

OPTICAL SOURCES

- Optical transmitter converts an **electrical input signals into corresponding optical signal.**
 - **LED** (Light Emitting Diode) and
 - **LASER** (Light Amplification by Stimulated Emission of Radiation)

Characteristics (Properties) of Light Source of Communication

- It must be possible to operate the device continuously at a variety of temperatures for many years.
- Must have compatible size and configuration to effectively launch light into an optical fiber.
- Emit light at wavelength where fiber has low losses and low dispersion.
- Must have high intensity light output.
- Their light must be nearly monochromatic as much as possible.

- Allow direct modulation over wide bandwidth.
- The power requirement for its operation must be low.
- High coupling efficiency.
- High optical output power.
- High reliability.
- Low weight and low cost.

LED (Light Emitting Diode)

- It releases light when current passes through it.
- The LED concept is based on a semiconductor device where holes and electrons recombine to produce energy in the form of photons.
- The need for light-emitting materials comes from the need for the wavelength of radiation.
- LEDs are used in different applications, such as decorative lights, remote control circuits, etc.

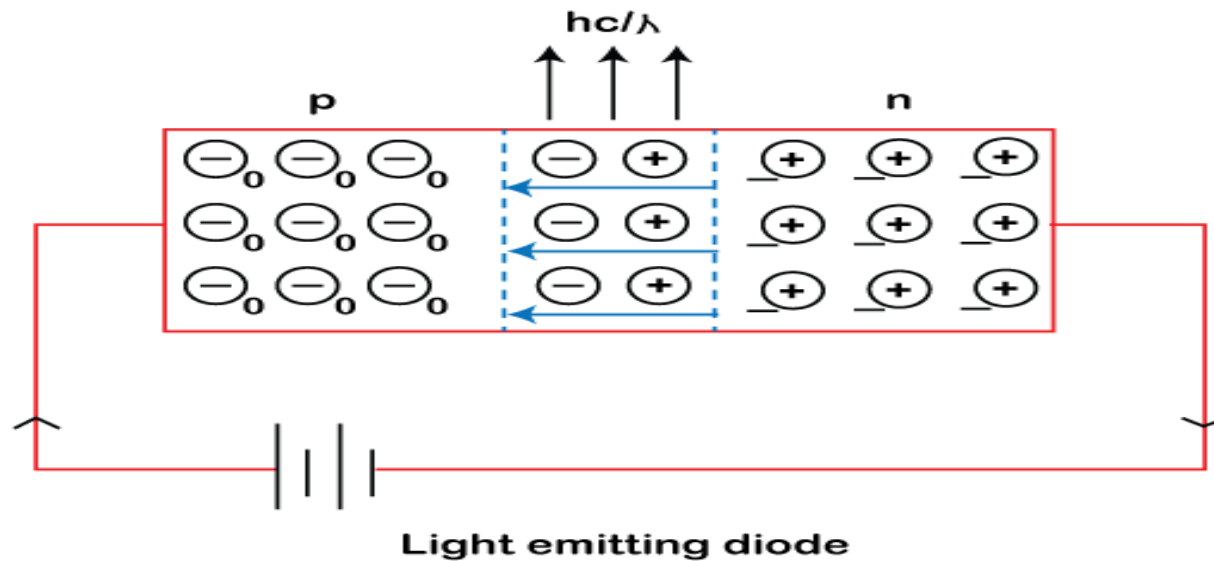
Working of an LED

- LED is defined as a p-n junction diode with an energy gap in the range required for visible light production.
- The semiconductor consists of a p junction, n-junction and a neutral region between them.
- The p-junction possesses majority carriers holes (positive charged), while the n-junction possesses majority carriers electrons (negative charged).

Working

- When sufficient forward voltage is applied to the p-n junction diode, the majority carriers enough energy to move through the neutral region.
- These electrons recombine with other majority carriers holes.
- The recombination seems like a particle occupying a high energy state to a low energy state.
- Thus, it produces electromagnetic radiation.
- Each time an electron recombines with a hole, electrostatic potential energy converts into electromagnetic energy.
- The released energy is in the form of photons.

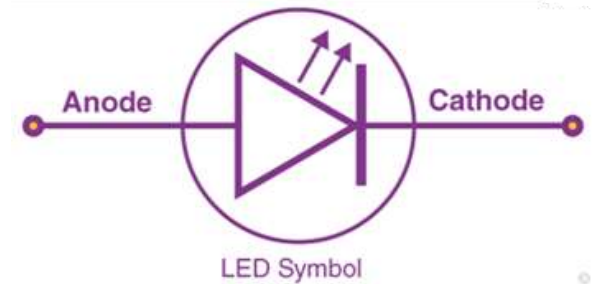
- Most of the Light Emitting Diodes operate at low voltages ranging from 1V to 4V. It draws a current between 10mA to 40mA.



Colored LED

- The variation in the concentration of **Phosphors** can cause a change in the color temperature.
- Phosphor is defined as a substance present over a semiconductor die used to display the property of luminescence.
- The phosphor is responsible for the colored lights in the LED.
- There are around 16 million shades of LEDs.

- Some LEDs used different materials that emit photons at a different wavelength, which appears as colored light.
- All the colors are generated from the three basic colors **Red, Blue, and Green**.



- A light-emitting diode (LED) is a semiconductor device that emits **incoherent light, through spontaneous emission**, when a current is passed through it.
- Typically LEDs for the 850-nm region are fabricated using GaAs and AlGaAs.
- LEDs for the 1300-nm and 1550-nm regions are fabricated using InGaAsP and InP.

- Conventional p-n junction is called as **Homo-junction** as same semiconductor material is used on both sides junction.
- The electron-hole recombination occurs in relatively layer ($10\mu\text{m}$).
- As the carriers are not confined to the immediate vicinity of junction, hence high current densities cannot be realized.

- The **carrier confinement problem can be resolved by sandwiching a thin layer (0.1 μ m) between p-type and n-type layers.**
- The middle layer may or may not be doped.
- The **carrier confinement occurs due to bandgap discontinuity of the junction.**
- Such a junction is called **heterojunction** and the device is called **Double Heterostructure.**
- LED Principle “**Double Heterostructure**”.

- LED performance differences help link designers decide which device is appropriate for the intended application.
- For short distance (0 to 3 km), low-data-rate fiber optic systems, SLEDs and ELEDs are the preferred optical source.
- Typically, SLEDs operate efficiently for bit rates up to 250 megabits per second (Mb/s).

- When a light-emitting diode is forward biased (switched ON), electrons are able to recombine with holes within the device, releasing energy in the form of photons.
- This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

- The LED consists of a chip of semiconducting material doped with impurities to create a p-n junction.
- As in other diodes, current flows easily from the p-side, or anode, to the n-side, or cathode, but not in the reverse direction.
- Charge-carriers—electrons and holes—flow into the junction from electrodes with different voltages.
- When an electron meets a hole, it falls into a lower energy level and releases energy in the form of a photon.

- When the junction is forward biased, electrons & holes are injected into p & n regions.
- These injected minority carriers can combine either radiatively, in which case a photon of energy $h\nu$ is emitted or non-radiatively i.e recombination energy is dispatched in the form of heat.
- This pn junction is thus known as “active or Recombination region”.
- The recombination of excess minority carriers is the mechanism by which optical radiation is generated.

LED-Principle of Operation

- High radiance output or brightness
- Measure of optical power radiated into a unit solid angle per unit area of the emitting surface
- Fast emission response time
- It is a time delay between the application of a current pulse and respective optical emission
- High quantum efficiency
- It is related to the fraction of the electron hole pairs that recombine radiatively
- LED structure should provide a high radiance and high quantum efficiency.
- It must achieve carrier and optical confinement

Types of LEDs

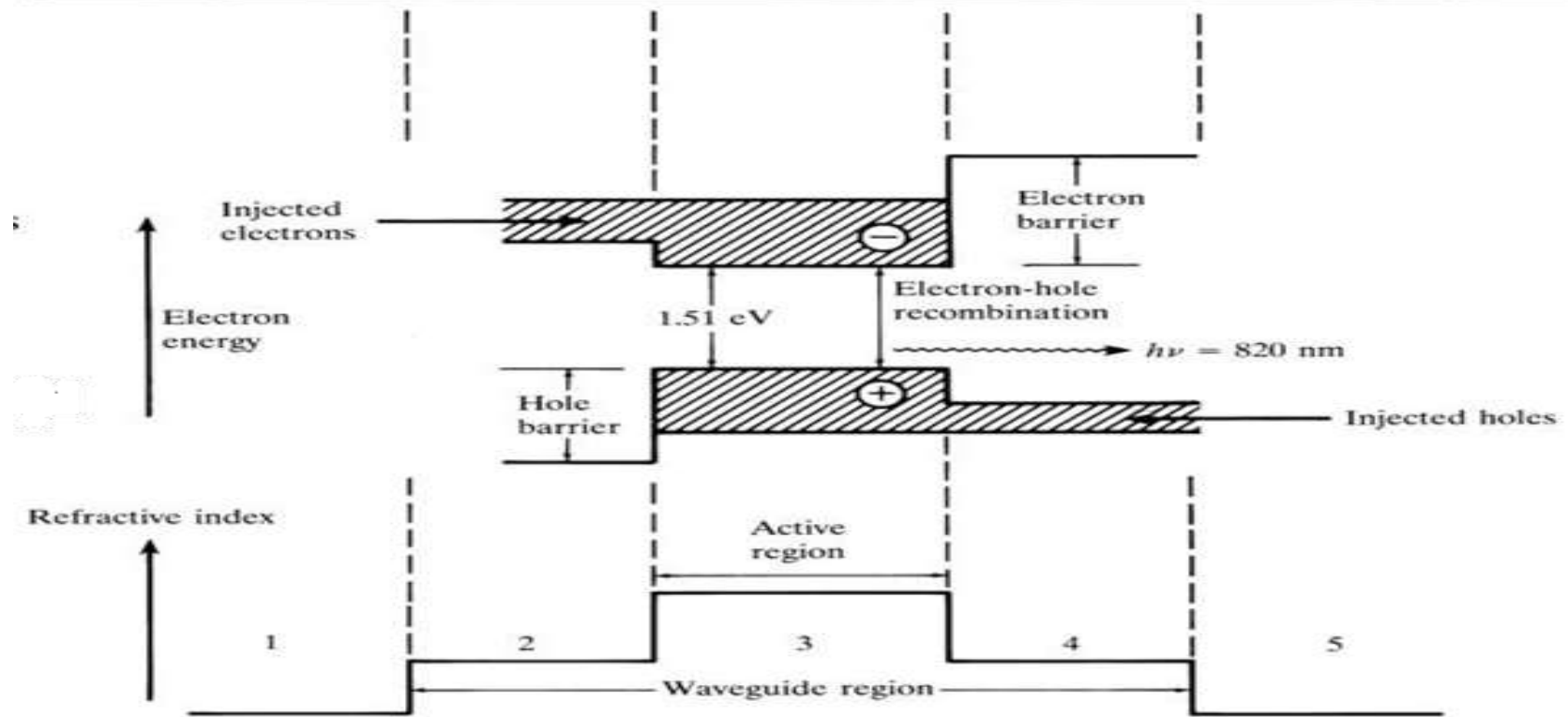
- Homo-junctions structure
- Hetero-junctions structure
- **Homo-junctions:** P- type and N-type from same material
 - Carriers are not confined
 - Light is not confined
 - LED should have a high radiance (light intensity), fast response time and high quantum efficiency.

- **Hetero-junctions:** Different p- and n- materials
 - Carriers are confined
 - Light is also confined
 - Single Heterojunction, Double Heterojunction.
 - A heterojunction is a junction between semiconductors with different bandgap energies.

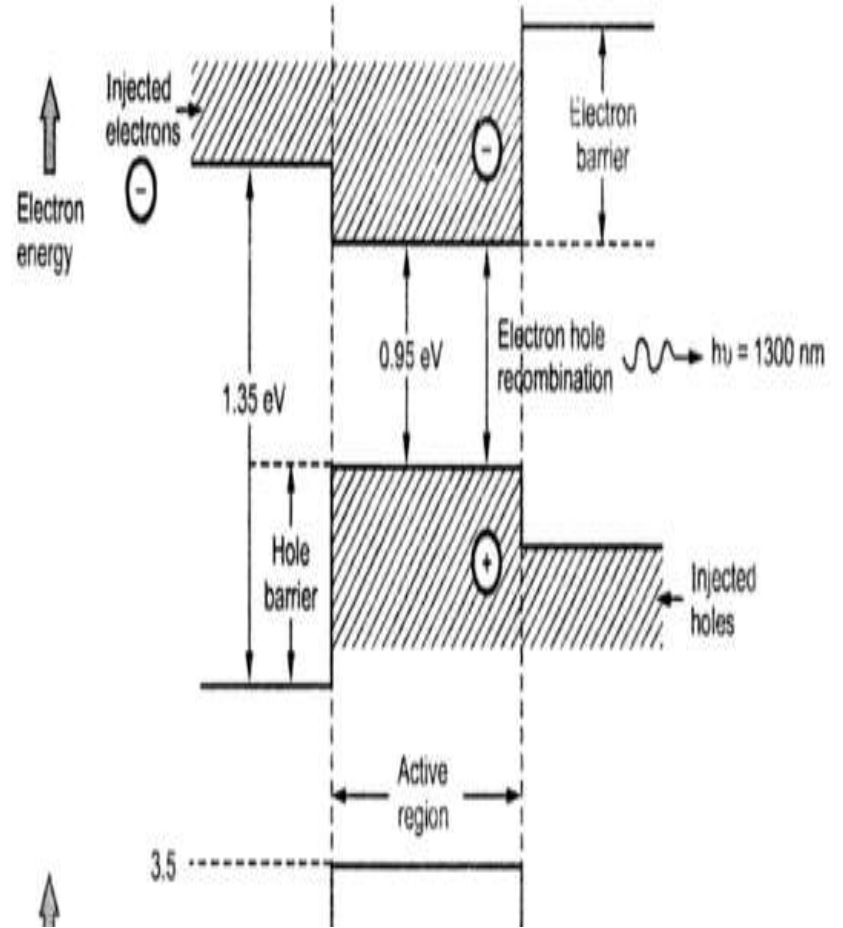
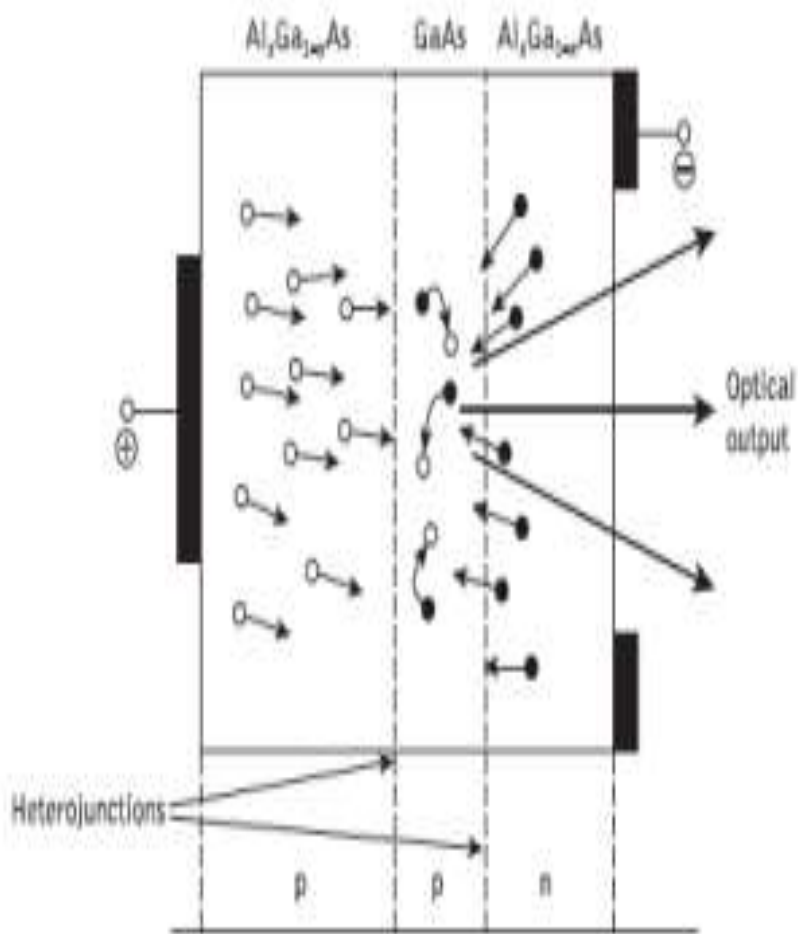
Double-Heterojunction LED

- The device shown consists of a p-type GaAs layer sandwiched between a p-type AlGaAs and an n-type AlGaAs layer.
- When a forward bias is applied electrons from the n-type layer are injected through the p–n junction into the p-type GaAs layer where they become minority carriers.
- In order to achieve efficient confinement of emitted radiation double heterojunctions are used in LED structure.
- A heterojunction is a junction formed by dissimilar semiconductors.
- Double heterojunction (DH) is formed by two different semiconductors on each side of active region.

Metal contact	<i>n</i> -type GaAs substrate	<i>n</i> -type Ga _{1-x} Al _x As Light guiding and carrier confinement ~ 1 μm	<i>n</i> -type Ga _{1-y} Al _y As Recombination region ~ 0.3 μm	<i>p</i> -type Ga _{1-x} Al _x As Light guiding and carrier confinement ~ 1 μm	<i>p</i> -type GaAs Metal contact improvement layer ~ 1 μm	Metal contact
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Optical Fiber communications, 3rd ed., G. Keiser, McGrawHill, 2000



- The crosshatched regions represent the energy levels of free charge.
- Recombination occurs only in active In GaAsP layer.
- The two materials have different band gap energies and different refractive indices.
- The changes in band gap energies create potential barrier for both holes and electrons.
- The free charges can recombine only in narrow, well defined active layer side.

- A double heterojunction (DH) structure will confine both hole and electrons to a narrow active layer.
- Under forward bias, there will be a large number of carriers injected into active region where they are efficiently confined.
- Carrier recombination occurs in small active region so leading to an efficient device.
- Another advantage DH structure is that the active region has a higher refractive index than the materials on either side, hence light emission occurs in an optical waveguide, which serves to narrow the output beam.

Types of LED Configurations

- **Surface Emitting LED's (SLED)**
- **Edge Emitting LED's (EELED)**
- **Super luminescent LED's (SLD)**

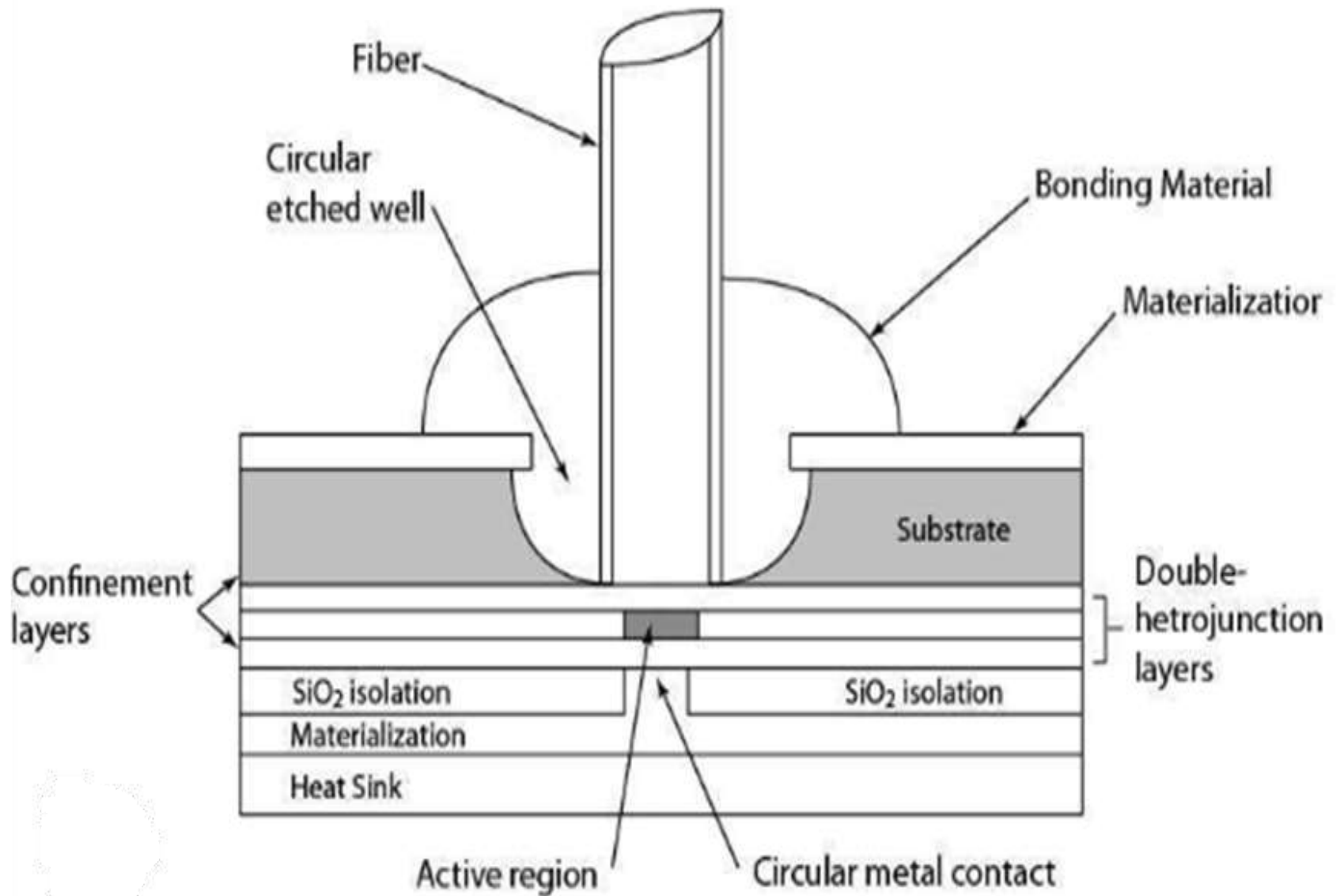
Surface Emitting LED's (SLED)

- Surface emitter LED (SLED) has been widely employed within optical fiber communications in which a method for obtaining high radiance is to restrict the emission to a small active region within the device.
- These structures have low thermal impedance in the active region allowing high current densities and giving high- radiance emission into the optical fiber.
- The structure of a high-radiance etched well DH surface emitter* for the 0.8 to 0.9 μm wavelength band.

- The plane of active light emitting region is oriented perpendicularly to the axis of the fiber.
- A DH diode is grown on an N-type substrate at the top of the diode.
- A circular well is etched through the substrate of the device.
- A fiber is then connected to accept the emitted light.
- In addition, the epoxy resin that binds the optical fiber to the SLED reduces the refractive index mismatch, increasing coupling efficiency.

- At the back of device is a heat sink. The current flows through the p-type material and forms the small circular active region resulting in the intense beam of light.
- The circular active area in practical surface emitters is nominally $50\mu\text{m}$ in diameter and upto $2.5\mu\text{m}$ thick.
- The emission pattern is essentially isotropic with a 120° half-power beamwidth.

- The isotropic emission pattern from surface emitting LED is of Lambertian Pattern.
- In Lambertian pattern, the emitting surface is uniformly bright.
- [There is a common pattern to the angular distribution escaping light from certain diffuse sources. The so-called Lambertian pattern depends on the angle θ relative to the normal that is perpendicular to the surface of the source.]



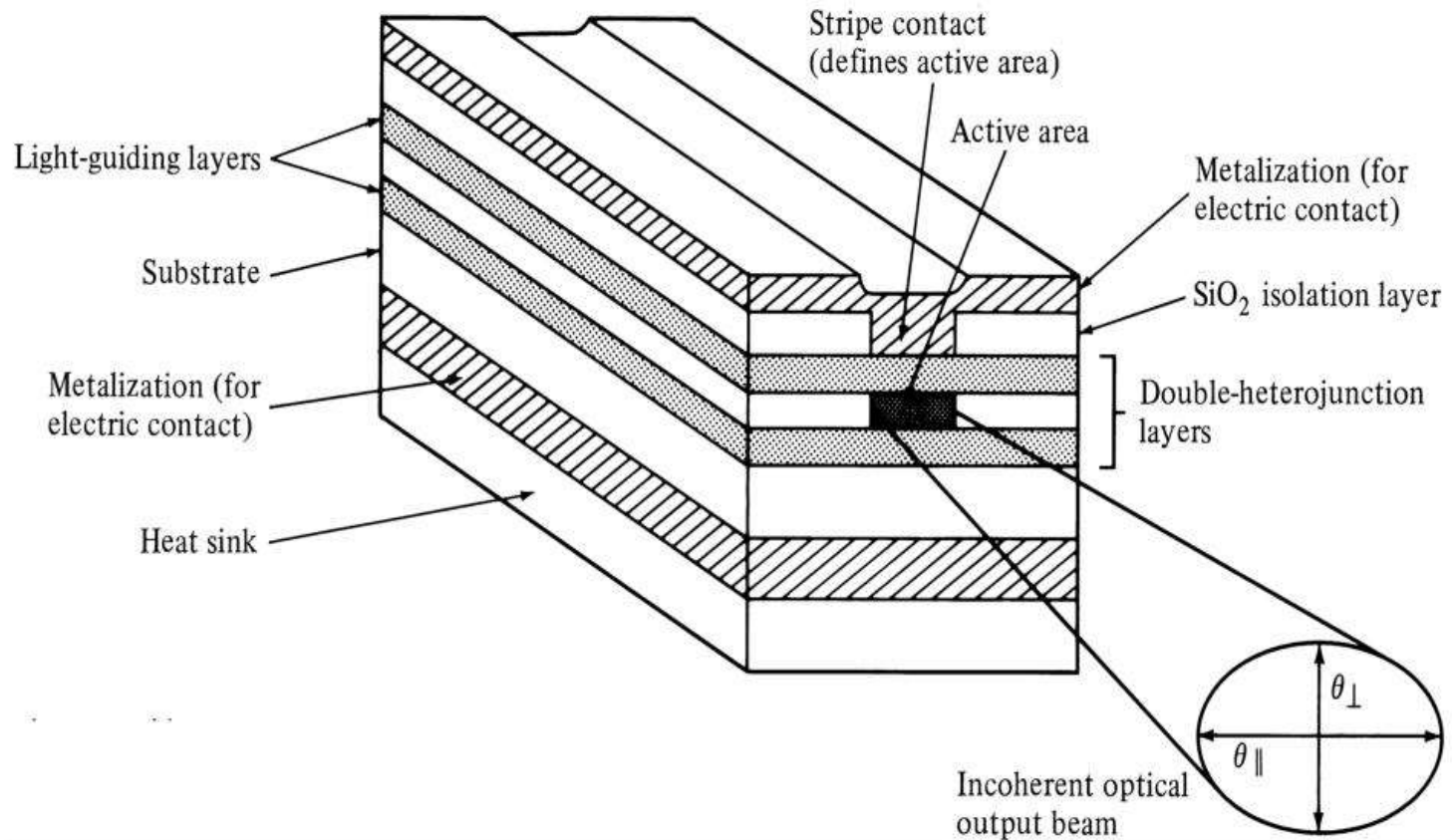
Edge Emitting LED's (EELED)

- In order to reduce the losses caused by absorption in the active layer and to make the beam more directional, the light is collected from the edge of the LED.
- Such a device is known as edge emitting LED or ELED.

- It consists of an active junction region which is the source of incoherent light and two guiding layers.
- The refractive index of guiding layers is lower than active region but higher than outer surrounding material.
- Thus a waveguide channel is formed and optical radiation is directed into the fiber.

- Edge emitter's emission pattern is **more concentrated (directional) providing improved coupling efficiency**.
- The beam is Lambertian in the plane parallel to the junction but diverges more slowly in the plane perpendicular to the junction.
- In this plane, the beam divergence is limited. In the parallel plane, **there is no beam confinement** and the radiation is Lambertian.
- To maximize the useful output power, a reflector may be placed at the end of the diode opposite the emitting edge.

Edge-emitting LED



Features of ELED

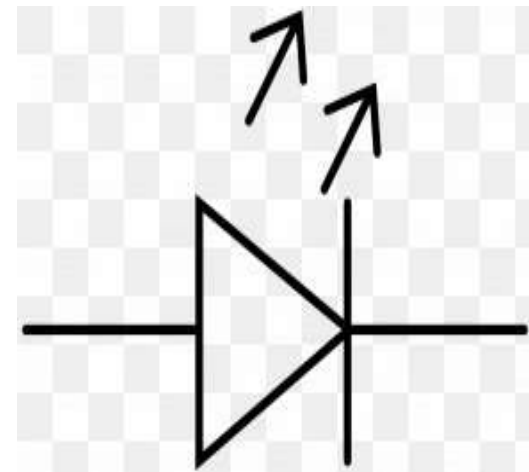
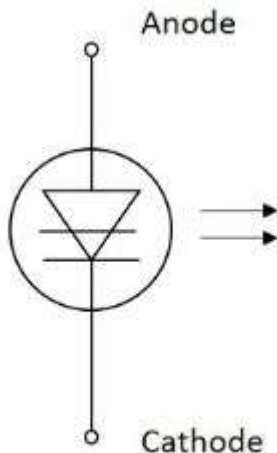
- Linear relationship between optical output and current.
- Spectral width is 25 to 400 nm for $\lambda = 0.8 - 0.9 \mu\text{m}$.
- Modulation bandwidth is much large.
- Not affected by catastrophic gradation mechanisms hence are more reliable.
- ELEDs have better coupling efficiency than surface emitter.
- ELEDs are temperature sensitive.

Usage

- LEDs are suited for short range narrow and medium bandwidth links.
- Suitable for digital systems up to 140 Mb/sec.
- Long distance analog links.

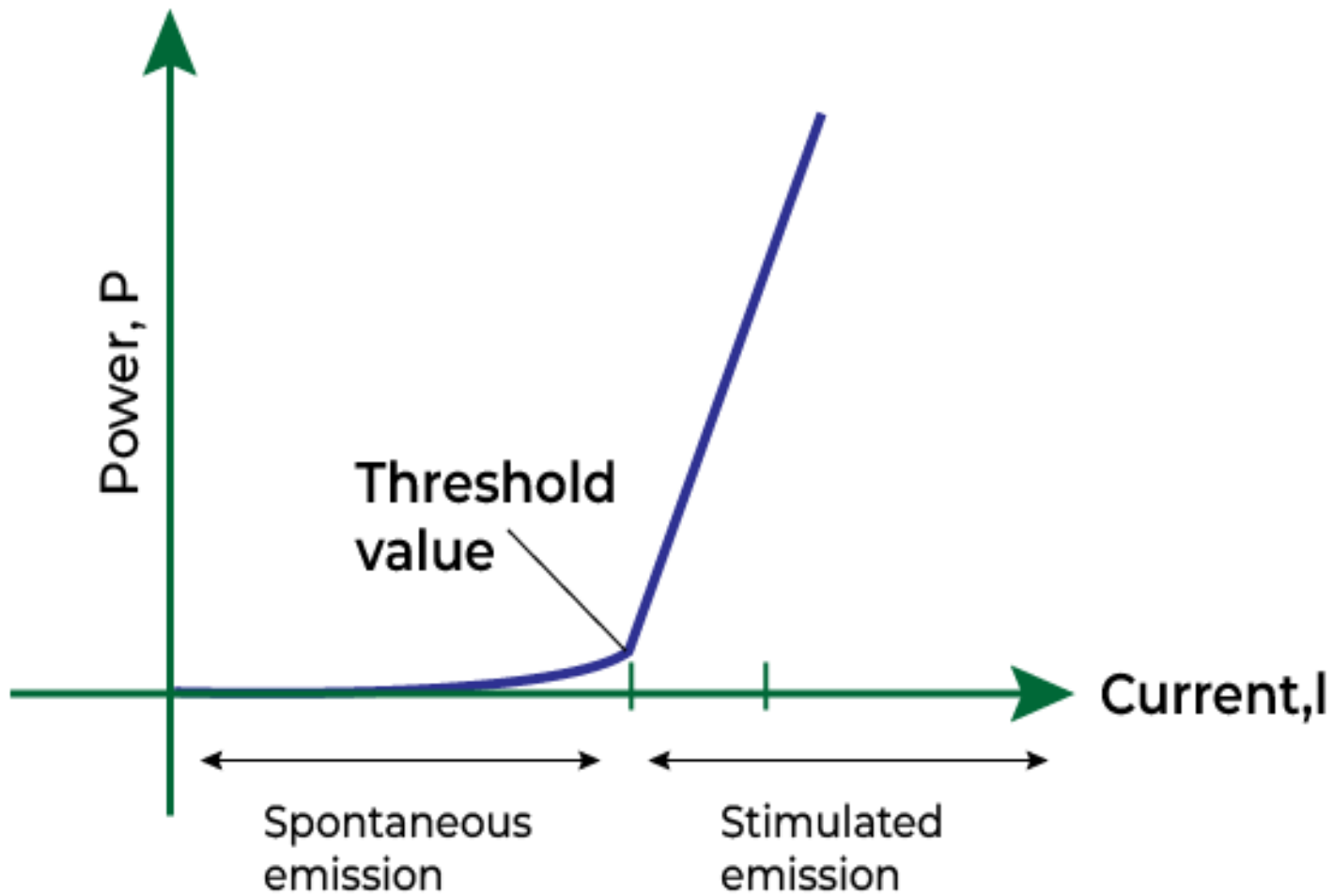
LASER

- **Coherent** light Sources.
- Process “Light Amplification by Stimulated Radiation Emission”.
- As it uses p-n junction to produce laser light, hence the name laser diode.



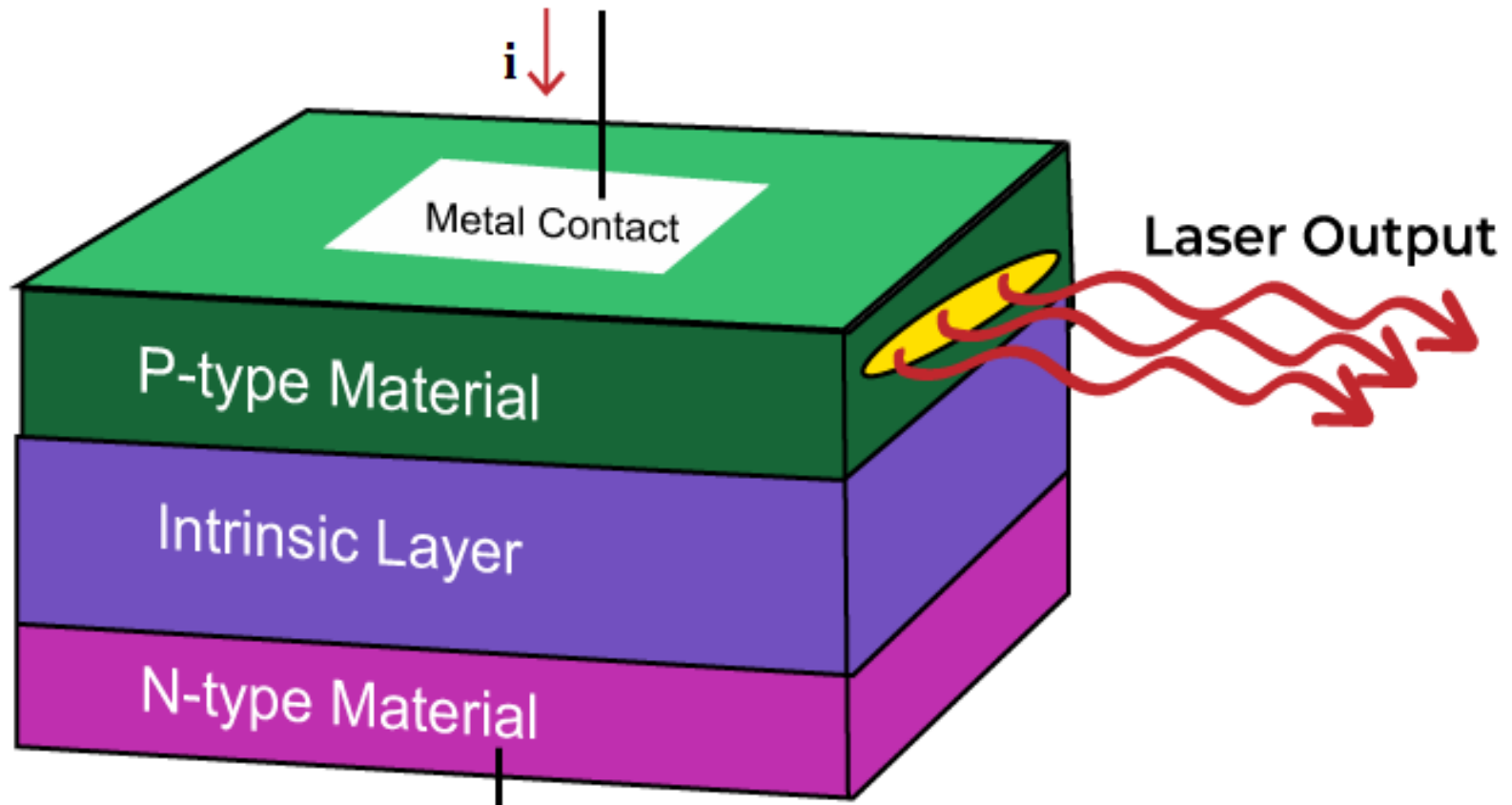
Characteristics of Laser Diodes

- **Coherence:** Laser diodes emit coherent, meaning the transmitted photons have a similar frequency and are **in same phase, creating highly focused and intense beam**.
- **Monochromatic:** It means **one color**. Laser diodes are monochromatic because it emits light of one color of a particular wavelength. This characteristic is used in the field like fiber optics.
- **Well-directed:** The light will be directed into a **narrow beam** in this case. It is simple to deploy over optical fiber.
- **Compact Size:** Laser diodes can be incorporated into small systems and devices due to their small size and lightweight.
- **Threshold Value:** It is the most important characteristic of the laser diode. It operates only when the power is more than the threshold value is applied. This is because emissions are weaker at the lower energy. The graph given below explains this phenomenon.



Construction of Laser Diode

- Semiconductors like Gallium Arsenide (GaAs) or Indium Gallium Arsenide (InGaAs) are used to build a laser diode.
- It comprises of a few layers.



Laser Diode Construction

- **P-N junction:** It is the fundamental structure of laser diode. A p-n junction is formed when the p-type and n-type regions meet. P-type and N-type regions are often made of materials such as gallium arsenide (GaAs) grown epitaxially on a substrate. The p-n junction creates a barrier that prevents the carriers (electrons and holes) from moving between two regions.
- **Active Region:** The laser action takes place here. It is located within the p-n junction. It is a thin layer of semiconductor material usually made of different compounds such as GaAs or InGaAs. In the active area; charge carriers (electrons and holes) recombine, releasing energy in the form of photons. This area is also known as the enhancement medium because it is responsible for amplifying the light from stimulated emission.

- **Mirrors:** Each end of a laser diode has two mirrors, one of which is completely reflective and the other of which is only partially reflective. Highly reflective mirrors are created through the process of cleaving. This glass is necessary to create optical gaps that allow photons to bounce back and forth, making light visible.
- **Metal Contact:** The input terminals are attached to the metal plates which is between the n -type and p- type layers.

Working of LASER Diode

- Basically, a laser emits a beam of electromagnetic nature which is coherent in nature.
- The working of the laser diode is based on:
 - Absorption
 - Spontaneous emission
 - Stimulated emission

Absorption

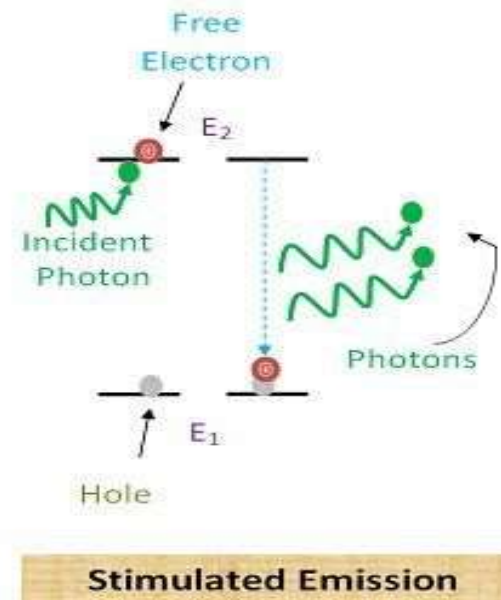
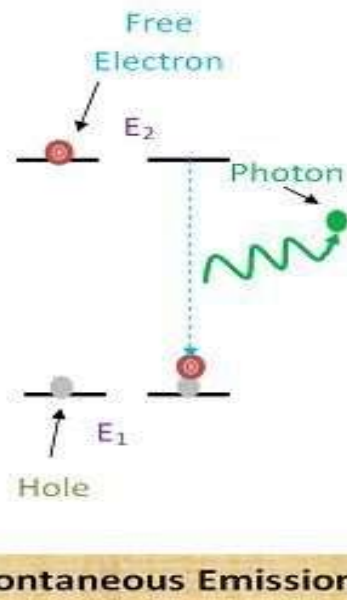
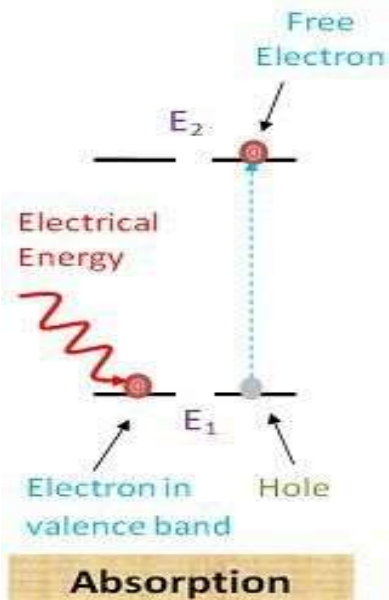
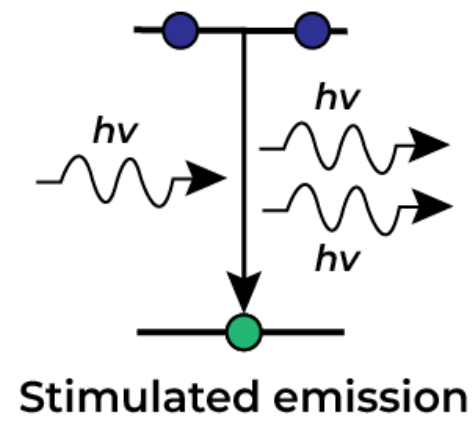
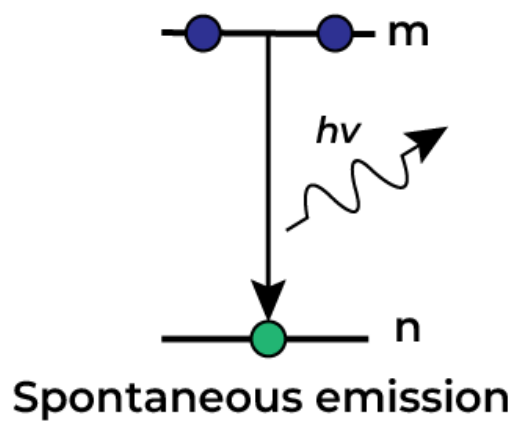
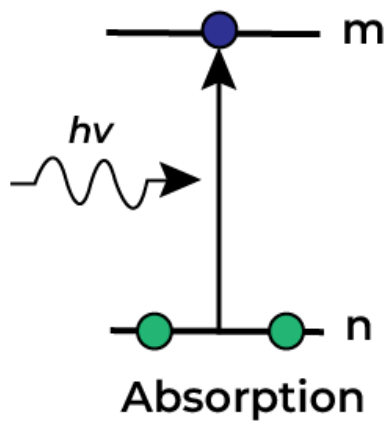
- The laser diode has a p-n junction with holes and electrons in it. In absorption, **electrons jump to a higher energy level by absorbing the energy when a certain voltage is applied.** This means that the **electron jumps from the valence band to the conduction band** as seen in the figure below. This transition is called absorption.

Spontaneous Emission

- After the lifetime of the excited electrons in the upper state ends, they recombine in the hole. The **electrons move to the lower energy level to achieve stability. While coming down to the lower energy level, electrons will release the energy 'hv'.** This energy is the difference between the two levels which is **used to determine the frequency of emission photons.** The energy released is in the form of light and thus photons will be emitted. This process is known as spontaneous emission.

Stimulated Emission

- In stimulated emission, **electrons are hit by the photons with a high energy and photons are produced by external light.** The **electron absorbs the energy and recombines with the hole when photon reaches the electron, this lead to the emission of more number of photons.** Therefore, an incident photon causes the release of another photon. Therefore it is called stimulated emission.

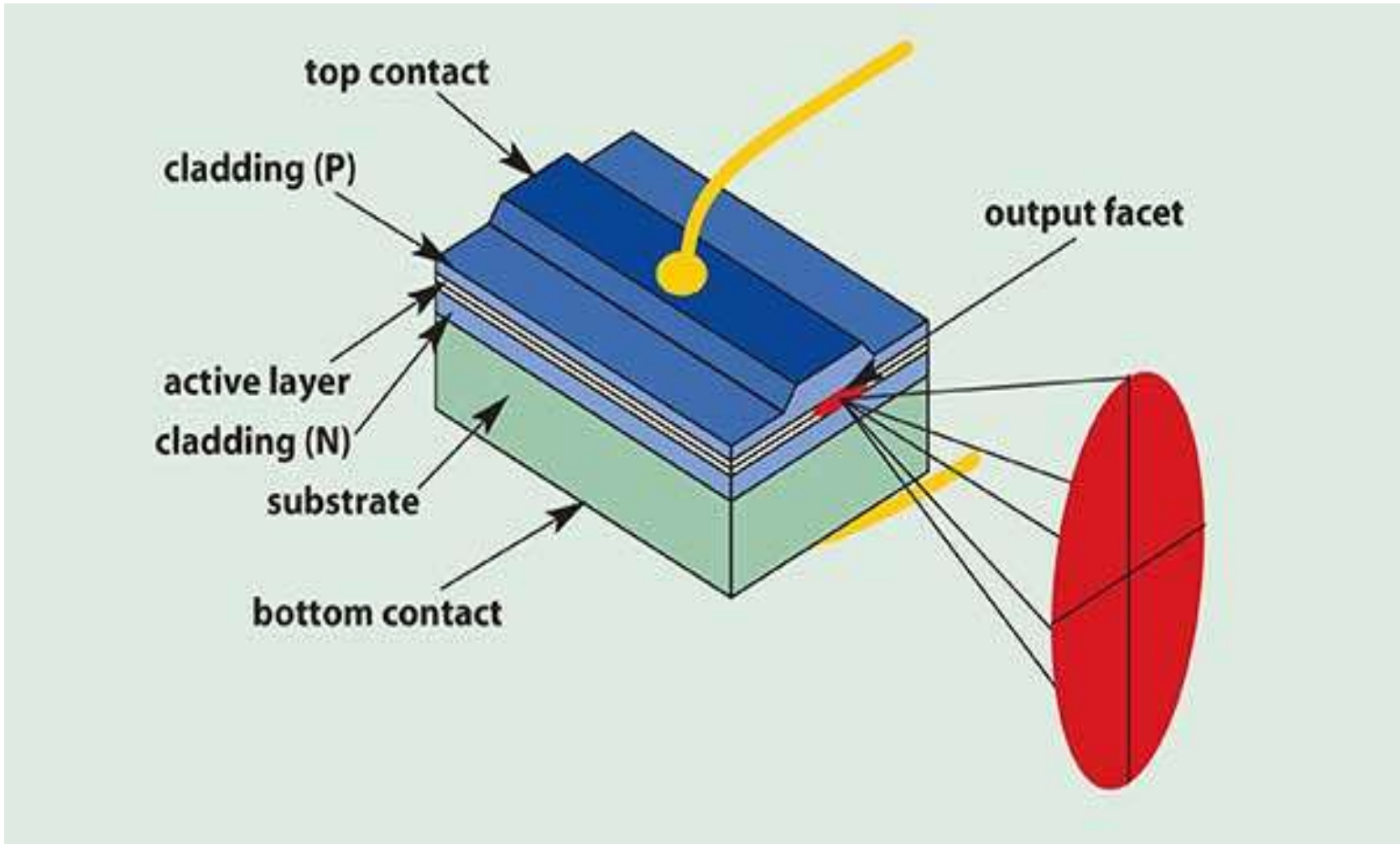


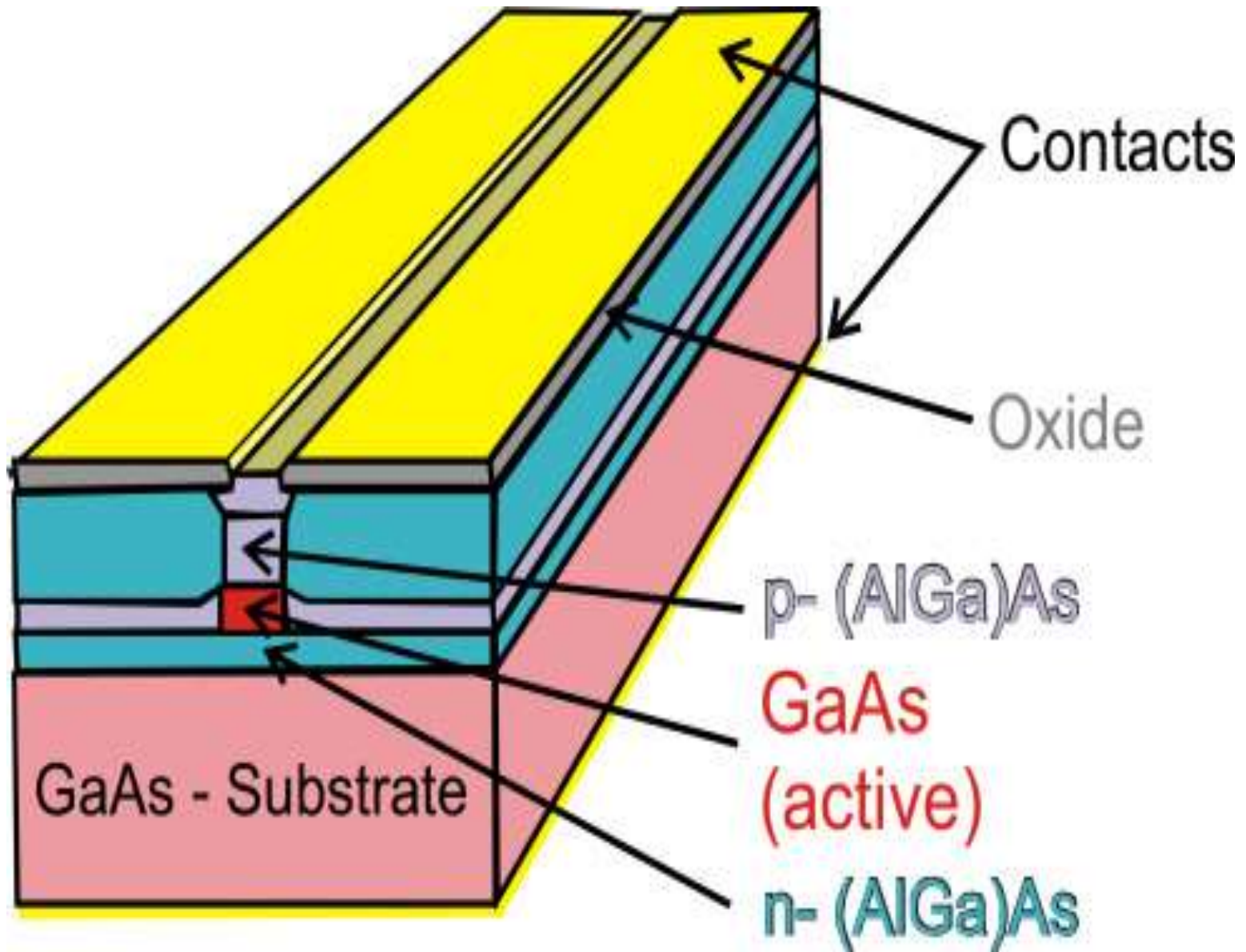
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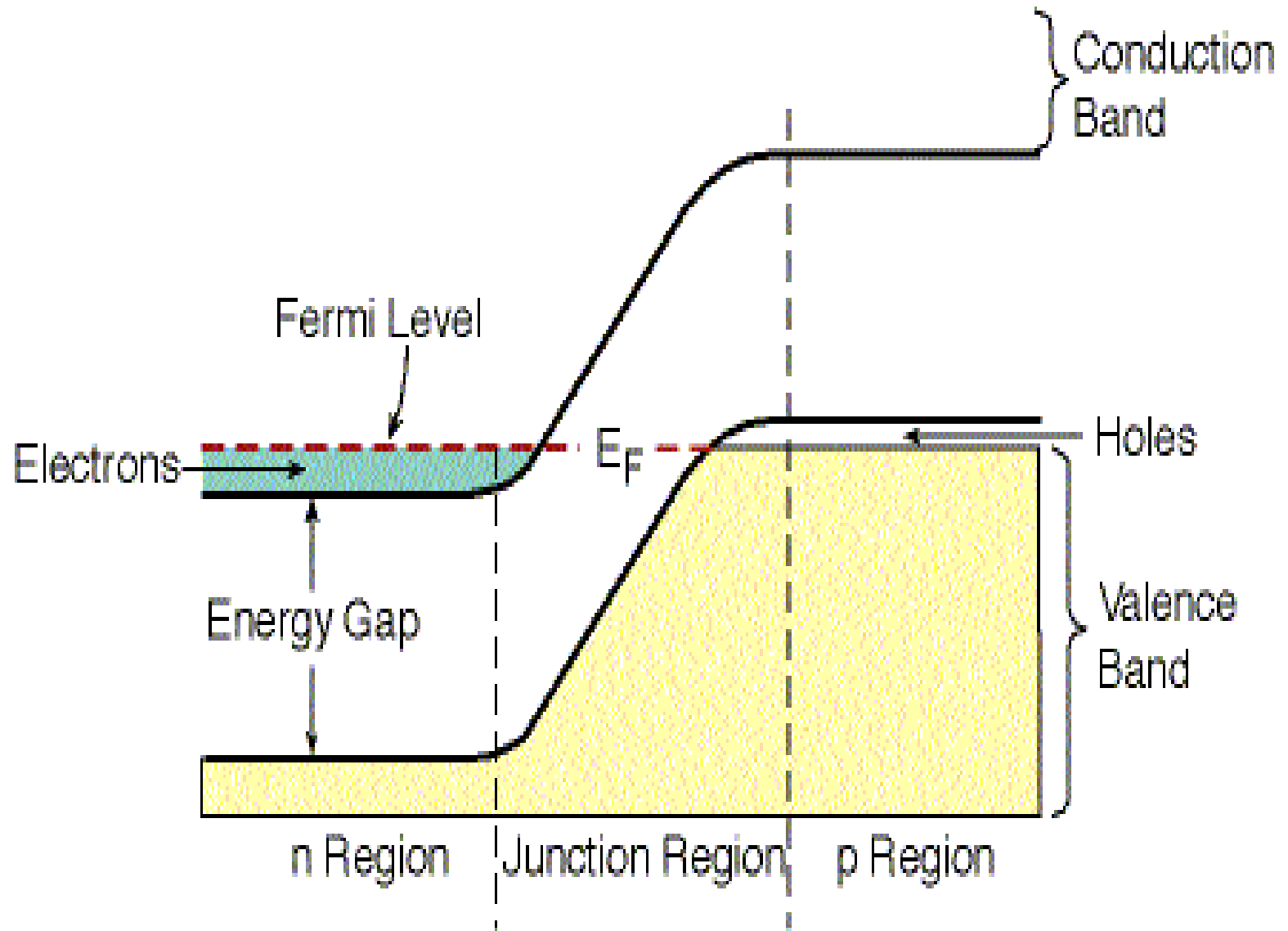
How Laser Beam are Formed?

- Laser beams are formed through a process called stimulated emission within a laser cavity. This process creates a highly concentrated, coherent, and well-defined beam of light. The step of laser beam formation is given below:
- **Stimulated Emission:** In stimulated emission, electrons are hit by the photons with a high energy and photons are produced by external light. The electron absorbs the energy and recombines with the hole when photon reaches the electron, this lead to the emission of more number of photons. Therefore, an incident photon causes the release of another photon. Therefore it is called stimulated emission.
- **Population Inversion:** When more number of atoms or molecule are in the excited state than in the ground state, the phenomena is referred as population inversion. Due to this condition, we are able to operate lasers.
- **Feedback:** The stimulated emission leads to photon amplification, but to develop a well-defined beam, optical feedback is required.
- **Laser threshold:** When the light intensity in the cavity reaches the threshold value, a laser beam begins to form.
- **Laser Beam Emission:** When a light beam reaches the laser's threshold, part of the mirror allows some photons to pass, forming a laser beam.

Fabry Perot Resonator Cavity







DFB LASER

- Distributed Feedback Laser
- The DFB laser exhibits **very narrow linewidths** with a very low relative intensity noise.
- Fabry Perot (FP) lasers have long been utilized as a light source for fiber communication. These lasers, however, were only successful for short-distance communication. Because FP lasers have serious problems with long-distance transmission. The DFB laser provided a solution to all of these restrictions.
- Another element that separates the DFB laser from other lasers is its construction. Unlike conventional laser diodes, It does not construct the optical cavity with two separate mirrors. Instead, a diffraction grating on top of the active zone creates the **upper waveguide layer**.
- Furthermore, Distributed Feedback Lasers are commonly constructed with a **quantum well structure**. Whenever light is confined in a cavity smaller than its wavelength, it acts as a particle rather than a wave.
- Because of DFBs Quantum Well (QW) structure, it has a **low threshold current**, less temperature dependence, and a narrow gain spectrum.

PARAMETERS	LED	LASER
Working Principle	Electro-luminance	Stimulated Emission
Full Form	Light Emitting Diode	Light Amplification by Stimulated Emission of Radiation
Response	Slow Response	Fast response in comparison to LED
Driving Current	It ranges from 50 to 100 mA.	It ranges from 5 to 40 mA.
Nature of Emitted Light	Incoherent and consists of various colours.	Coherent and Monochromatic.
Junction Area during Manufacturing	Wide Junction Area	Narrow and small Junction
Bandwidth Range	It lies in the range of 10 to 50 THz.	It lies in the narrow range i.e. from 1 MHz to 2 MHz.
Power to light Conversion Efficiency	Approx 20 %	Approx 70 %
Numerical Aperture of the obtained Light Beam	Higher in LEDs	Extremely low as compared to LEDs.
Cost	Low cost and thus economical.	High cost and thus used in the specific application.

Optical Detectors

- Optical detector is an essential component of an optical receiver which **converts received optical signal into an electrical signal**.
- Photo-detectors can influence the performance of a fiber optic communication link.



Requirements of Optical Detector

- High sensitivity at the operating wavelength
- High Fidelity
- Large electrical response to the optical signal
- Short response time to obtain a suitable bandwidth
- A minimum noise introduced by the detector
- Stability of performance characteristics
- Small Size
- Low bias voltage
- High reliability
- Low cost

Types of Optical Detectors

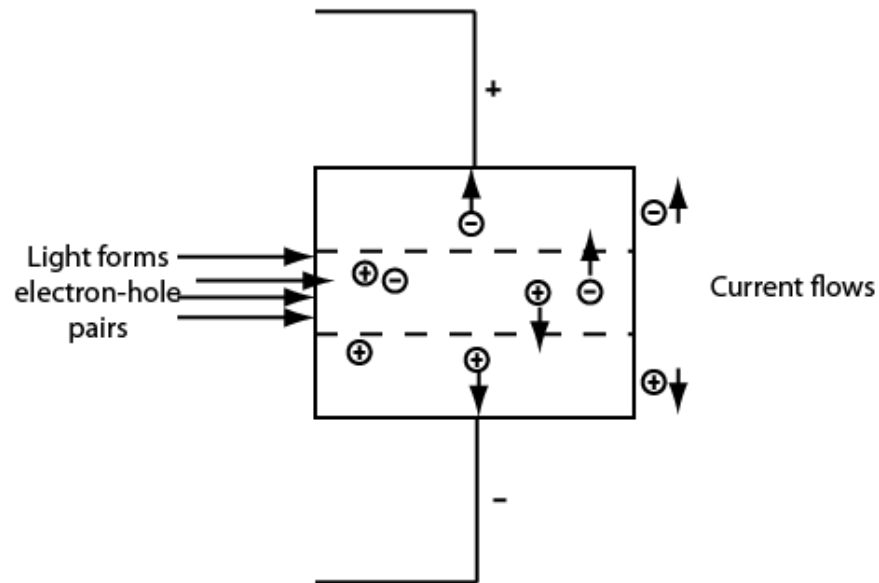
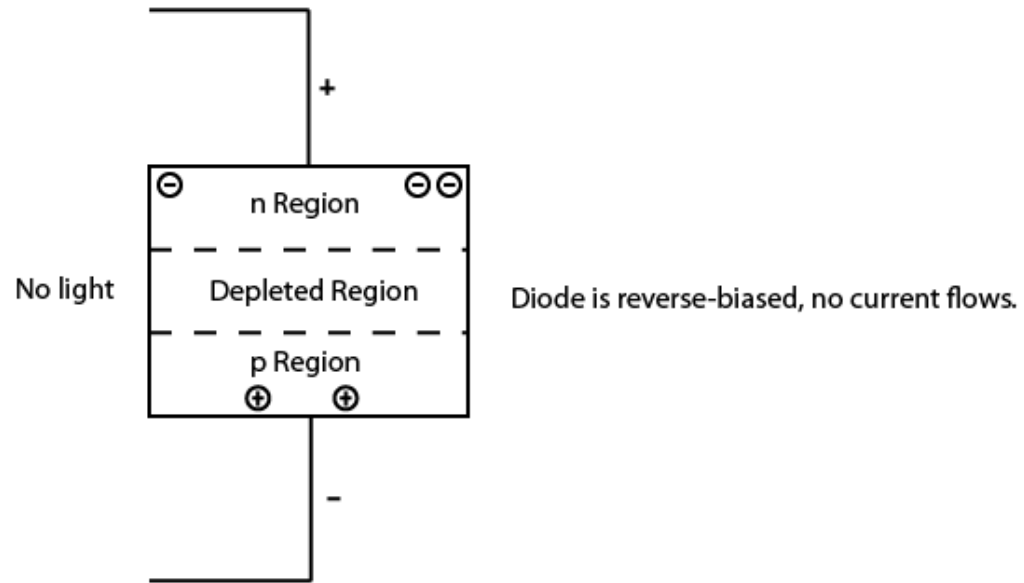
- PN Photo Diode
- PIN diode
- APD

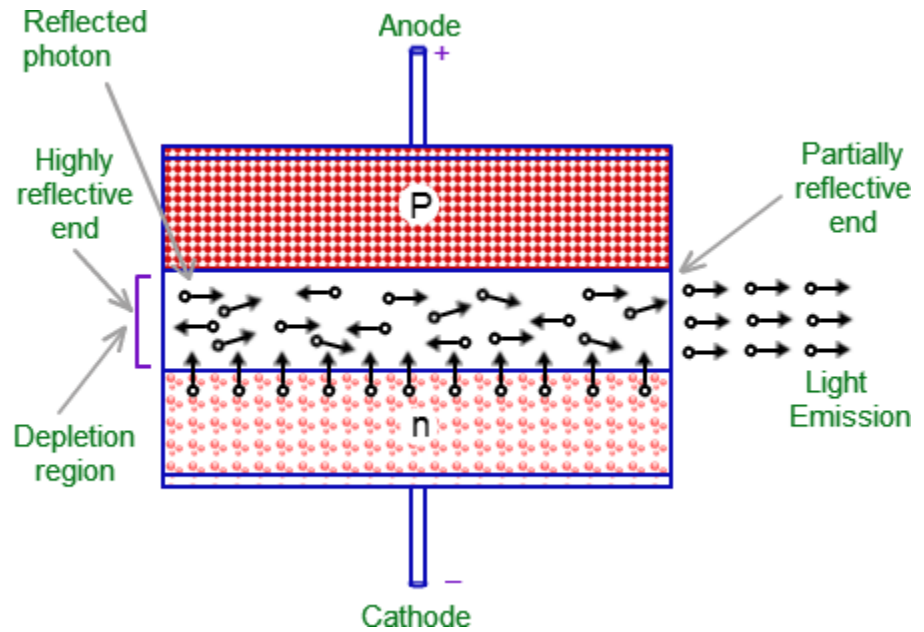
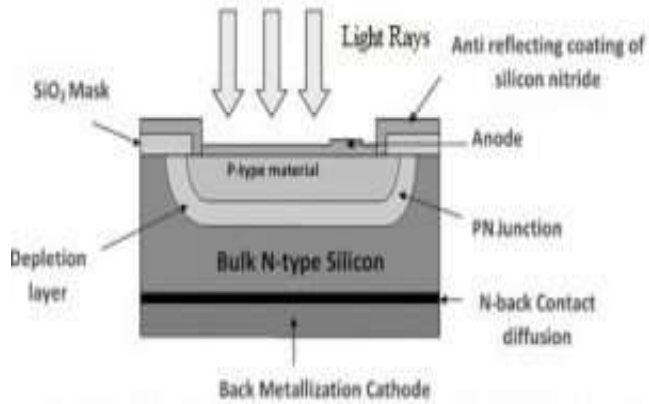
PN Photo Diode

- The photodiode is made using two semiconductors like P-type & N-type.
- In this design, the formation of P-type material can be done from the diffusion of the P-type substrate which is lightly doped.
- So, the P+ ions layer can be formed because of the diffusion method.
- On the substrate of N-type, the N-type epitaxial layer can be grown.

- The development of a P+ diffusion layer can be done over the heavily doped N-type epitaxial layer.
- The contacts are designed with metals to make two terminals like anode and cathode.
- The front region of the diode can be separated into two types like active & non-active surfaces.

- The designing of the non-active surface can be done with silicon dioxide (SiO_2).
- On an active surface, the light rays can strike over it whereas, on a non-active surface, the light rays cannot strike.
- The active surface can be covered through the material of anti-reflection so that the energy of light cannot lose and the highest of it can be changed into the current.

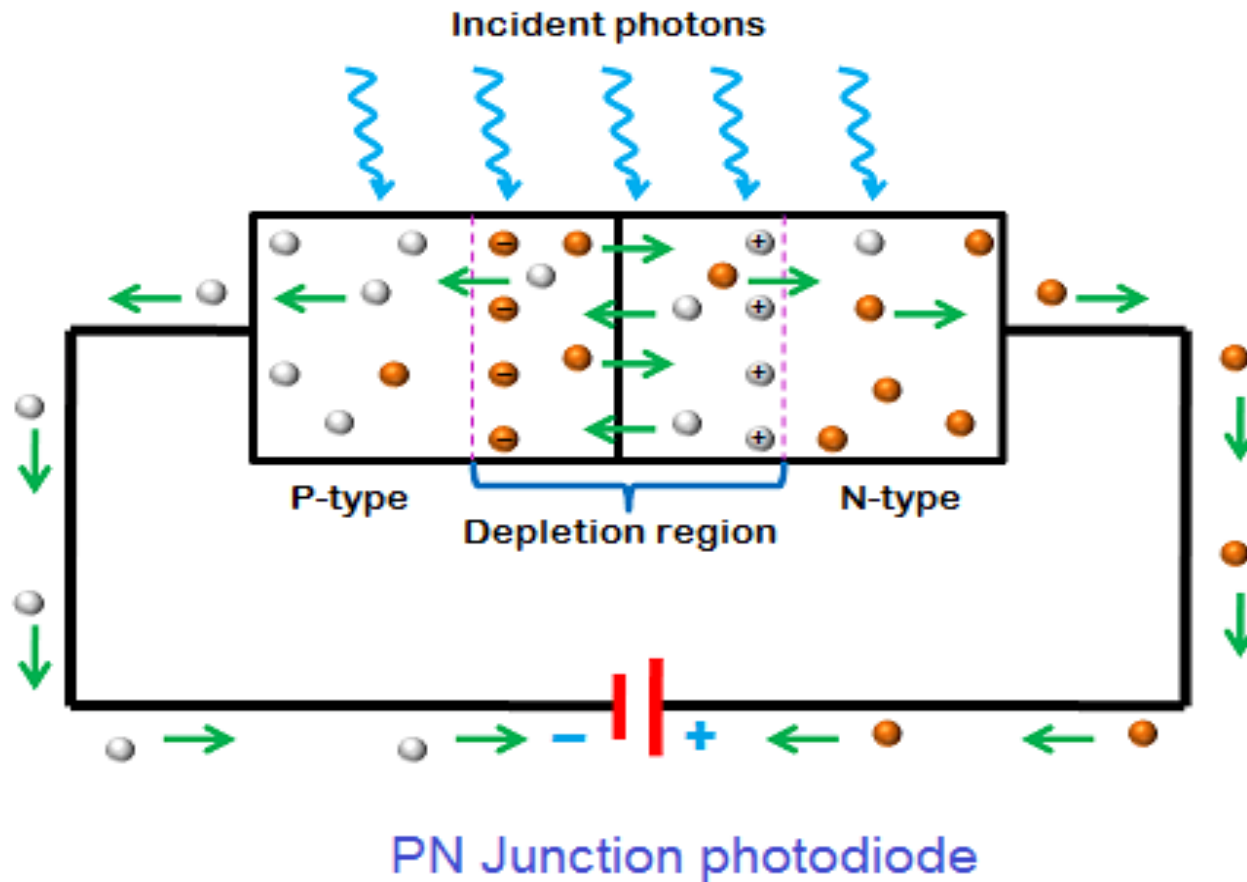




Working of Photodiode

- The working principle of a photodiode is, when a photon of ample energy strikes the diode, it makes a couple of an electron-hole.
- This mechanism is also called the **inner photoelectric effect**.
- If the absorption arises in the depletion region junction, then the carriers are removed from the junction by the inbuilt electric field of the depletion region.

- Therefore, holes in the region move toward the anode, and electrons move toward the cathode, and a photocurrent will be generated.
- The entire current through the diode is the sum of the absence of light and the photocurrent.
- So the absent current must be reduced to maximize the sensitivity of the device.



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Modes of Operation

- **Photovoltaic Mode:** This mode is also known as **zero-bias mode**, in which a voltage is produced by the lightened photodiode. It gives a very small dynamic range & non-linear necessity of the voltage formed.
- **Photoconductive Mode:** The photodiode used in this photoconductive mode is more **usually reverse biased**. The reverse voltage application will increase the depletion layer's width, which in turn decreases the response time & the junction capacitance. This mode is too fast and displays electronic noise
- **Avalanche Diode Mode:** Avalanche diodes operate in a **high reverse bias condition, which permits the multiplication of an avalanche breakdown to each photo-produced electron-hole pair**. This outcome is an internal gain in the photodiode, which slowly increases the device response.

Why is Photodiode Operated in Reverse Bias?

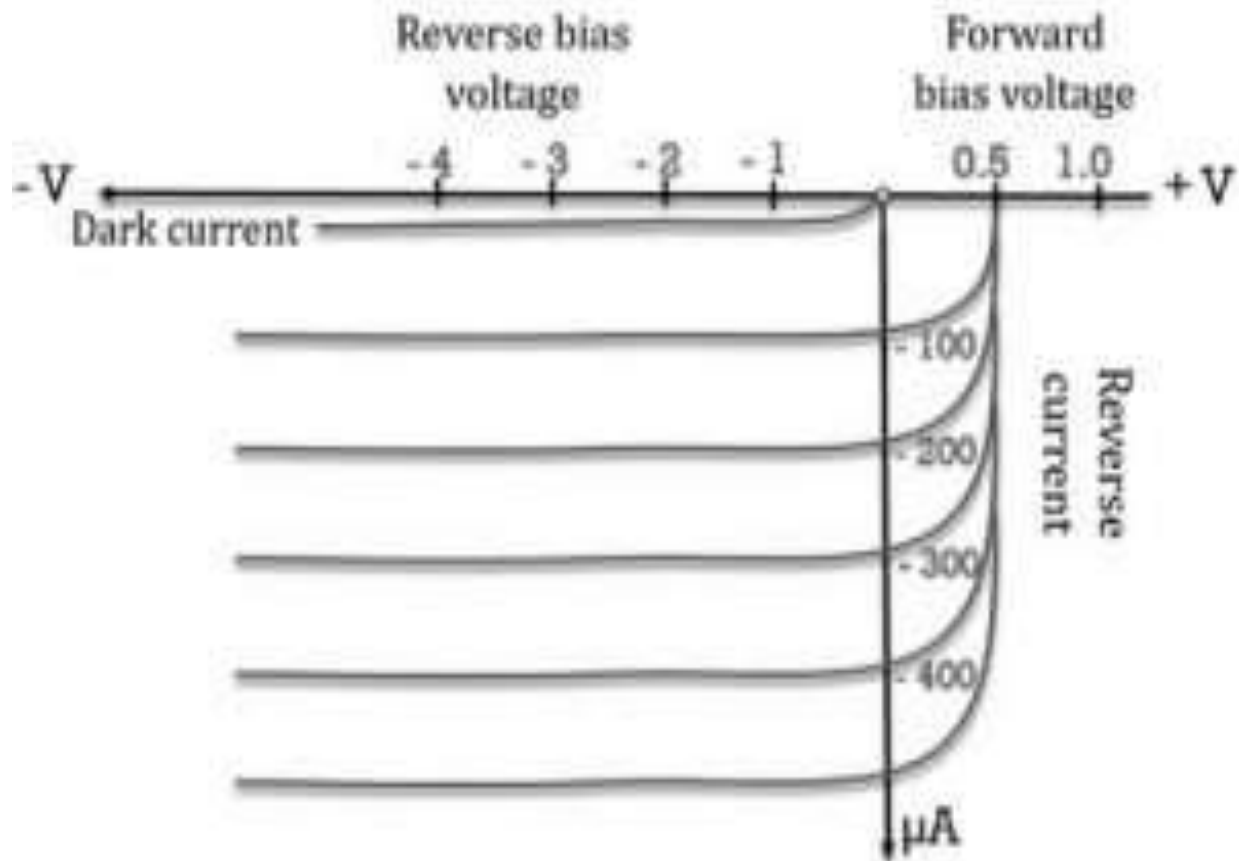
- The photodiode operates in the mode of photoconductive.
- When the diode is connected in reverse bias, then the depletion layer width can be increased.
- So this will diminish the capacitance of the junction & the response time.
- In fact, this biasing will cause quicker response times for the diode.
- So the relation between photocurrent & illuminance is linearly proportional.

Which is better Photodiode or Phototransistor?

Photodiode	Phototransistor
The semiconductor device that converts the energy from light to electrical current is known as a photodiode.	The phototransistor is used to change the energy of light into an electrical current using the transistor.
It generates both the current and voltage	It generates current
The response time is speed	The response time is slow
It is less responsive as compared with a phototransistor	It is responsive and generates a huge o/p current.
This diode works in both the biasing conditions	This diode works in forward biasing only.
It is used in a light meter, solar power plant, etc	It is used to detect the light

V-I Characteristics of Photodiode

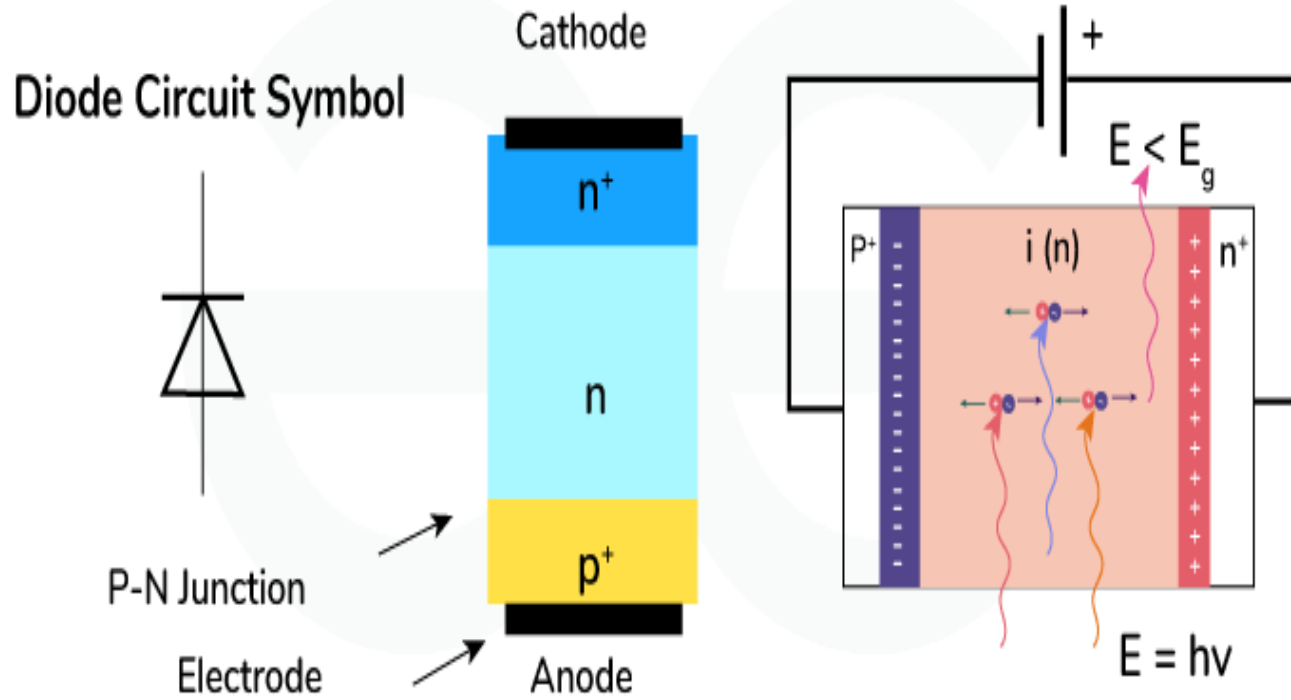
- A photodiode continually operates in a reverse bias mode.
- The photocurrent is nearly independent of reverse bias voltage which is applied.
- For zero luminance, the photocurrent is almost zero excluding for small dark current.
- It is of the order of nano amperes.
- As optical power rises the photocurrent also rises linearly.
- The max photocurrent is incomplete by the power dissipation of the photodiode.



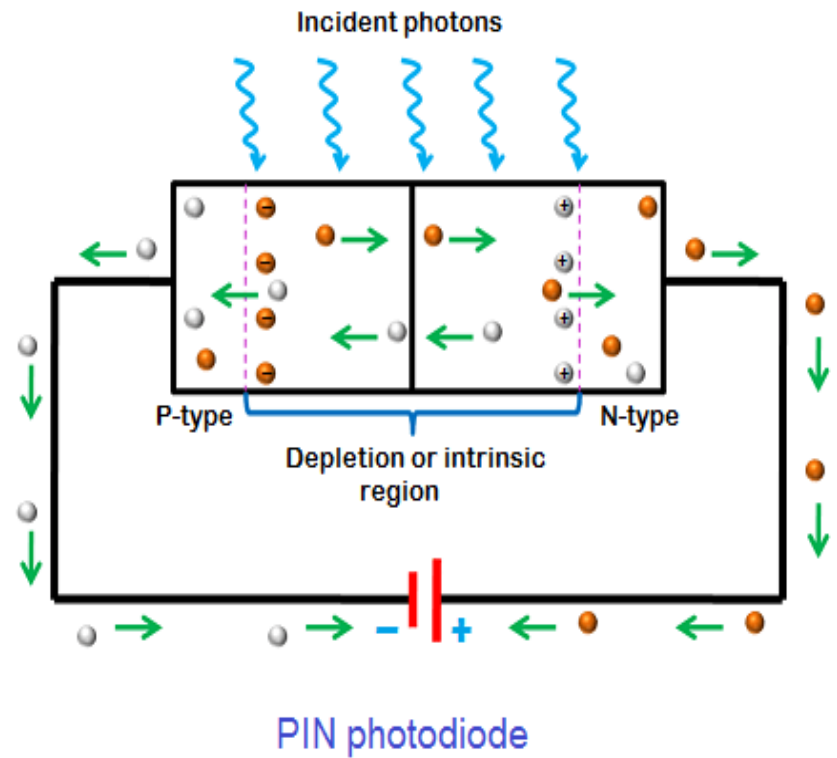
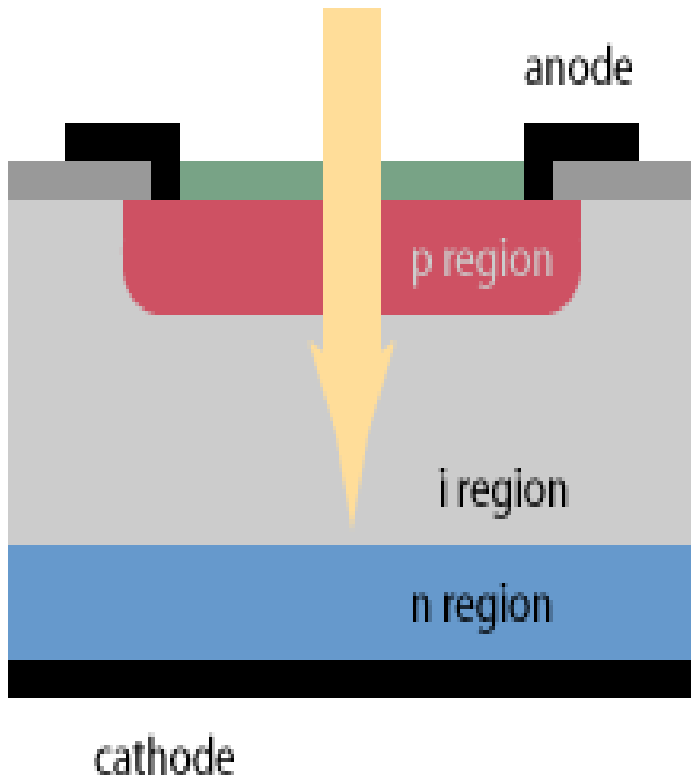
PIN Photodetector

- The most common semiconductor photodetector is the PIN photodiode.
- PIN photodiode has an intrinsic (very lightly doped) semiconductor region sandwiched between a p-doped and an n-doped region.

Pin diode

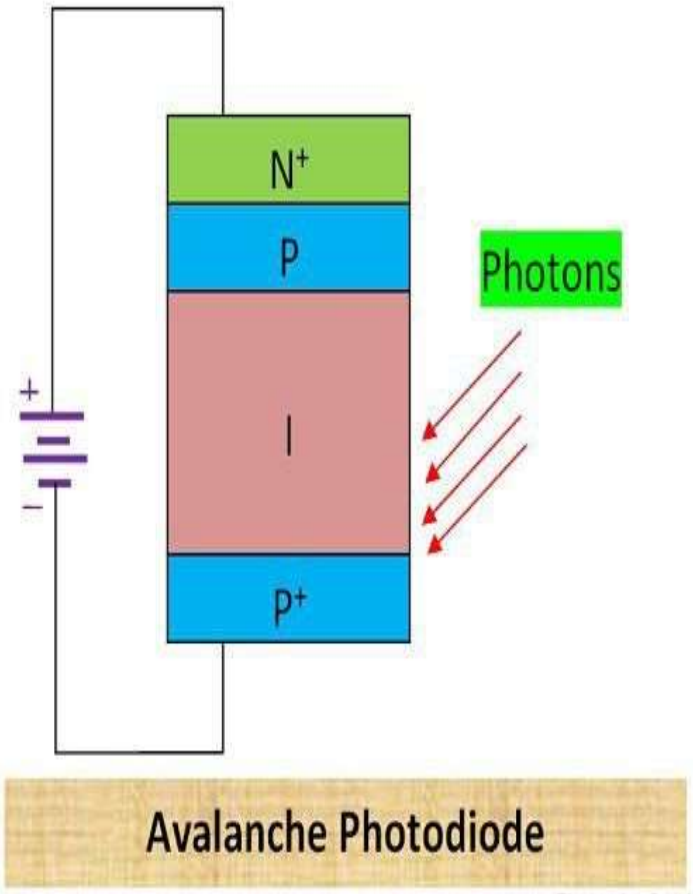


- The PIN photodiode is reverse-biased as shown above. Since the intrinsic (i) region has no free charges, its resistance is high, so that most of the reverse-biased voltage is applied to this i region.
- The I region is usually wide so that incoming photons have a greater probability of absorption in the i region rather than in the p or n regions.
- Since the electric field is high in the I region, any electron-hole pairs generated in this region are immediately swept away by the field.
- e-h pairs generated in the p and n regions have to first diffuse into the depletion region before being swept away.
- Also, these e-h pairs may suffer recombination, resulting in a reduced current.

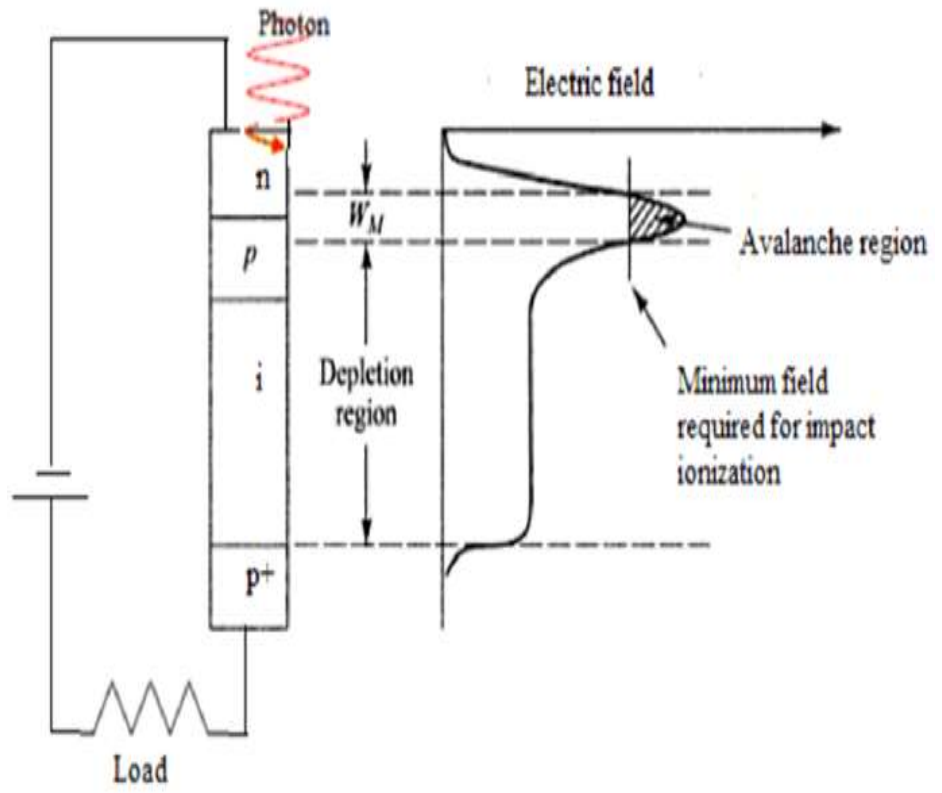


Avalanche photodiode (APD)

- In fiber optic communication systems, a single component such as an avalanche photodiode is used to convert light into an electrical signal.
- During the avalanche process, charge carriers are generated by collisions.
- The light particle-like photons create many electrons, which in turn create an electric current.
- The avalanche photodiode or APD was designed by a Japanese engineer namely “Jun-ichi Nishizawa” in the year 1952.
- An APD is a very responsive semiconductor detector that used the photoelectric effect to change light into [electricity](#).
- In fiber-optic communication systems, the light is changed into electrical signals using a single component like avalanche photodiode or APD.
- In the avalanche process, charge carriers are produced through collisions.
- A light particle-like photon generates many electrons to produce an electric current.



Electronics Coach



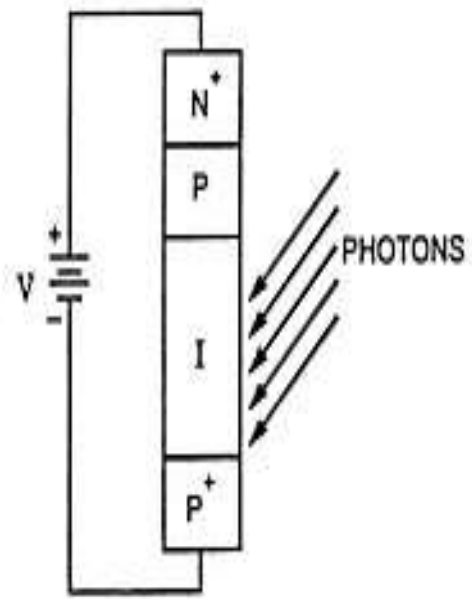
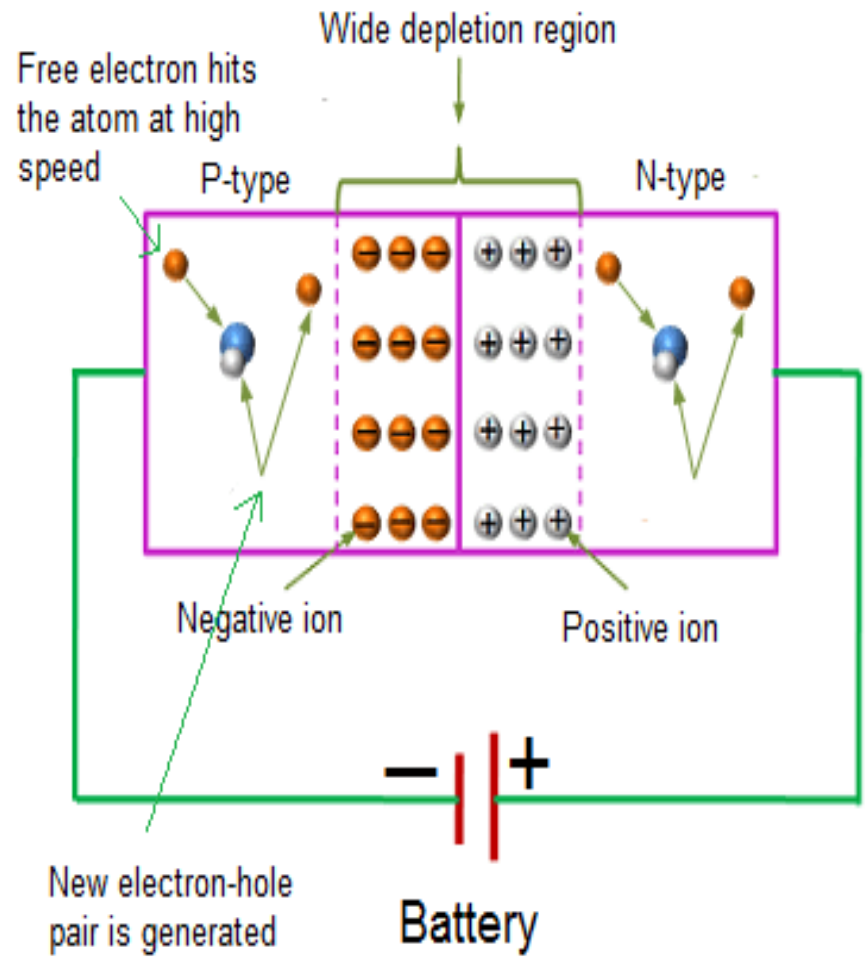
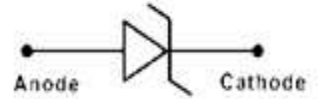


Fig. 25.27 Structure of Avalanche Photodiode



What is Avalanche Photodiode?

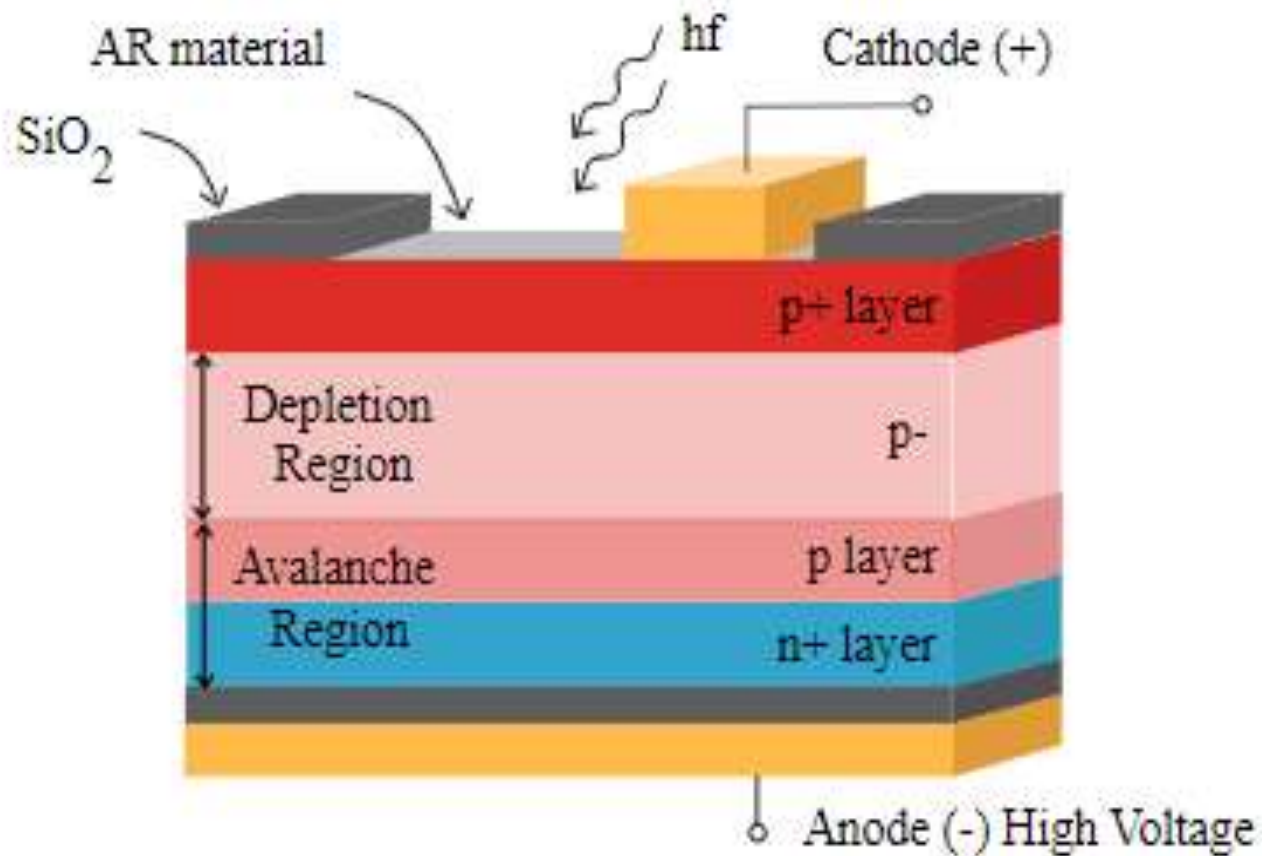


- The diode which uses the avalanche method to provide extra performance as compared to other diodes is known as avalanche photodiode.
- These diodes are used to change the signals from optical to electrical.
- These diodes can be operated in high reverse bias.
- The **avalanche photodiode symbol** is similar to the Zener diode.

Avalanche Photodiode Construction

- The construction of both the PIN photodiode and Avalanche photodiode is similar.
- This diode includes two heavily doped & two lightly doped regions.
- Here, heavily doped regions are P+ & N+ whereas lightly doped regions are I & P.

Avalanche Photodiode



- In the intrinsic region, the depletion layer width is fairly thinner in this diode as compared to the PIN photodiode.
- Here, the p+ region works like the anode whereas the n+ region acts as the cathode.
- As compared to other photodiodes, this diode works in a high reverse bias condition.
- So this allows avalanche multiplication of the charge carriers formed through the light impact or photon.
- The avalanche action allows the gain of the photodiode to be enhanced several times to provide a high range of sensitivity.

Working Principle

- Avalanche breakdown occurs mainly once the photodiode is subjected to maximum reverse voltage.
- This voltage enhances the electric field beyond the depletion layer.
- When incident light penetrates the p+ region then it gets absorbed within the extremely resistive p region then electron-hole pairs are generated.
- Charge carriers drift including their saturation velocity to the pn+ region wherever a high electric field exists.
- When the velocity is highest, then charge carriers will collide through other atoms & produce new electron-hole pairs.
- A huge charge carrier's pair will result in high photocurrent.

Avalanche Photodiode Operation

- This diode operation can be done in a depleted mode completely.
- However, they can also work in the Geiger mode in addition to the linear avalanche mode.
- In this type of operation mode, the photodiode can be operated at the above breakdown voltage.
- At present, another mode is launched namely “Sub-Geiger mode”.

Avalanche Photodiode in Optical Fiber Communication

- In optical fiber communication (OFC) systems, avalanche photodiodes are generally used for the recognition of weak signals but circuits need to optimize enough so that high Signal to noise ratio (S/N). Here, SNR is
 - **$S/N = \text{Power from the photocurrent/photo detector's power} + \text{Amplifier noise power}$**
- For obtaining the perfect signal-to-noise ratio, quantum efficiency should be high because this value is almost maximum, so most of the signals are noticed.

Avalanche Photodiode Characteristics

- Avalanche photodiodes are highly sensitive, high-speed-based diodes which use an internal gain method that works through applying a reverse voltage.
- As compared to PIN type photodiode, these diodes measure low range light so used in different applications where high sensitivity is required like measurement of optical distance and optical communication for long-distance.
- There are different avalanche photodiode families which are designed mainly for detecting short wavelengths otherwise near-infrared.

PIN Photodiode and Avalanche Photodiode?

Avalanche Diode	PIN Diode
<u>Avalanche diode</u> includes four layers like P+, I, P & N+.	PIN diode includes four layers like P+, I & N+.
Response time is very high.	Response time is very low.
Output current is low.	The multiplication of carrier current can cause amplifier current value.
Internal gain is 200 dB.	Internal gain is insignificant.
Sensitivity is high.	Sensitivity is low.
High noise.	Low noise.
The reverse bias voltage is very high.	The reverse bias voltage is very low.
High-temperature stability.	Low-temperature stability.
The amplifier is not necessary because of the available gain.	The amplifier is mandatory due to not available gain.

What are Avalanche and Zener Breakdown Phenomena?

- The Avalanche & Zener Breakdown are two dissimilar mechanisms where a PN junction breaks.
- This mechanism mainly occurs within the diode in reverse bias conditions.
- The avalanche breakdown mainly occurs due to the electrons ionization & hole pairs while the Zener breakdown takes place due to heavy doping.

Advantages

- The sensitivity range is high.
- High performance.
- Quick response time.
- These diodes are applicable here the gain level is very important as the high voltage required, through lower reliability means that they are frequently less convenient to utilize.
- It detects low-intensity light.
- A single-photon generates a huge number of charge carrier pairs.

Disadvantages

- The required operating voltage is high
- The output of this diode is not linear
- High range of noise
- It is not used regularly because of the low reliability
- It uses high reverse bias for its proper operation

Applications

- LASER scanner
- Analyzer bridge of antenna
- PET scanner
- Barcode reader
- Laser microscopy
- Laser Rangefinders
- Speed gun
- APDs are used in receivers of OFC (optical fiber communications), imaging, finding the range, laser microscopy, laser scanners & OTDR (optical-time domain reflectometers).

Characteristics of Optical Detectors

- **Quantum Efficiency**
- **Responsivity**
- **Speed of Response and Bandwidth**
- **Dark Current**
- **Noise-Equivalent Power (NEP)**

Quantum Efficiency

- η measures the fraction of incoming photons that generate electrons at the detector. It is defined as
$$\text{Quantum Efficiency} = \frac{\text{Electrons Out}}{\text{Photons input}}$$
- η is the ratio of the number of electron-hole (e-h) pairs generated to the number of incident photons.

Responsivity

- The ratio of electrical output from the detector to the input optical power.
- If the output current varies proportionally to the input, this is measured as amps per watt (A/W).
- Since in fiber optic communication systems, input powers are usually in microwatt level, responsivity is often expressed as $\mu\text{A}/\mu\text{W}$.
- ρ is the photo current generated per unit optical power.

Speed of Response and Bandwidth

- The speed of response and bandwidth of a photodetector depend on three factors.
- The transit time of the photo-generated carriers through the depletion region
- The electrical frequency response as determined by the RC time constant, which depends on the diode's capacitance
- The slow diffusion of carriers generated outside the depletion region

Dark Current

- Dark current is the current through the photodiode in the absence of light, when it is operated in photoconductive mode.
- The dark current includes photocurrent generated by background radiation and the saturation current of the semiconductor junction.
- Dark current sets a floor on the minimum detectable signal, because a signal must produce more current than the dark current in order to be detected.
- Dark current depends on operating temperature, bias voltage, and the type of detector.
- Dark current must be accounted for by calibration if a photodiode is used to make an accurate optical power measurement, and it is also a source of noise when a photodiode is used in an optical communication system.

Noise-Equivalent Power (NEP)

- Noise-Equivalent Power (NEP) is the minimum input optical power to generate photocurrent, equal to the rms noise current in a 1 hertz bandwidth.
- This more directly measures the minimum detectable signal because it compares noise directly to optical power.
- NEP depends on the frequency of the modulated signal, the bandwidth over which noise is measured, the detector area, and the operating temperature.