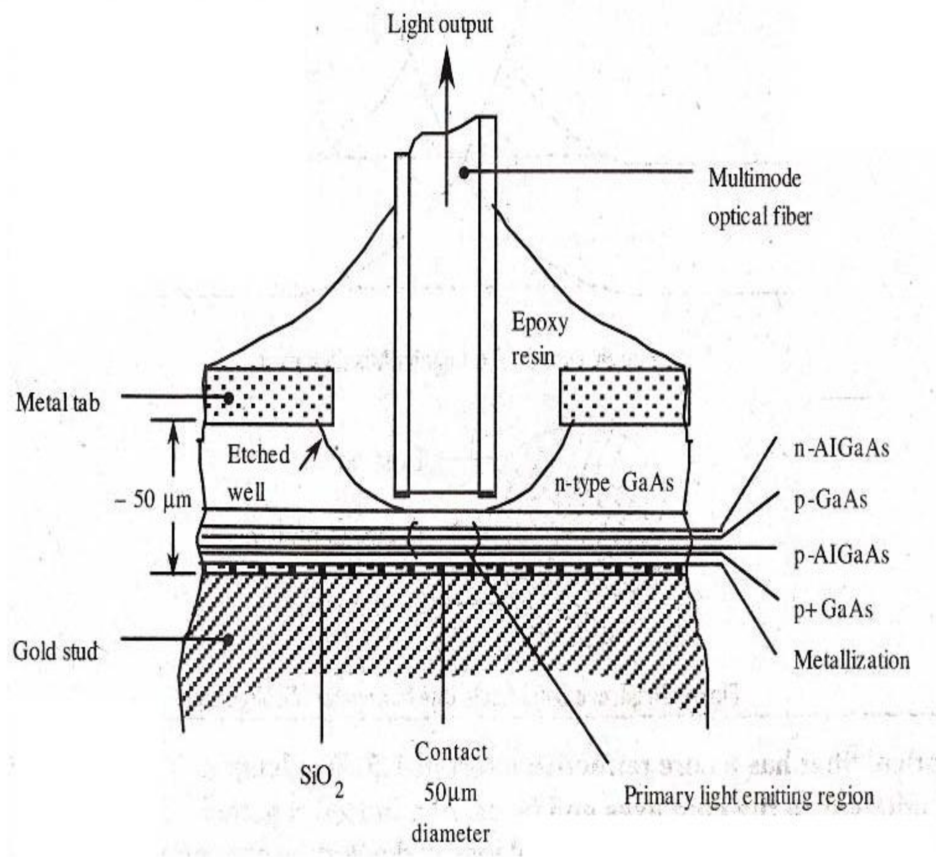
UNIT-IV

OBJECTIVES:
Optical sources- LEDs, Structures, Materials, Quantum efficiency, Power, Modulation, Power bandwidth product. Injection Laser Diodes- Modes, Threshold conditions, External quantum efficiency, Laser diode rate equations, Resonant frequencies, Reliability of LED&ILD, Optical detectors-Physical principles of PIN and APD, Detector response time, Temperature effect on Avalanche gain, Comparison of Photo detectors, Related problems.

HIGH RADIANCE SURFACE EMITTING LED:

High radiance is obtained by restricting the emission to a small active region within the device. A well is etched in a substrate (GaAs) to avoid the heavy absorption of the emitter radiation and to accommodate the fiber. These structures have a low thermal impedance in the active region and hence radiance emission into the fiber. Double hetero structures are used to get increased efficiency and less optical absorption. The structure of a high radiance etched well DH (Double Hetero structure) surface emitter which is also known as burrus type LED is as shown in The below figure. This structure emits light in band of 0.8 to 0.9 um wavelength. The plane of the active light emitting region is made perpendicular to the fiber axis. The fiber is cemented in a well matched through the substrate of the fiber so that maximum emitted light is coupled to the fiber. Due to large band gap conjoining area, the internal absorption is less and the reflection coefficient at the back crystal face is high, hence forward radiance is good. The active area in circle is of 50µm in diameter and up to 2.5µm thick. The emission from this active area is isotropic with 120° half power beam width is used for practical purpose. Isotropic pattern from a surface emitter is lambertian pattern.
The source is equally bright when viewed from any direction but power diminishes as cosΦ where $ is the angle between viewing direction and to the normal to the surface. Power is down to 50%, when Φ = 60°, so that the total half power beam width is 120°. The power coupled into a multimode step index fiber may be estimated from the relationship.



The Sturucture of an AlGaAs DH surface - Emitted LED(Burrus Type)

Where

$$P_C = \Pi(1-r)AR_D(NA)^2$$

P_C = Power coupled into fiber

r = Fresnel reflection coefficient

A = Emission area of source

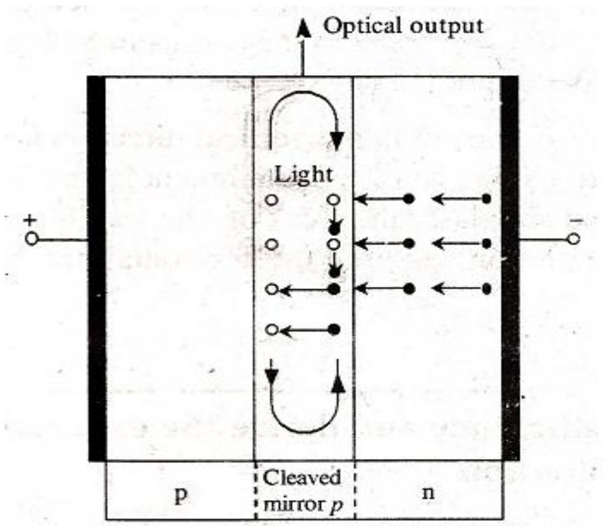
R_D = Radiance of the source

NA = Numerical aperture

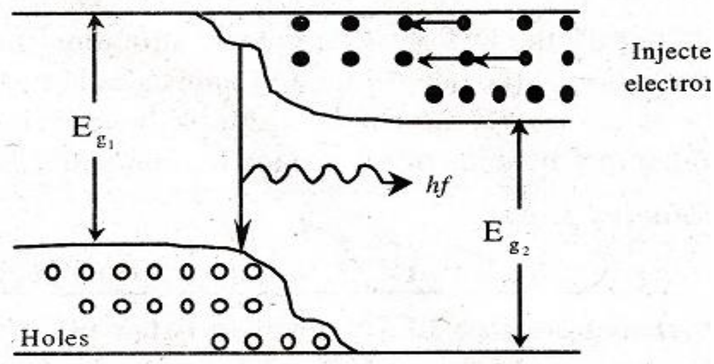
Power coupled into the fiber depends on
(i) Distance and alignment between emission area and the fiber.
(ii) Medium between the emitting area and the fiber.
(iii) Emission pattern of SLED
Addition of Epoxy resin in the etched well reduces the refractive index mismatch and increases the external power efficiency of the device. Hence the power coupled in the double hetero structure surface emitters are more than Pc(optical power) that is given by the above equation , For graded index fiber-direct coupling requires the source diameter of about one half the fiber core Diameter.

DOUBLE HETERO JUNCTION LASER:

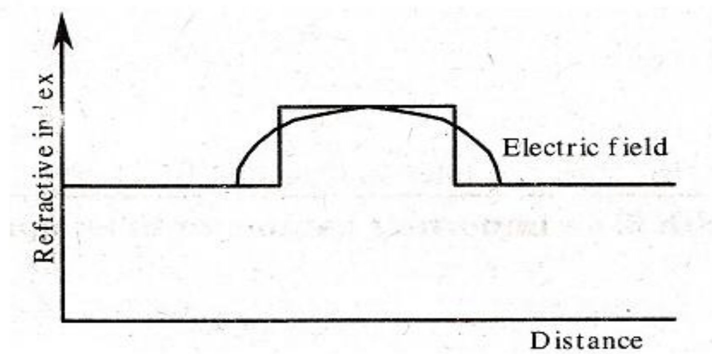
If a single p-n junction diode is fabricated from suitable single crystal semiconductor material it exhibits photo emissive properties. It is known as 'homo junction' p-n diode. However the emissive properties of a junction diode can be improved considerably by the use of 'hetero junction'. A hetero junction is an interface between two adjoining crystal semiconductors having different values of band gap energies. Devices are fabricated with hetero junction are said to have hetero structures.
They are of two types,
(i) Isotopes such as n-n or p-p type
(ii) An isotope such as p-n type.
The isotope p-p junction has a potential barrier within the structure. The structure is capable of confining min carriers to small active region called cavity. It effectively reduces the diffusion length of the carrier and thus the volume of the structure where radioactive recombination may occur.



Layer Structure



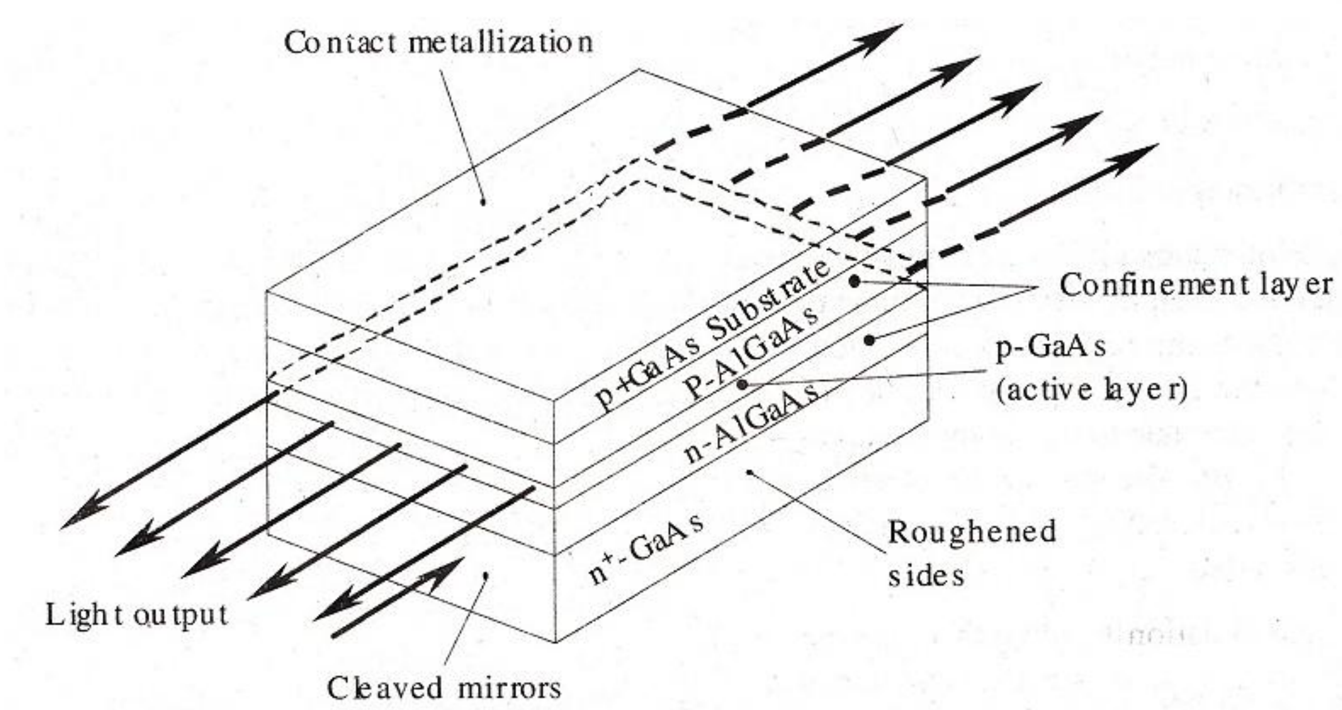
Energy Band Diagram



Refractive index Profile and Electric field distribution

Figures show the schematic layer structure, energy band diagram and refractive index profile, for a double hetero junction injection laser diode with biasing. The laser oscillations take place in the central p-type GaAs region which is known as active layer. There is hetero junction at the both sides of the active layer. A forward bias voltage is applied by connecting the positive electrode of the power supply voltage to the P-side of the structure and negative electrode to the n-side when a voltage which is almost equal to the band gap energy. The hetero junctions are used to provide potential barrier in the injection laser. In this structure it is possible to obtain both carrier and optical containment to the active layer.

BROAD AREA DOUBLE HETEROJUNCTION LASER (DH LASER):

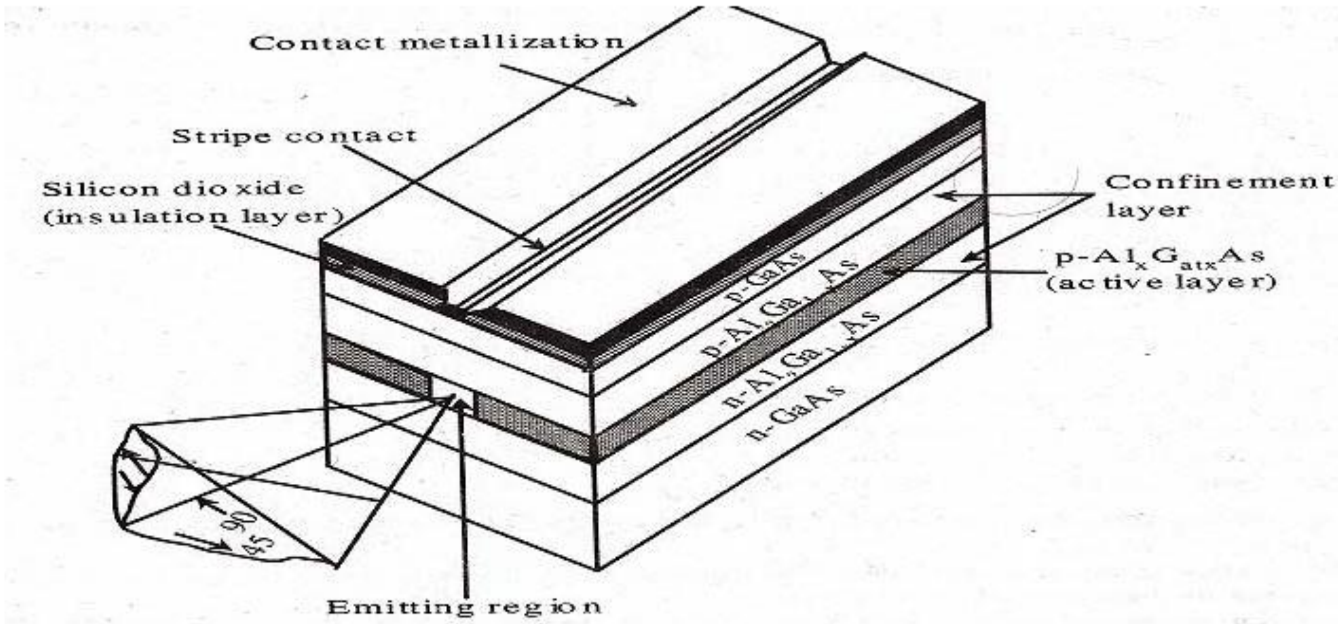


The layered structure of a Based Area GaAs/GaAs DH injection laser

The above figure represents the layer structure of a broad area DH. The GaAs layers acts as active layer which is sandwiched between p-type AZGaAs and n-A/GaAs layer and these two layers act as the confinement layers. Light is emitted from the central GaAs active layer through the front and back side of the device. In the case of the DH broad area laser structure, the optical confinement in the vertical direction is achieved by the refractive index at the hetero junction interfaces between the active layer and the containment layers, but the laser .action takes places across the whole width of the device. In a broad area laser the sides of the cavity are formed by simple roughening the ends of the device to reduce the unwanted emission and limit the horizontal transverse modes.

STRIPE GEOMETRY LASER:

In order to overcome the difficulties in a broad area laser structure, the stripe geometry laser structure has developed and in this structure the active area does not enter up to the edges of the device.



The Stucture of Strips Geometry Laser

A common method is used to introduce the stripe geometry to the structure which provides the optical contaminant in the horizontal plane as shown in the figure above. The stripe geometry is usually formed by creating a high resistance area on either side of the stripe by 'Proton bombardment' technique or by oxide oscillation. The stripe usually acts as a guiding mechanism which avoids all major difficulties encountered in the case of a broad area laser. The contact stripe provides the balance of guiding single transverse mode operation in a direction parallel to the junction plane, whereas broad area devices allow multiple mode operation in this horizontal plane. The width of the stripe generally ranges from 2.0 to 65 mm and stripe laser find wide application in fiber communications.

POPULATION INVERSION:

The lifetime of an atom in excited state is of the order of 10~8 seconds. So before an excited atom can be stimulated to emit a photon, it is most likely to make a spontaneous emission. The photons emitted by a spontaneous emission are not coherent. The ratio of the number n' of excited atoms to that of n in the ground state is given by the Boltzmann's equation.

$$n'/n = e^{-W/kT}$$

W = Energy difference between excited state and ground state;

K = Boltzmann constant

T = Kelvin temperature.

Consider three level system in which three active energy levels E1, E2 and E3 are present and population in those energy levels are N, $1 and 7V3 respectively. In normal conditions E1< E2 < E3 and N1 > N2 >N3

E1 is the ground state, its lifetime is unlimited.E3 is highest energy state, its lifetime is very less and it is the most unstable state. E. is in excited state and has more life time. Hence E2 is a Meta stable state. When suitable form of energy is supplied to the system in a suitable way, then the atoms excite from ground state (E1) to excited states (E2 and E3). Due to un stability, Excited atoms will come back to ground state after the Life time of the respective energy states E2 and E3 If this process is continued then atoms will excite continuously to E2 and E3 Because E3 is the most unstable state, atoms will fall into E2 immediately. At some stage the population in E2, will become more than the population in ground state. This situation is called population inversion and is shown in the below figure .There are several ways of pumping a laser and producing population inversion necessary for Stimulated emission to occur.

Most commonly used methods are as follows.

1. Optical pumping
2. Electric discharge
3. Inelastic atom to atom collision
4. Direct conversion
5. Chemical reactions.

The emission process can occur in two ways

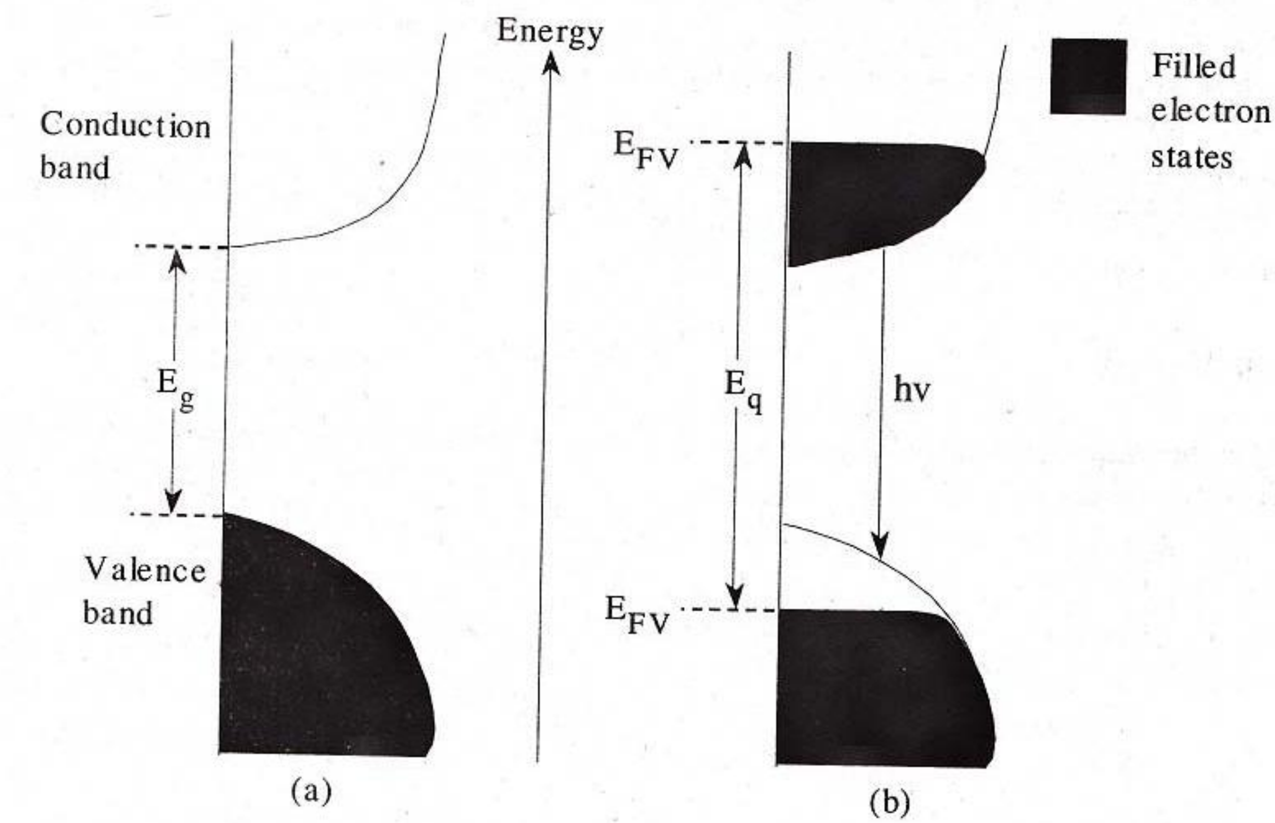
(i) Spontaneous Emission

The electrons in the excited state E2 are unstable. They return back to the lower energy state without any external influence. This process leads to spontaneous emission.

(ii) Stimulated Emission

When an external photon of energy which is equal to the energy difference between two states (E2 – E1) hit the excited electron, this excited electron return to the ground state (E1) by emitting a photon of energy hv12. This emission is known as stimulated emission. Semiconductor laser diodes are preferred over LED for the optical fiber communication systems requiring bandwidth greater than approximately 200 MHz

Laser diodes have
(i) Response time less than 1 ns
(ii) Optical bandwidth of 2nm
(iii) High coupling efficiency



The filled Electron states for an intrinsic Band Gap Semi conductor at obsulte zero (a) Equilibrium (b) With high carrier injection

For the efficient functioning of laser the method of exciting electrons in atoms is from,

1. Lower energy levels to higher energy levels.
2. Lower energy levels to large population inversion high energy level.

The stimulated emission in semiconductor laser arises from optical transitions between distributions of energy state in the valence and conduction bands. Stimulated emission is achieved in an intrinsic semiconductor by the injection of electrons into the material. Figure represents the electron states for an intrinsic direct band gap semiconductor at absolute zero.

The population when the conduction band contains no electrons is injected into the material, fill the lower energy states in the conduction band gap up to the injection energy or quasi Fermi level for electrons.
Since the charge is neutrally conserved with the material, an equal density of holes is created in the top of the valence band by the absence of electrons as shown in the figure (b). Since more electrons are there in valence band than the conduction band population inversion is achieved.

THE EXPRESSION FOR THE 3DB MODULATION BANDWIDTH OF LED:

The expression for the 3 dB modulation bandwidth of LED in optical communication may be obtained in either electrical or optical terms. If we consider the associated electrical circuitry in an optical fiber communication system to use the electrical definition, where the electrical signal power has dropped to half of its constant value due to the modulated portion of the optical signal. Hence, this corresponds to the electrical 3 dB frequency at which the output electrical power is reduced by 3 dB with respect to the input electrical power. We can also consider the high frequency 3 dB point, when the optical source operates down to D.C. The expression for the electrical bandwidth can be obtained from the ratio of the electrical output power to the electrical input power in decibels and is given as

$$RE_{dB} = 10\log_{10}(\text{Electrical output power /Electrical input power})$$

$$= 10\log_{10}\frac{\frac{Iout^2}{Rout}}{\frac{Iin^2}{Rin}}$$

$$= 10\ \log_{10}\left[\frac{I_{out}}{I_{in}}\right]^2$$

The electrical 3 dB points occur when the ratio of electrical powers shown in above expression is $\sqrt{2}$ Hence, it follows that this must Occur when,

$$\left[\frac{I_{out}}{I_{in}}\right] = 1/\sqrt{2}$$

Thus this expression depicts that the bandwidth of the electrical regime may be defined by the frequency when the output current has dropped to 1/√2 (or) 0.707 of the input current of the system.

Optical bandwidth can be obtained from the ratio of the optical power output to optical power input in decibels RO_{dB} is given by

$$RO_{dB} = 10 \log_{10} \frac{\text{optical power output}}{\text{optical power input}}$$

$$= 10 \log_{10} \frac{I_{out}}{I_{in}}$$

Hence, the optical 3 dB points occur when the currents is equal to 0.5,hence

$$\frac{I_{out}}{I_{in}} = 0.5$$

Therefore In optical regime the bandwidth is defined by the frequency at which the output current has dropped to 0.5 of the input current to the system.

The Modulation bandwidth of LED is generally determined by three methods ,They are

1. The doping level in the active layer,
2. Due to the injected carriers, the reduction in radiative lifetime.
3. The parasitic capacitance of the device.

If we assume that the parasitic capacitance is negligible, then the speed at which an LED can be directly current modulated is fundamentally limited by the recombination lifetime of the carriers,

$$\frac{P_e^{(\omega)}}{P_{dc}} = \frac{1}{[1 + (\omega\tau_i)^2]^{\frac{1}{2}}}$$

Where

$P_e^{(\omega)}$ = Optical output power of the device

ω= Angular modulation frequency.

τ_i = Injected carrier lifetime in the recombination region

P_{dc} = D.C. optical output power for the same drive current

ADVANTAGEOUS OF LED:

1. Simple Fabrication: There are no mirror facets and is some structures no striped geometry

2. Cost: The simpler construction of LED leas to much reduced cost which is always likely to be maintained.

3. Reliability: The LED does not exhibit catastrophic degradation and has proved to be less sensitive to gradual degradation than the injection laser.

4. Simpler Drive Circuitry: This is due to lower drive currents and reduced temperature dependance which makes temperature compensation circuits unnecessary.

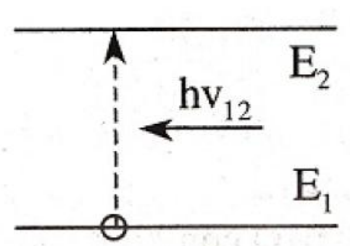
5. Linearity: Ideally, the LED has a linear light output against current characteristics unlike the injection laser.

DISADVANTAGEOUS OF LED: An LED radiates rather dispersed light, which makes coupling this light into an optical fiber a problem.

THE KEY PROCESSES INVOLVED IN LASER ACTION ARE AS GIVEN BELOW:

(i) Absorption.
(ii) Spontaneous emission.
(iii) Stimulated emission.
These three key processes are represented by 2-energy level diagrams.
Where, E1= Energy of ground state.
E2 = Energy of excited state.

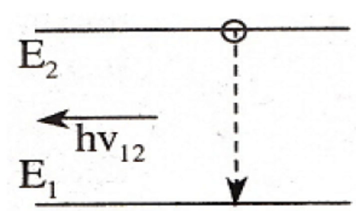
(i) Absorption



When transition occurs between two states, then it involves the emission and absorption of energy in the form of photon energy $hv_n = E_2 - E_1$

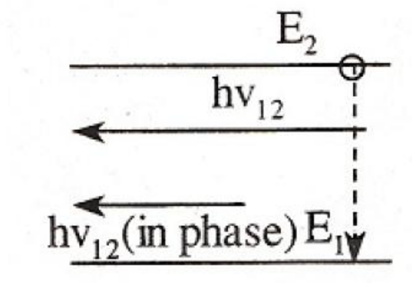
In the above figure we can see that electron in 'E_1' absorbs the photon energy and is excited to state 'E_2' when photon of energy hv_n is incident on the system.

(ii) Spontaneous Emission



Charge carriers are unstable in excited state so they try to come back in stable state and this is possible by emission of radiation. This emission takes place when energy hv_v is released. As it occurs without any external stimulation, it is known as spontaneous emission.

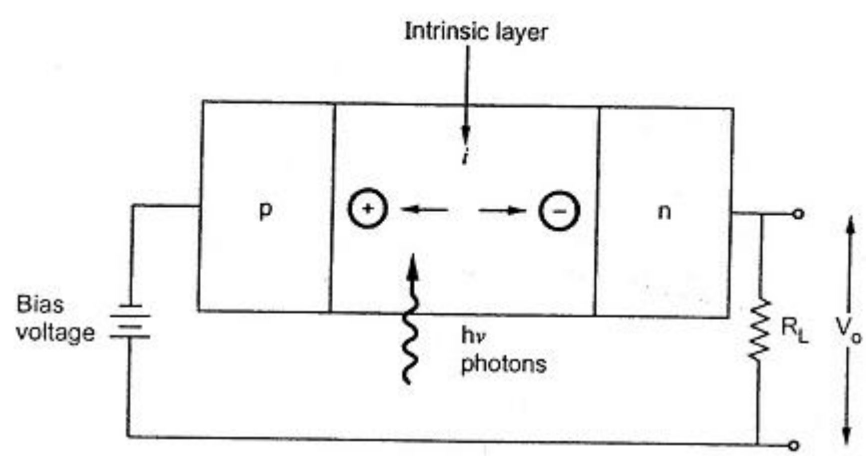
(iii) Stimulated Emission



Here in this type of emission when a photon of energy hv_{12} is striking on system while the electron is still in its excited state, then the electron is stimulated so that it drops on to ground state and gives a photon of energy hv_n and the emitted photon will be in phase with incident photon. The resultant emission is called as stimulated emission.

PIN PHOTODIODE:

PIN diode consists of an intrinsic semiconductor sandwiched between two heavily doped p-type and n-type semiconductors as shown in the below Figure. Sufficient reverse voltage is applied so as to keep intrinsic region free from carriers, so its resistance is high, most of diode voltage appears across it, and the electrical forces are strong within it. The incident photons give up their energy and excite an electron from valance to conduction band. Thus a free electron hole pair is generated; these are called as photo carriers. These carriers are collected across the reverse biased junction resulting in rise in current in external circuit called photocurrent.



PIN Photodiode

In the absence of light, PIN photodiodes behave electrically just like an ordinary rectifier diode. If forward biased, they conduct large amount of current. PIN detectors can be operated in two modes, Photovoltaic and photoconductive. In photovoltaic mode, no bias is applied to the detector. In this case the detector works very slow, and output is approximately logarithmic to the input light level. Real world fiber optic receivers never use the photovoltaic mode. In photoconductive mode, the detector is reverse biased. The output in this case is a current that is very linear with the input light power. The intrinsic region somewhat improves the sensitivity of the device. It does not provide internal gain. The combination of different semiconductors operating at different wavelengths allows the selection of material capable of responding to the desired operating wavelength.

PHOTO DETECTOR:

Photo detector is an essential component of an optical fiber communication system. Its function is to convert the received optical signal into an electrical signal which is amplified before further processing. The requirements for photo detector can be given as follows.

1. They should have high sensitivity at operating wavelength.
2. It should have high fidelity to reproduce the original waveform effectively.
3. It should produce maximum electrical signal for a given amount of optical power.
4. It should have short response time to obtain a suitable bandwidth.
5. Dark currents, leakage currents, shunt conductance should be low.
6. Performance characteristics should be independent of changes in ambient conditions.
7. The physical size of detector must be small for effective coupling.
8. Detector should not require excessive bias voltages or currents.
9. It must be highly reliable and must be capable of continuous stable operation at room temperature.
10. It should be economical. The detector must satisfy the above requirements of performance and compatibility.

PHOTODIODE:

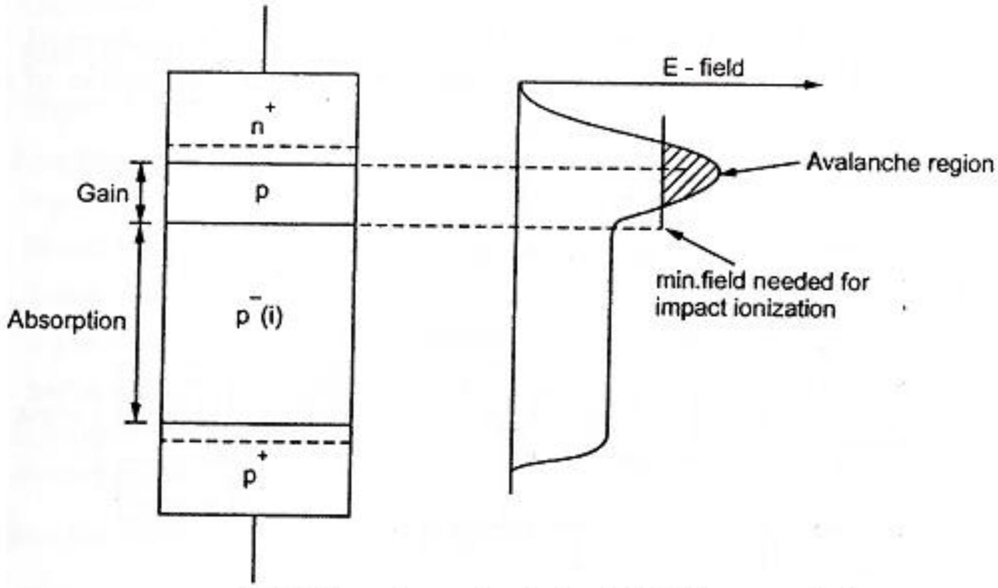
Photodiodes are preferred for photo detection in optical system. The photodiodes provide good performance and compatibility with relatively low cost. These photodiodes are made from semiconductors such as silicon, germanium and an increasing number of III-V alloys. Internal photoemission process may take place in both intrinsic and extrinsic semiconductors. The intrinsic absorption process is preferred as they have fast response coupled with efficient absorption of photons. These photodiodes are sensitive, have adequate speed, negligible shunt, conductance, low dark current, long term stability. Thus they are widely used. Avalanche photodiodes are also widely employed in fiber communication system. They have very sophisticated structure.

AVALANCHE PHOTODIODE:

When a p-n junction diode is applied with high reverse bias breakdown can occur by two separate mechanisms direct ionization of the lattice atoms, zener breakdown and high velocity carriers causing impact ionization of the lattice atoms called avalanche breakdown. APDs use the avalanche breakdown phenomena for its operation. The APD has its internal gain which increases its responsivity. The below figure shows the schematic structure of an APD. By virtue of the doping concentration and physical construction of the n+ p junction, the electric field is high enough to cause impact ionization. Under normal operating bias, the I-layer (the p~ region) is completely depleted. This is known as reach through condition, hence APDs are also known as reach through APD or RAPDs.
Similar to PIN photodiode, light absorption in APDs is most efficient in I-layer. In this region, the E-field separates the carriers and the electrons drift into the avalanche region where carrier multiplication occurs. If the APD is biased close to breakdown, it will result in reverse

Leakage current. Thus APDs are usually biased just below breakdown, with the bias voltage being tightly controlled. The multiplication for all carriers generated in the photodiode is given

$$\text{as } M = \frac{I_M}{I_P}$$



APD Schematic and variation of E-field across diode

Where,

I_M = Average value of total multiplied output current.

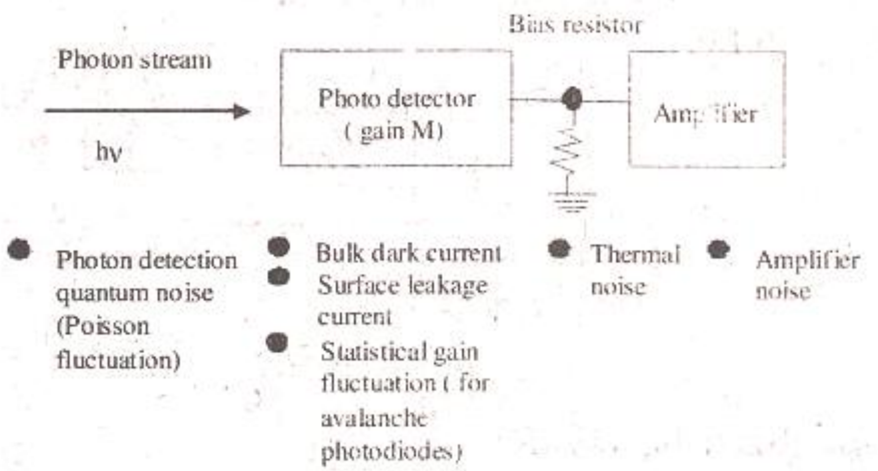
I_P = Primary unmultiplied photocurrent.

Responsivity of APD is given by

$$\mathfrak{R}_{APD} = \frac{\eta q}{h\upsilon} M$$

$$\mathfrak{R}_{APD} = \frac{\eta q \lambda}{hc} \qquad \because \upsilon = \frac{c}{\lambda}$$

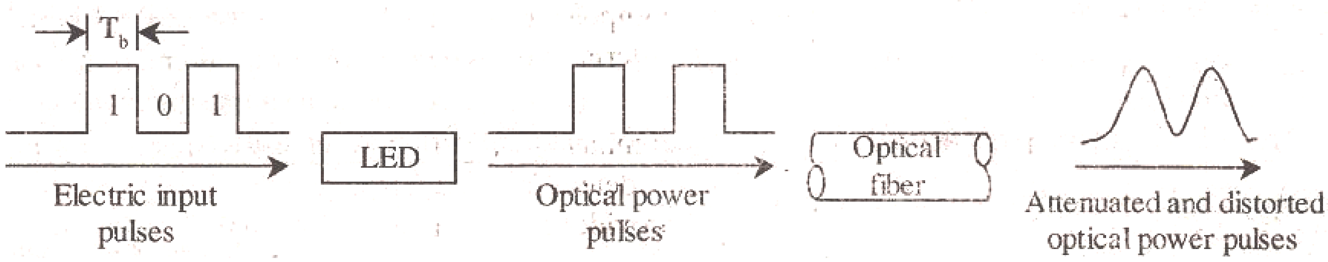
VARIOUS ERRORS THAT OCCUR IN THE DETECTION MECHANISM:



Noise Sources and Disturbances in the Optical Pulse Detection Mechanisum

Errors in detection mechanism can arise from various noises and disturbances Associated with the signal detection system, as shown in figure. The term noise is used customarily to describe unwanted components of an electric signal that tend to disturb the transmission and processing of the signal in a physical system, and over which we have incomplete control. The noise sources can be either external to the system or internal to the system. The two most common noises are shot noise and thermal noise. Shot noise arises in electronic devices since of the discrete nature of current flow in the device. Thermal noise arises from the random motion of electrons in a conductor. The random arrival rate of signal photons produces a quantum or shot noise at the photo detector. Since this noise depends on the signal level, it is of particular importance for pin receivers that have large optical levels and for avalanche photodiode receivers. An additional photo detector noise comes from the dark current and leakage current. These are independent of photodiode illumination and can generally be made very small in relation to other noise currents by a judicious choice of components. Thermal noises arising from the detector load resistor and from the amplifier electronics tend to dominate in application with low signal-to-noise ratio when a pin photodiode is used. When an avalanche photodiode is used in low Optical signal level applications the optimum avalanche gain is determined by a design tradeoff between the thermal noise and gain-dependent quantum noise. A further error source is attributed to inter symbol interference (ISI) which results front pulse spreading in the optical fiber. When a pulse is transmitted in a given time slot, most of the pulse energy will arrive in the corresponding time slot at the receiver. The presence of this energy in adjacent time slots results in an interfering signal, hence the terms inter symbol interference.

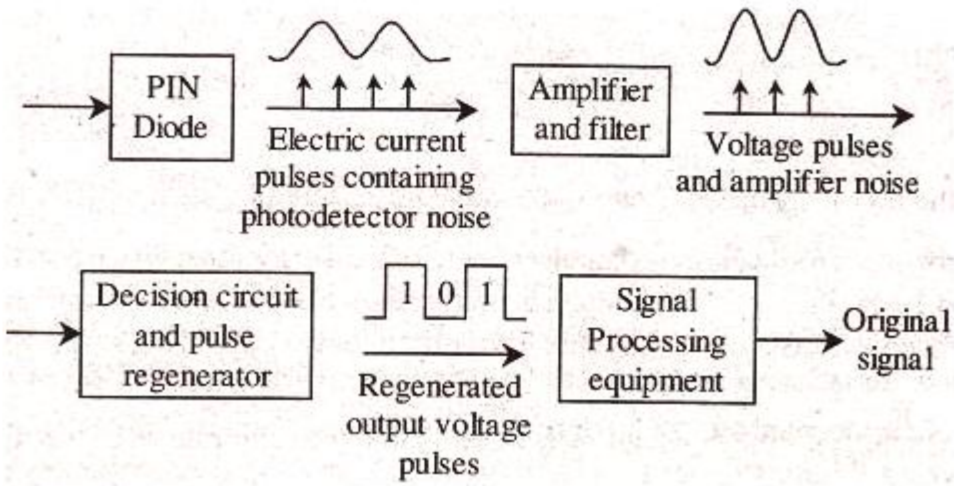
THE OPTICAL FIBER TRANSMISSION LINK:



The Optical Fiber Transmission Link

Here a two level binary signal is used for transmission purpose. The two levels are represented by 1 and 0 respectively. Each level has finite time duration known as bit period Tb. The stream of l's and 0's are transmitted using amplitude shift keying modulation technique. In ASK the voltage has two levels which are V volts for binary 1 and 0 volts for binary 0.

Corresponding to these voltage levels the optical source will produce pulses of optical power. These pulses are coupled to an optical fiber and are transmitted. The signal gets attenuated for various reasons and therefore it is distorted. The below figure shows a block diagram of an optical receiver. At the receiver the distorted signal is coupled to a photo detector generally a pin diode which produces an electric current which is equivalent to the incoming signal. The amplifier and filter removes noise and amplifies the signal. The decision making device gives output binary 1 for a voltage V and 0 for a voltage 0 respectively. At the signal processing circuiting the signal is demodulated thus producing the desired output.



Optical Receiver

SPECIFICATIONS OF A SEMICONDUCTOR PHOTO DIODE:

The important performance parameters of a semiconductor photodiode are described below.

1. Responsivity:
The ratio of generated photocurrent to incident light power, typically expressed in A/W when used in photo conductive mode. The responsivity may also be expressed as quantum efficiency or the ratio of the number of photo generated carriers to incident photons and thus, a unit less quantity. The typical values for responsivity are, 0.65 for A/W silicon at 900 nm, 0.45 A/W for germanium at 1.3 µm and 0.9 A/W for InGaAs at 1.3 µm.

2. Dark Current:
The current through the photodiode in the absence of light, when it is operated in photoconductive m dark current includes photocurrent generated by background radiation and the saturation current of the semiconductor junction. Dark current must be accounted for calibration if a photodiode is used to make an accurate optical measurement. It is also a source of noise when a photo diode is used in an optical communication system.

3. Noise Equivalent Power (NEP):
The minimum input optical power to generate photocurrent, equal to the r.m.s noise current in a 1 Hz bandwidth. The related characteristic directivity D IS the inverse of NEP i.e., 1/NEP and the specific directivity D* is the directivity normalized to the area, A of the photodiode i.e.

$$D^* = D\sqrt{A}$$

4. Quantum Efficiency:
The photodiode's capability to convert light energy to electrical energy is referred as quantum efficiency; it can be also described as the ratio of number of electron-hole pairs generated to the number of incident photons. In a practical photodiode, the quantum efficiency of the detector ranges from 30 to 95%.

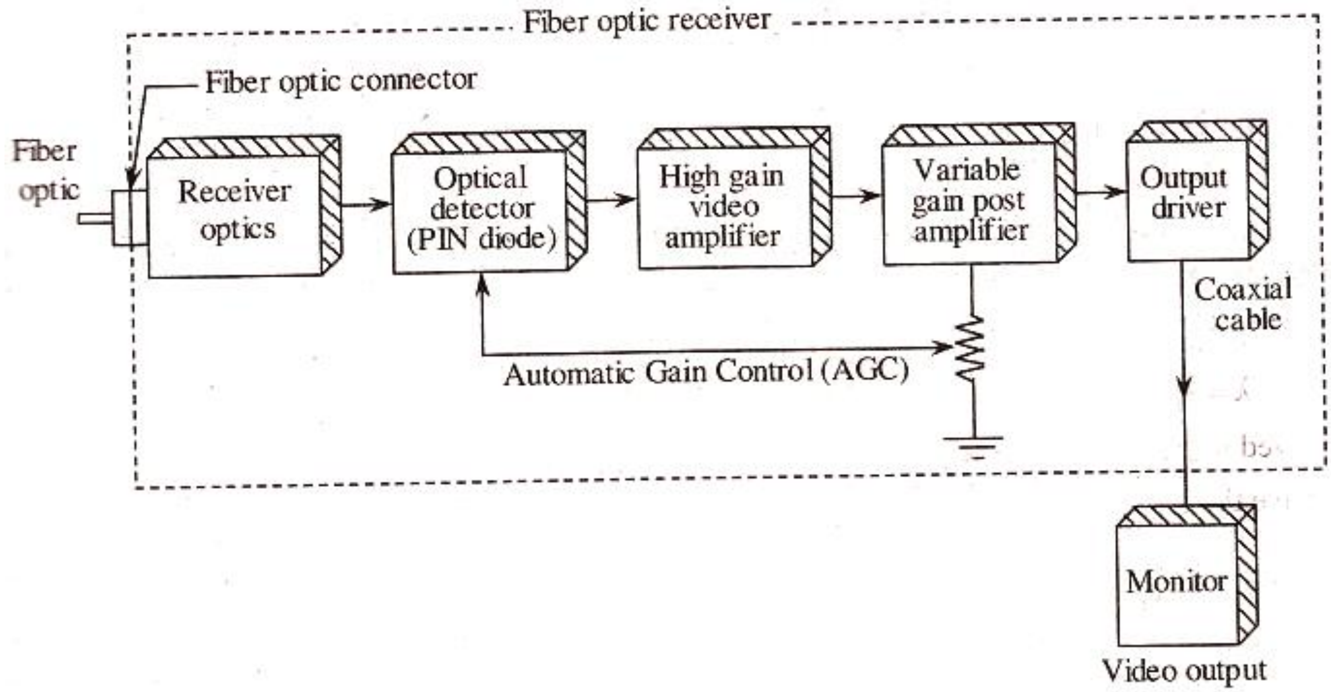
5. Sensitivity:
It is a measure of the effectiveness of a detector in producing an electrical signal at the peak sensitivity wavelength.

6. Rise time:
The time required for a detector output to reach from 10 to 90% of its final value.

FIBER OPTIC RECEIVER:

The terra receiver at the output end of the fiber optic cable refers to both a light detecting transducer and its related electronics, which provides any necessary signal conditioning to restore the signal to its original shape at the input, as well as additional signal amplification. To interface the receiver with the optical fiber, the proper match between light source, fiber optic cable and light detector is required. In the AM transmission system, the optical power input at the fiber is modulated so that the photo detector operating in the photocurrent mode must provide good linearity, speed and stability.

The photodiode produces no electrical gain and is therefore followed by circuits that amplify electrical voltage and power to drive the coaxial cable. Figure below illustrates the block diagram for the optical fiber receiver unit.



Optical Fiber Receiver Unit

As light enters from the receiver end of an optical fiber, it spreads out with a divergence approximately equal to the acceptance cone angle at the transmitter end of the fiber. Photodiodes are packaged with lenses on their housings so that the lens collects this output energy and focuses it down onto the photodiode-sensitive area. The most common fiber optic receiver uses a photodiode to convert the incident light from the fiber into electrical energy. After the light energy is converted into an electrical signal by the photodiode, it is linearly amplified and conditioned to be suitable for transmission over standard coaxial cable to a monitor or recorder.

QUANTUM LIMIT:

The minimum received optical power required for a particular bit error rate performance using an ideal photo detector (which has zero dark current and unity quantum efficiency) is referred as quantum efficiency. In this case, the performance of the system will depend only on the photo detection statistics as the remaining all the system parameters are considered to be ideal. Due to several nonlinear distortions and noise effects in the transmission link, the practical values of most of the receiver sensitivities will be around 20 dB higher than the quantum limit. It is also very important to differentiate average power and peak power while specifying he quantum limit.

DARK CURRENT:

In the absence of light, the current that flows continuously through the basic circuit of the device is referred as dark current or the leakage current that flows when the photodiode is in the dark and a reverse voltage is applied across the junction is referred as dark current. This voltage may be low as 10 mV or as high as 50 V and the dark current may vary from pA to uA depending on the junction area and the process used. The dark current is temperature dependent. The rule of thumb is that the dark current will approximately double for every 10°C increase in ambient temperature. However, specific diode types can vary considerably from this relationship.

SENSITIVITY:

The sensitivity of the receiver is defined as the minimum amount of optical power required to achieve a specific receiver performance. The receiver takes many signals such as synchronous signals (to recover the clock signal similar to that is used at transmitter), decoded data and errors. So, in order to generate a correct signal in the presence of all these signals, a receiver should have high sensitivity. If it has high sensitivity it will be even able to detect low level optical signals. Thus, the higher the sensitivity, the more efficiently the receivers can detect the attenuated on low level signals. The sensitivity of receiver can be sketched taking the data rate and optical power that the receiver can detect.

BIT ERROR RATE (BER):

In practice, that there are several standard ways of measuring the rate of error occurrences in a digital data stream. One common approach is to divide the number Ne of errors occurring over a certain time interval t by number Nt of pulses (ones and zeros) transmitted during this interval. This is called either the error rate of the bit error rate, which is commonly abbreviated as BER. Thus, we have

$$BER = N_e/N_t$$

PROBLEMS

*** A pin photodiode on average generates one electron hole pair per three incident photons at a wavelength of 0.8 µm. Assuming all the electrons are collected, calculate**

i) The quantum efficiency of the device

ii) Its maximum possible band gap energy

iii) The mean output photocurrent when the received optical power is 10^{-7} W.

Solution:

Given that,

For a pin photodiode one electron hole pair generated for every three incident photons.

Operating wavelength, $\lambda = 0.8$ µm

i) Quantum efficiency of the device, $\boldsymbol{\eta} = ?$

ii) Maximum possible band gap energy, $E_g = ?$

iii) Received optical power, $P_0 = 10^{-7}$ W

iv) Mean output photocurrent, $I_p = ?$

i) Quantum efficiency of the device is given by,

$$\eta = \frac{\textit{Number of electron hole pairs generated}}{\text{Number of incident photons}} * 100$$

$$\eta = \frac{n}{3n} * 100 = \frac{1}{3} * 100 = 0.3333 * 100 = 33.33$$

$$\eta = 33.33\%$$

ii) The maximum possible band gap energy is given by,

$$E_g = hf/e$$

$$hf = \frac{hc}{\lambda}$$

$$= \frac{6.63*10^{-34}*3*10^{8}}{0.8*10^{-6}} = 2.486 * 10^{-19}$$

$$E_g = \frac{2.486*10^{-19}}{1.602*10^{-19}} = 1.552\ eV$$

iii) The mean output photo current is given by,

$$I_p = \frac{\eta P_0}{E_g} = \frac{0.3333*10^{-7}}{1.552} = 21.46\ nA$$

$I_p = 21.46$ nA