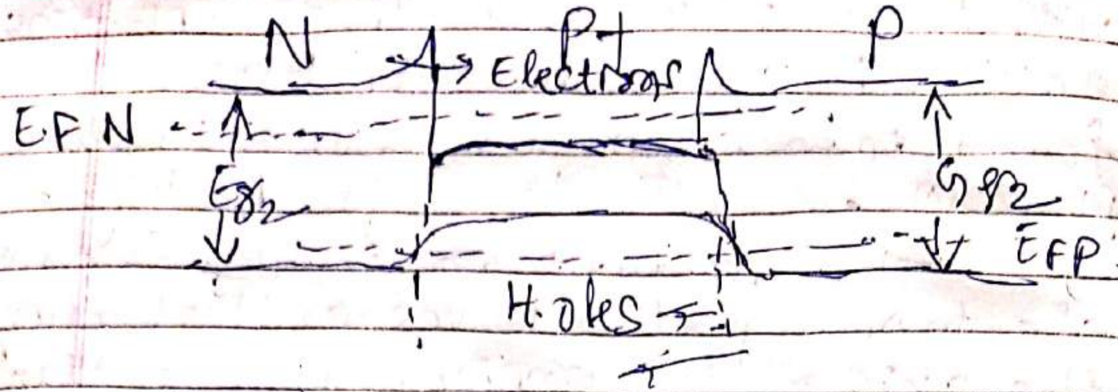


Fig-(a) ADH laser diode



Fig(b) Energy level diagram of laser Action.

Laser action in semiconductors may be achieved by forming an optical cavity in the active region of a DH, as shown in fig(a)

This configuration is analogous to a broad area DH-LED with the difference that the end faces of the crystal forming the active region along the longitudinal direction are clear so that they act as mirrors.

When the device is strongly forward biased the energy levels of the different regions of the N-p+-p, DH typically form as shown in fig(b)

The electrons are injected from the N-region in to the CB of the p-region and the holes are injected from the p-region in to the VB of the p-region. As a result population inversion occurs.

The refractive index of the active region is greater than the confining layer. So applied confinement in transverse direction. optical feedback occurs in longitudinal direction.

Thus the laser action takes place along the longitudinal direction.

continuous and pulsed laser.

A Laser can be classified as operating in either continuous or pulsed mode, depending on whether the power output is essentially continuous over time or whether its output takes ~~place~~ the form of pulses of light on one another time scale. Of course even a laser whose output is normally continuous can be intentionally turned on and off at some rate in order to create pulses of light. When the modulation rate is on time scale much slower the cavity life time and the time period over which energy can be stored in the lasing medium ~~of~~ or pumping mechanism, then it is still classified as as a 'modulated' or 'pulsed' continuous laser

10.

Uses

laser is used in every section of modern society

(i) consumer electronics

(ii) Information and technology

(iii) medicine

(iv) fiber optic communications.

and many more.

Date
Page

Fibere ~~opt~~ optic component.

couplers

A powerful aspect of an optical comm. link is that many different wavelengths selected from the optical regions will be sent through the single fibre.

This technology of sending different signals ~~the~~ in a number of wavelengths is known as wavelength Division multiple-xing (WDM)

Couplers are ~~th~~ devices that are used to combine and split optical signals. There are different types of couplers.

A simple 2x2 fiber-optic couplers consists of two input ports and two O/P ports as shown in the the fig below.

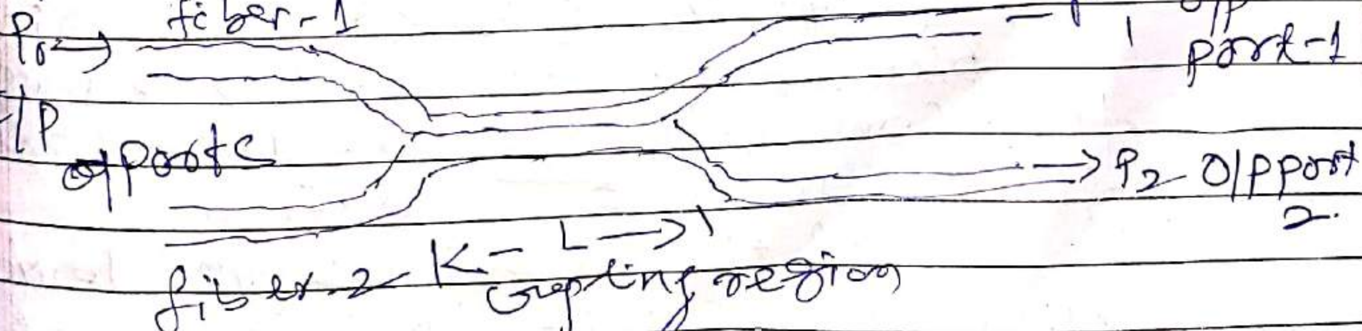


Fig- A 2x2 fiber optic coupler.

It can be made by fusing two optical fiber together.

Such devices can be made by fusing two optical fiber together in the middle and then stretching them so that a coupling region is created.

Such device can be made wavelength independent over a wide spectral range.

Hence an optical signal launched at input port 1 ~~can be~~ may be split into two signals and can be collected at the out put ports 1 and 2

The fraction of the power available at the output ports is called coupling ratio. ratio should be 1:99 to 50:50

A device which is coupled at 50:50 ratio is called a 3-dB coupler.

a coupler designed with a coupling ratio of 1:99 is used as an optical tap.

If the identical single mode fibers are used to make a 2×2 coupler. the coupler is said to be as Directional coupler because the fiber allows the launched light to pass through them in one direction.

if the ~~light allows~~ device allows the light to pass through in two opposite directions, it is called bidirectional coupler.

Losses in 2x2 coupler.

There are following losses in the coupler.

(i) Excess loss.

(ii) Insertion loss.

(iii) Cross talk loss.

(i) Excess loss - It is defined as the ratio in betn the input optical power at the i/p port to the optical power available at the o/p port. ~~Thats~~

(ii) Insertion loss. - It is measured from the i/p port to any one of the output port.

(iii) Cross talk - Due to the coupling region a part of the light signal reflected back to the port 2. This is called cross talk loss.

Fiber splicer.

A fiber splice is a permanent joint formed betwen two optical fiber

When the cable is broken or long cable required at that time splicing is needed. The objective is to establish long distance optical link.

Two ways in which splicing done. Those are.

(i) Fusion splices.

(ii) mechanical splices.

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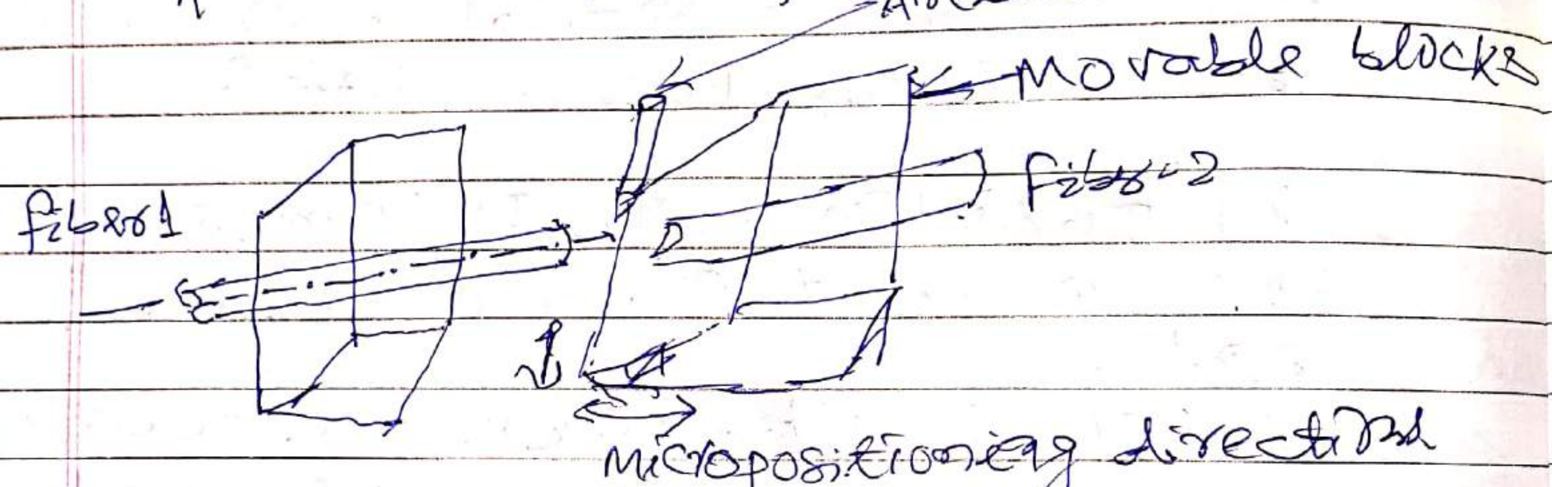
(i) Fusion splices:~

By fusion or welding type good quality of joint can be obtained.
Electric arc ~~splici~~ type of heating is generally used for ~~ꝑ~~ fusion.



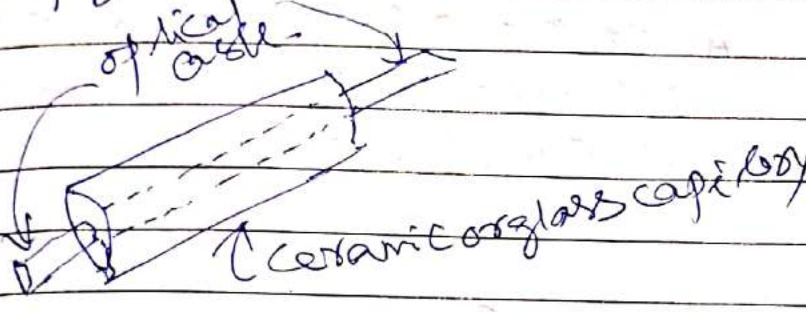
(Fusion splicing apparatus.)

Here the prepared fibre ends are placed in a precision allignment jig. The allignment is ~~st~~ done by a inspection microscope (not in fig)

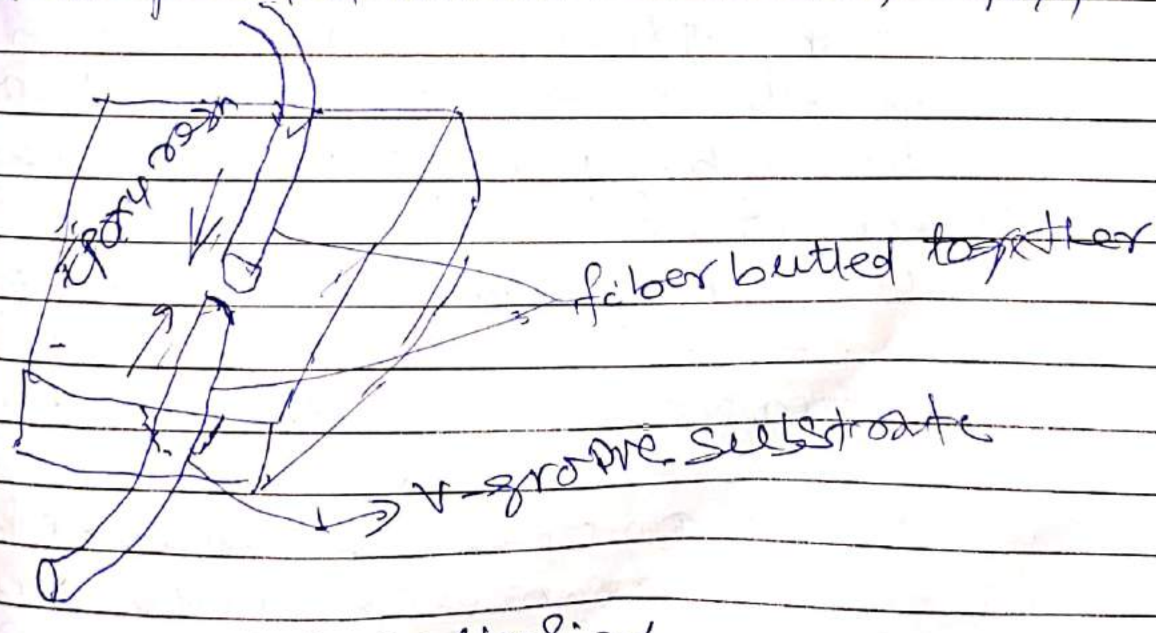
A short duration of arc discharg is given to the fibre ends. Then the two ends are pressed together and fused with a ~~sp~~ stronger arc producing a fusion splice.

(ii) Mechanical splices:~

Among a number of techniques the mostly used one is snug tube splice. It uses a glass or ceramic ~~coupling with inn~~ capillary with an inner diameter just large enough to acomodate the optical fibers as shown in the fig.



→ Other techniques of mechanical splicing normally employ V-groove. The simplex technique uses an open V-groove into which the prepared fiber ends are placed as given. The splice is accomplished with the aid of epoxy resin.



Multiple splices:~

For ribbon cables containing linear array of fiber, the following techniques are used as shown in fig.

Here the fiber ends are individually prepared and then placed in a groove substrate.

A cover plate retains the fibers in their position and also maintains mechanical shielding.

polarizers.

polarizer is an important device in fiber optic communication and sensor system.

The operational characteristics of many optical system depend on the polarization of the light guided in the optical fiber. polarization management is important in f.o.c, optical gyroscope sensor etc to avoid error and signal fading.

To obtain a high accuracy in measurement it is essential to have sightwise one polarization.

If the electric vectors of a group of transverse waves are at random angles, in all directions, the light on.

So polarization depends upon the electric vector in the plane. Fiber optic polarisations have been generated by using a crystal close to the core of the fiber using thin film.

Power coupled to fiber.

In a fiber optic communication system the optical source is coupled to the fiber at the transmitting end and the detector is coupled ~~to the~~ at the receiving end.

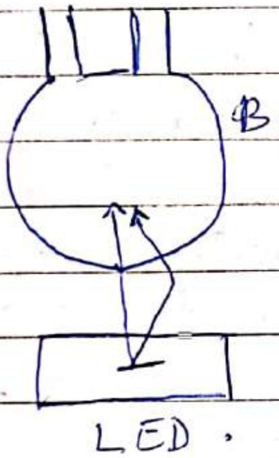
So performance depends how the coupling is done. As various types of sources and detectors coupled with the fiber, there are so many factors depends upon the the efficiency of the coupling system. Those are the size, radiance, refractive index of the fiber material.

Several steps have been suggested ~~for~~ and implemented to improve the efficiency,

(i) Some of them which are ~~emp~~ employed in communication purposes. DH-SLED (Double hetero structured or strip geometry ELED (edge-emitting LED) is used for short haul links and ILDs (Injection laser diode for long haul application.

(ii) second, the source is normally coupled with fiber in a way that optimizes the coupling efficiency:

One of the method utilize microlenses for coupling power into the fiber as shown below:-



Fig(a) Bulbended fiber coupled to SLED

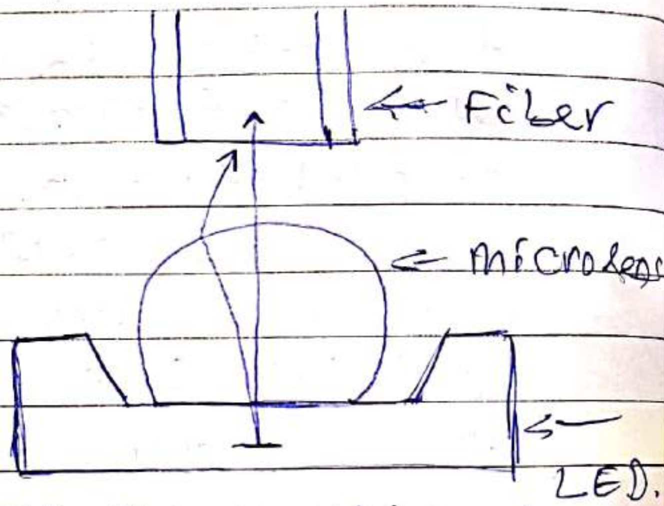


Fig (b) multimode fiber coupled to a Burrens-type SLED with truncated onion Lens

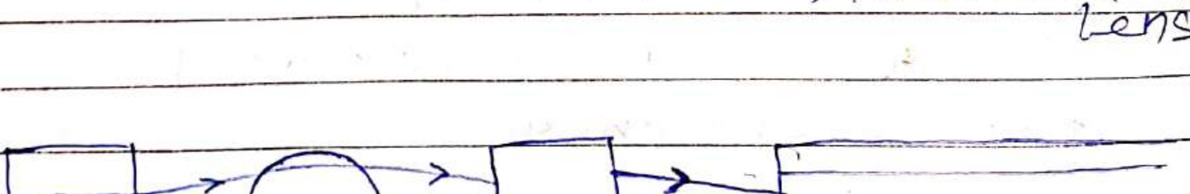


Fig (c) ILD coupled to a single mode fiber.

optoelectronic detectors.

Introduction:

In optical fiber communication system, the optical signal is required to be converted to the electrical signal at the receiving end. It is done by a optoelectronic detector.

These detectors should have high sensitive at the operating wavelength, high fidelity, fast response, high reliability, low cost and low noise.

Further, the size should be comparable with that of the core of fiber employed in the optical link.

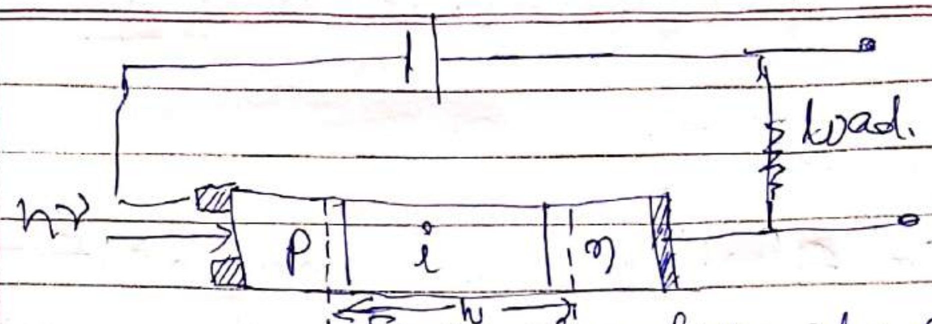
p-i-n-photodiode

p-n

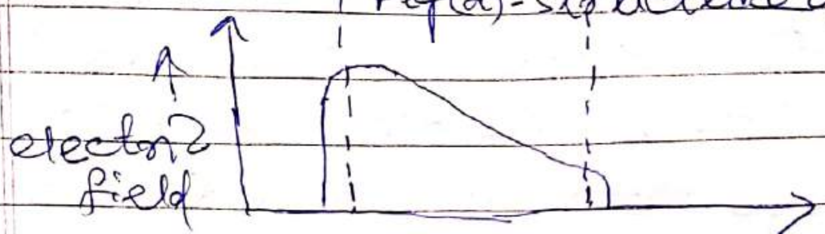
The diffusion component of a photo diode may be reduced by decreasing the width of the p-side and n-side and increasing the width of the depletion region, so that most of the photons are absorbed inside it.

To acheive this layer of semicon-ductor, it is so lightly doped that it seems as an intrinsic one.

Such a structure is called a p-i-n photodiode.



Fig(a)- structure of a p-i-n photo diode



Fig(b)- Electric field distribution inside the device under reverse bias.

As the middle layer is intrinsic in nature, it offers high resistance. So most of the voltage is dropped here. So across this region a strong electric field is being created.

This types of configuration dominates the diffusion component, due to ~~dif~~ drift of component of photo current. As most of the incident photons are absorbed inside the i-region.

The performance is ~~improved~~ of pin photodiode is improved due to a ~~dou~~ double heterostructure.

Here in, a the middle i-region is sandwitched betn the p and n type material of higher band gap. So the incident light only absorbed ~~by the~~ within the i-region such a configuration is shown below:-

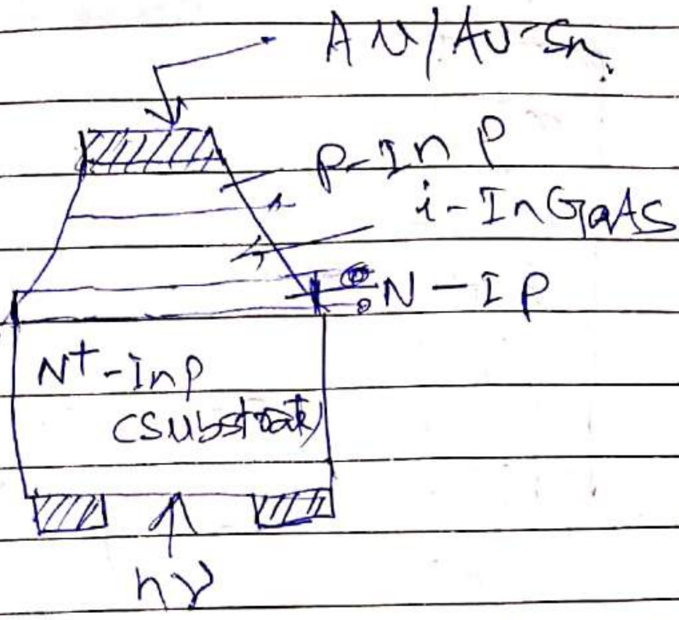


Fig- A double heterostructure (DH) design of a p-i-n photodiode using InGaAs/InP.

Here the band gap of InP is 1.35eV and hence it is transperent for light of wavelength greater than 0.92 μm, whereas the band gap of lattice ~~method~~ matched InGaAs is about 0.75 eV, which corresponds to a wavelength of 1.65 μm.

Hence, the intrinsic layer of InGaAs absorbs strongly ~~in~~ in the wavelength range 1.3—1.6 μm.

Such photodiodes are very useful for fiber optic systems operating in the range 1.3—1.6 μm.

Avalanche photo diode (APD)

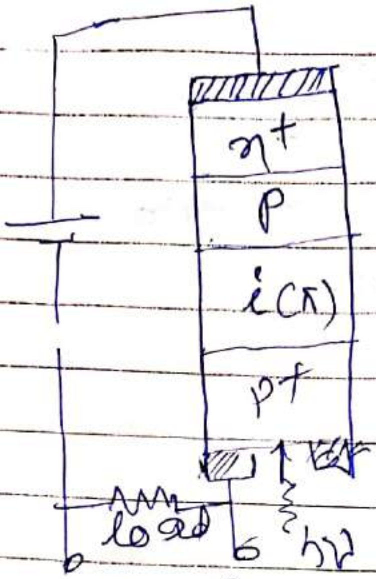


Fig- schematic configuration of a RAPD.

Avalanche photodiodes (APDs) internally multiply the primary photocurrent through multiplication of carrier pairs.

This increases receiver sensitivity because the photocurrent is multiplied before encountering the thermal noise associated with receiver ckt.

Through an appropriate structure of a photodiode, it is possible to create a high-electric field region within the device upon biasing.

The APDs are usually variation of p-i-n diodes. The semiconductor material used, and hence the spectral ranges are the same. one form of APD, is a reach through diode is given above.

Here n^+ and p^+ are heavily doped semiconductors and hence have very low resistance. The 'n' region is very heavily doped and hence nearly intrinsic.

Most of the incident light is absorbed in the region and electron hole pairs are generated. The electron moves towards the ~~p~~ p-region. The max^m voltage is dropped across p-n+ ~~region~~ junction. Here the multiplication is due to the electrons only. The holes that are generated drift toward the p+ and don't take part in multiplication process.

The RC time constant and the charge carrier transit time limit the response speed ~~of the~~ of the APD. The rise time limited by transit time range from few nanoseconds as low as a few tenths of a nano-seconds.

APDs having 100 ps have been achieved with both germanium and silicon.

These diodes are having excellent linearly over optic power levels ranging from a fraction of a nanowatt to several microwatt. APDs are not used rather the pin diodes are being used when the receiving power is more than micro watts.

The internal gain of the APD depends ~~of the~~ on the temp. The gain normally decreases as the temperature rises. It is due to the free path decrease at high temp. So many carriers don't get chance to reach the required velocities for producing secondary carrier.

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So APD ckt - temp compensation is needed over an extended temp. range.

The gain $G = \dfrac{1}{1-\left(\dfrac{V_d}{V_d}\right)^{n}}$

where V_d = carrier drift velocity

V_B : Break down voltage of the diode.

The current produced by an APD is purely dependent upon ~~are~~ the above gain.

The average no of carrier pair ~~is~~ K generated by an electron per unit length of the transversal is called the "electronic ionization rate" i.e. α_e.

Similarly the "Hole ionization rate" α_h can also be defined

The ratio $K = \dfrac{\alpha_h}{\alpha_e}$ is a ~~measure~~ measure of the performance of APDS.

An APD made of a material in which one type of carrier dominates impact of ionization exibits low noise and high gain.

The multiplication factor 'M' of an APD is a measure of the internal gain provided by the device.

It is defined as $M = I_M / I_P$ → (1)

where 'I_M' is average output current after multiplication and 'I_P' is the primary photo current before multiplication.

~~The performance of an APD is~~

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