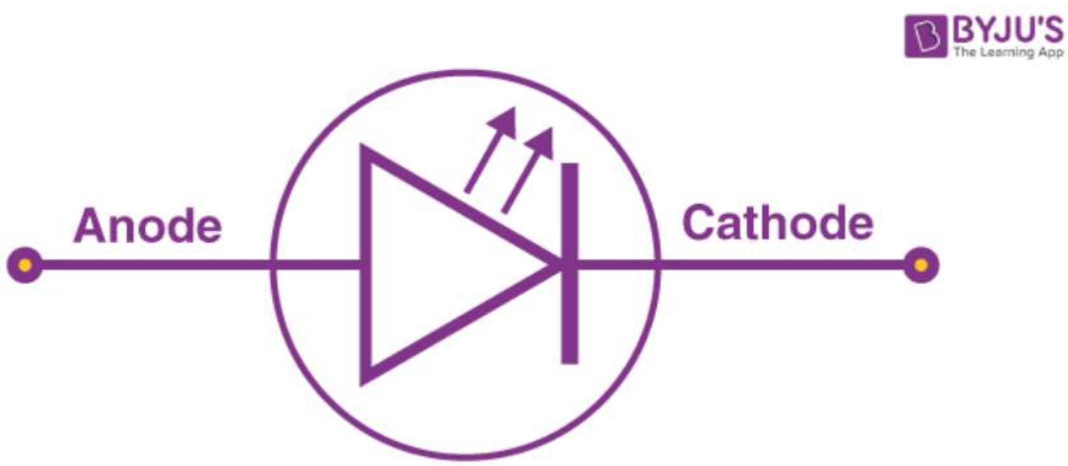
Light-emitting diodes are heavily doped p-n junctions. Based on the semiconductor material used and the amount of doping, an LED will emit coloured light at a particular spectral wavelength when forward biased. As shown in the figure, an LED is encapsulated with a transparent cover so that emitted light can come out.

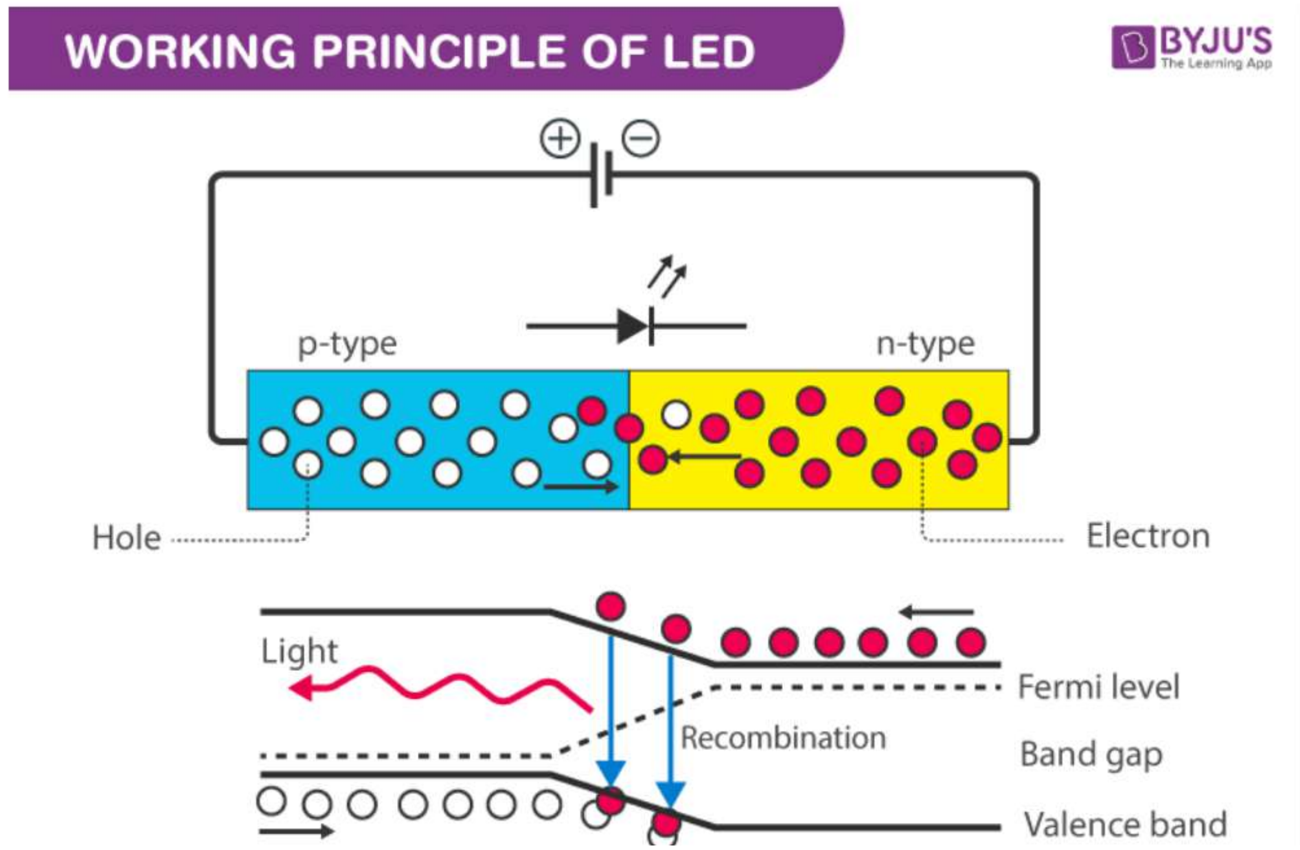
Read More: Diodes

LED Symbol

The LED symbol is the standard symbol for a diode, with the addition of two small arrows denoting the emission of light.



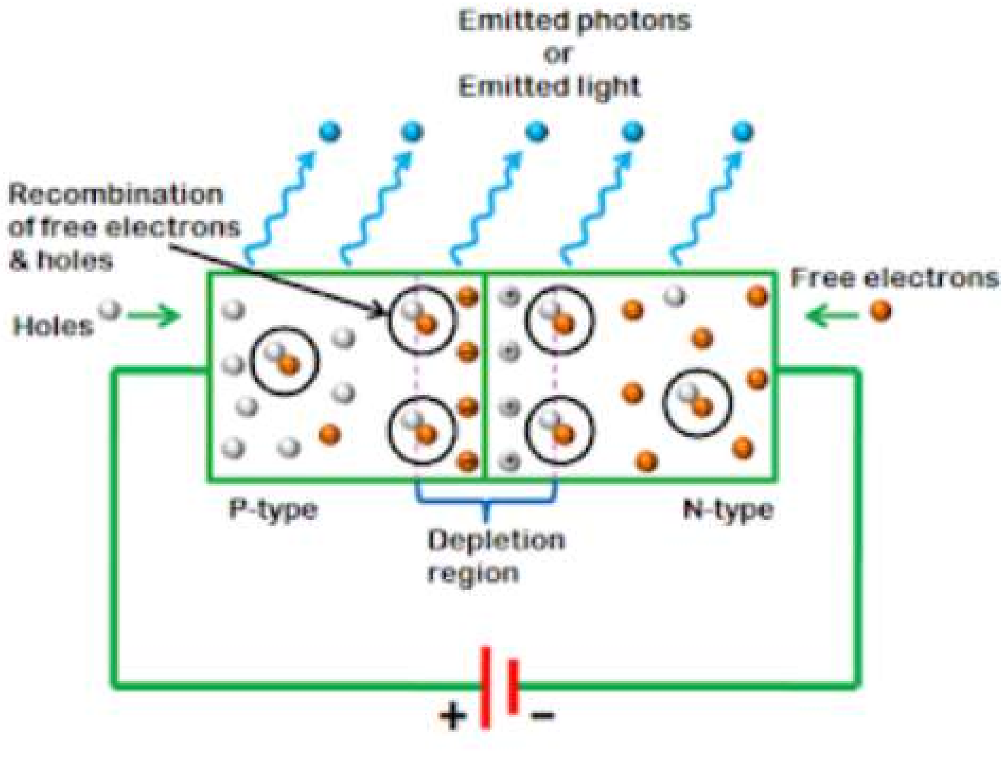
When the diode is forward biased, the minority electrons are sent from p → n while the minority holes are sent from n → p. At the junction boundary, the concentration of minority carriers increases. The excess minority carriers at the junction recombine with the majority charges carriers.



The energy is released in the form of photons on recombination. In standard diodes, the energy is released in the form of heat. But in light-emitting diodes, the energy is released in the form of photons. We call this phenomenon electroluminescence. Electroluminescence is an optical phenomenon, and electrical phenomenon where a material emits light in response to an electric current passed through it. As the forward voltage increases, the intensity of the light increases and reaches a maximum.

What determines the colour of an LED?

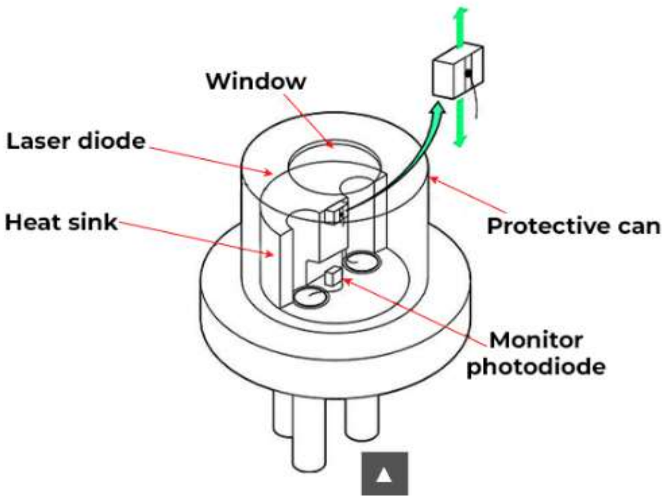
The colour of an LED is determined by the material used in the semiconducting element. The two primary materials used in LEDs are aluminium gallium indium phosphide alloys and indium gallium nitride alloys. Aluminium alloys are used to obtain red, orange and yellow light, and indium alloys are used to get green, blue and white light. Slight changes in the composition of these alloys change the colour of the emitted light.


Emitted photons
or
Emitted light
Recombination
of free electrons
& holes
Holes
Free electrons
P-type
N-type
Depletion
region
+
−

What is a Laser Diode?

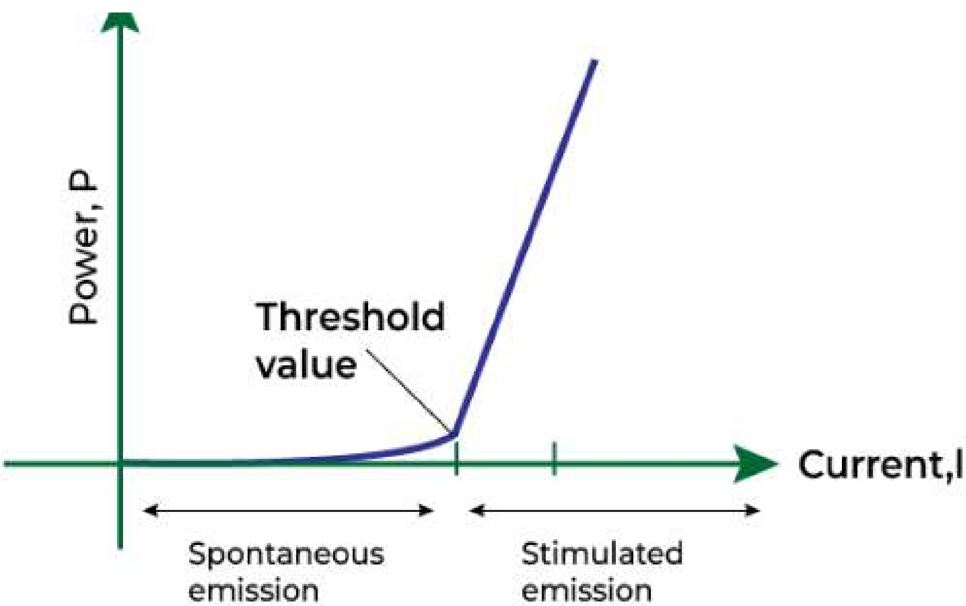
A laser diode is a semiconductor device that transmits coherent and highly focused light through a process called stimulated emission. It comprises a p-n junction, where electrons and holes combine, releasing energy as photons. This coherent light is delivered when photons stimulate further photon emission, making a concentrated and monochromatic laser beam. It produces coherent radiation with same frequency , which can be visible or infrared spectrum.

This process is spontaneous and produces light at same frequency and phase. Laser diodes are broadly utilized in different applications, including media communications, laser pointers, optical capacity gadgets, clinical instruments, and modern gear because of their productivity, compact size, and accuracy in conveying intense light beam emissions.



Characteristics of Laser Diodes

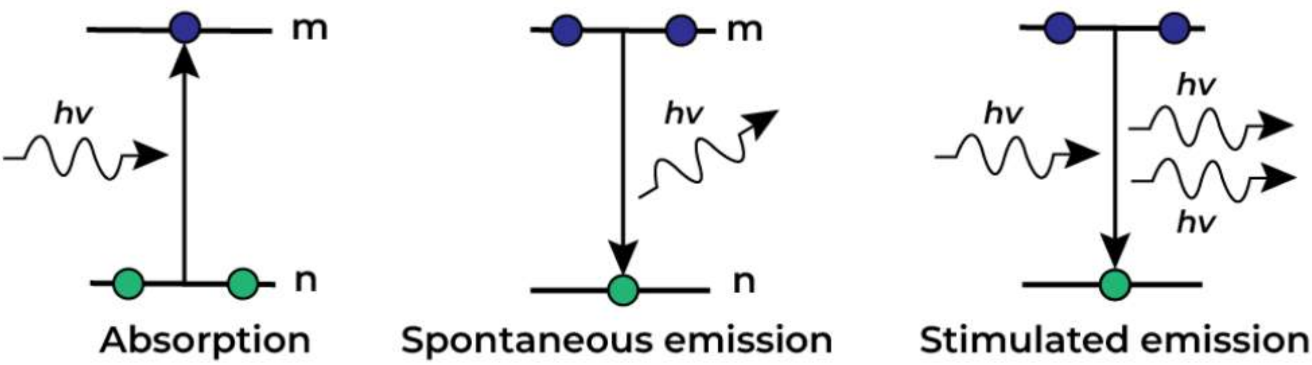
- **Coherence:** Laser diodes emit coherent, meaning the transmitted photons have a similar frequency and are in same phase, creating highly focused and intense beam.
- **Monochromatic:** It means one color. Laser diodes are monochromatic because it emits light of one color of a particular wavelength. 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.



Threshold Value

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.



Working Principle

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 steps 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.

What is PIN Diode?

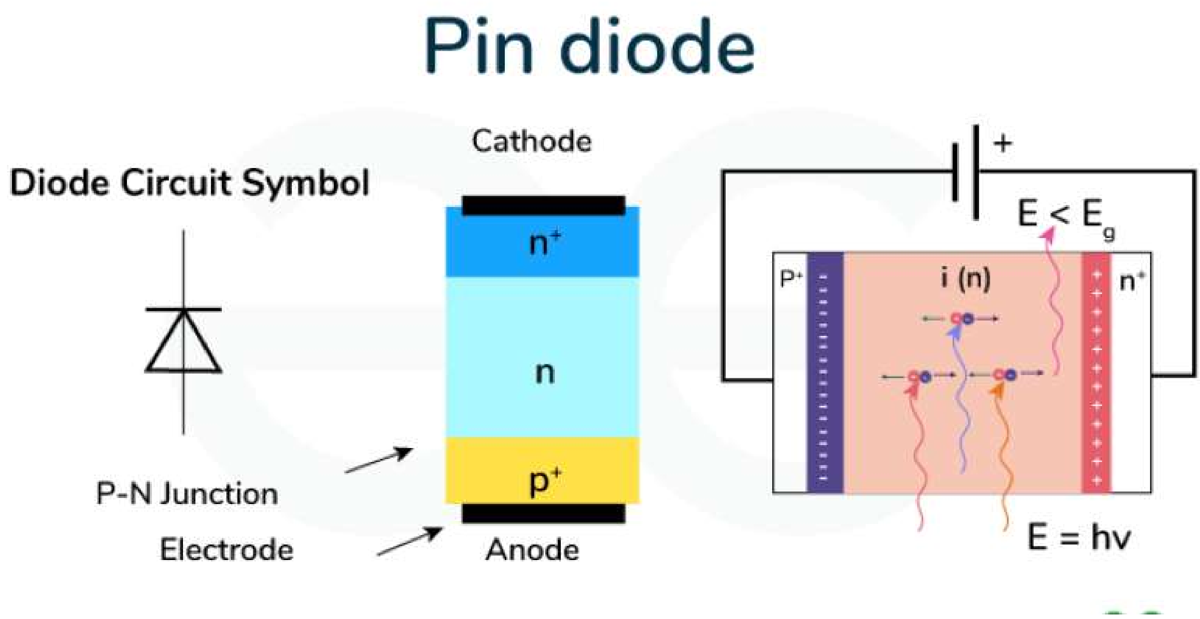
A PIN diode, quick for Positive-Intrinsic-Negative diode, is a semiconductor tool that belongs to the diode family. Unlike normal diodes, PIN diodes include three layers:

- p-type (high-quality) semiconductor layer
- Intrinsic (undoped or gently doped) semiconductor layer
- n-type (poor) semiconductor layer

The intrinsic layer performs a crucial role within the device's operation, permitting it to characteristic as a variable resistor in reaction to an implemented voltage.

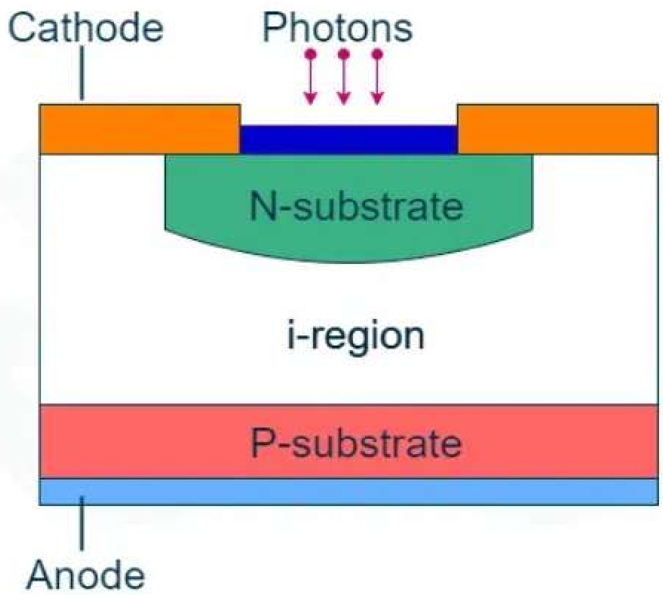
PIN Diode Symbol

as already discussed, PIN means Positive Intrinsic Negative. In symbol of PIN Diode, it represents the PIN diode structure. PIN diodes have two terminals anode and cathode.



Structure and Working of a PIN Diode

A PIN diode, quick for Positive-Intrinsic-Negative diode, has a 3-layer semiconductor shape. The layers are:



PIN Diode

- **P-Type Layer (Positive):** The top layer of the diode is the p-type semiconductor material, which is definitely doped with impurities. This layer is answerable for the fine terminal of the diode.

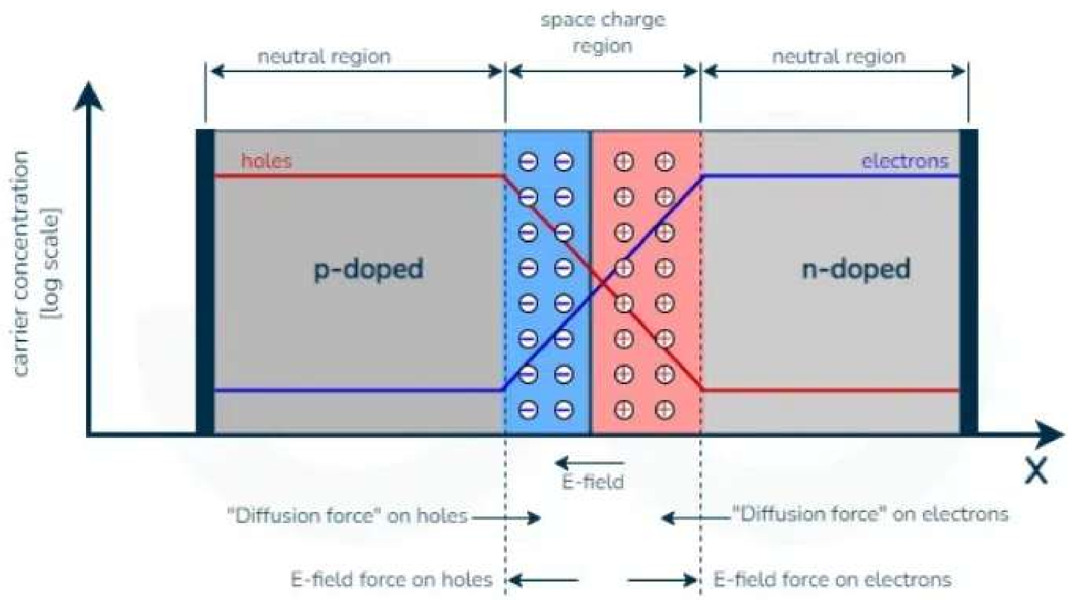
- **Intrinsic Layer:** Positioned within the middle, the intrinsic layer is an undoped or lightly doped semiconductor region. It is essential to the diode's operation, performing as a variable resistor in response to an outside voltage.

- **N-Type Layer (Negative):** The backside layer is the n-type semiconductor material, negatively doped with impurities. This layer paperwork the negative terminal of the diode.

Working Principle of a PIN Diode

The operating precept of a PIN diode revolves around its three-layer semiconductor shape, comprising a p-type (high-quality), intrinsic (undoped or lightly doped), and n-type (negative) layer. The intrinsic layer, vital to its operation, acts as a variable resistor in response to an implemented voltage.

Under forward bias, in which a high quality voltage is implemented to the p-type and a terrible voltage to the n-type, providers (electrons and holes) are injected into the intrinsic layer, reducing the width of the depletion region and improving diode conductivity. This state enables the PIN diode to function like a low-resistance switch.


space charge
region
neutral region
neutral region
carrier concentration
[log scale]
holes
electrons
p-doped
n-doped
X
E-field
"Diffusion force" on holes
"Diffusion force" on electrons
E-field force on holes
E-field force on electrons

Pin Diode

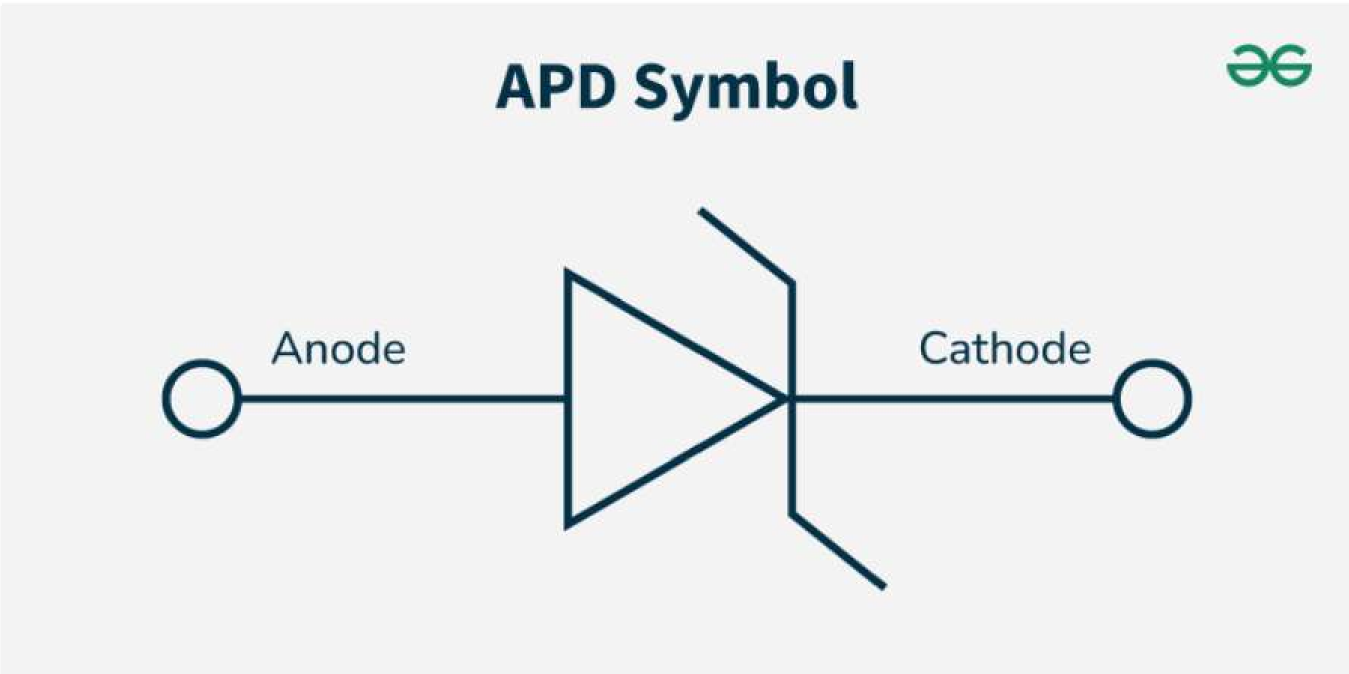
Avalanche Photodiode

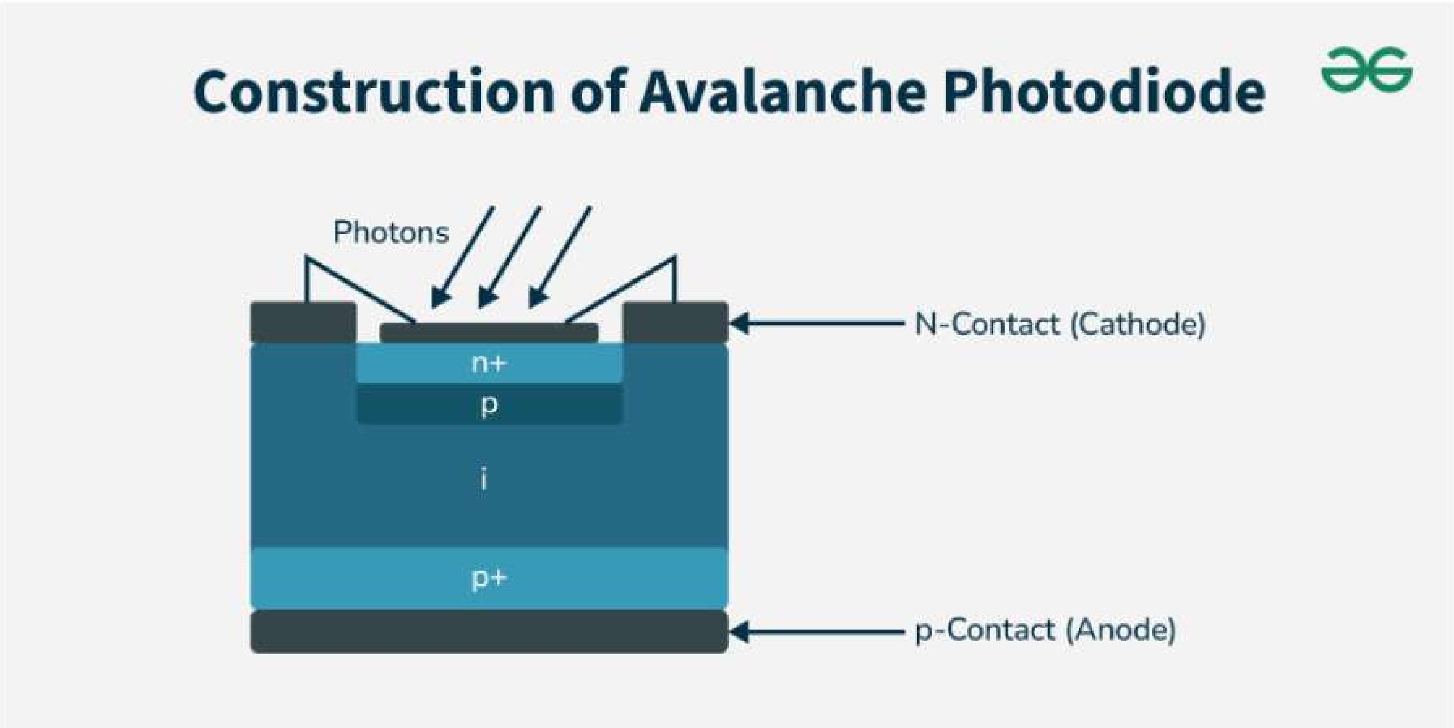
Last Updated : 17 Jul, 2024

An Avalanche photodiode (APD) is a highly sensitive semiconductor detector that uses the photoelectric effect to convert optical signals into electrical signals. In case of conventional photodiodes, PIN photodiodes operate in a linear mode and the output current is very small and also has limited gain. Whereas the APD operates in reverse bias and uses avalanche breakdown to amplify weak optical signals for higher sensitivity due to this process of detecting even the faint signals, the output currents are very large. It is also called a reach-through APD because this photodiode allows the electric field to extend or reach through the entire depletion region.

Symbol of APD (Avalanche Photodiode)

Its symbol is a graphical representation generally used in circuit diagrams. It contains an Anode and a Cathode




Construction of Avalanche Photodiode
Photons
N-Contact (Cathode)
n+
p
i
p+
p-Contact (Anode)

It has a p+ i-p-n+ Configuration as shown in the diagram. The construction of PIN photodiode and APD is similar is contains two heavily doped and two lightly doped regions. p+ and n+ are the heavily dopes regions whereas i and p are lightly doped regions. In the intrinsic region(i), the depletion layer width is fairly thinner in this photodiode as compared to PIN photodiode. Here p+ region acts like anode and n+ region acts like cathode. Here this p layer is having high resistivity, so all the reverse bias is mostly applied across p and n+ region. When the reverse bias is increased, the width of the depletion layer also gets increased.

Types of Avalanche Photodiode

There are 3 main types of APD

- Silicon APD
- InGaAs APD
- Ge APD

Working of APD

APD is similar to PIN diode the exception is the addition of high intensity electric field region.
In this region primary electron hole pairs are generated by the incident photons which are able to absorb enough kinetic energy from strong electric field to collide with the atoms present in this region, thus generating more electron hole pairs. The physical phenomenon behind the internal current gain is known as the impact ionization. This impact ionization leads to avalanche breakdown in ordinary reverse bias. It requires very high reverse bias voltage in order that the new carriers created by impact ionization can themselves produce additional carriers by same mechanism. This process of generating more than one electron hole pair from incident photon through ionization process is referred to as the avalanche effect. Thus the avalanche multiplication results in amplification of photodiode current. Multiplication factor: Multiplication factor M is a measure of internal gain provided by APD. It is defined as the ratio of total multiplied output current to the primary un multiplied current. M=IIpM=IIp Where I the Total multiplied output current IpIp is the primary un multiplied current Multiplication depends on physical and operational characteristics of photo detector device. Operational characteristics include the width of avalanche region, the strength of electric field and type of semiconductor material employed.

The responsivity (or *radiant sensitivity*) of a **photodiode** or some other kind of **photodetector** is the ratio of generated **photocurrent** and incident (or sometimes absorbed) **optical power** (neglecting noise influences), determined in the linear region of response. In the case of photodiodes, the responsivity is typically highest in a wavelength region where the **photon** energy is somewhat above the **band gap energy**, and declining sharply in the region of the bandgap, where the **absorption** decreases. It can be calculated according to

$$R = \eta \frac{e}{h\nu}$$

where $h\nu$ is the **photon** energy, η is the **quantum efficiency**, and e the elementary charge. From this, one sees that the result units of R are C/J = A/W; the latter is most common.

For example, a silicon photodiode with 90% quantum efficiency at a wavelength of 800 nm, the responsivity would be ≈ 0.58 A/W. Values for other types of photodiode are basically always of that order of magnitude.

Bit Error Rate (BER) Calculation:

The bit error rate (BER) is a measure of the number of erroneous bits received in a communication system compared to the total number of transmitted bits. To calculate the BER, you need to consider several factors, such as the modulation format, signal-to-noise ratio (SNR), and the presence of impairments like optical noise, dispersion, and nonlinearities.

The most common method for BER calculation is through the use of the error function (erf) or the Q-function, which relates the BER to the SNR. The formula for BER calculation is:

BER = 0.5 * erfc(sqrt(SNR/2))

where erfc is the complementary error function and SNR is the signal-to-noise ratio.Quantum Limit: The quantum limit, also known as the shot noise limit, is the fundamental limit to the sensitivity of an optical communication system imposed by quantum mechanics. It arises due to the statistical nature of photon arrivals at the detector. The shot noise results from the uncertainty associated with the discrete nature of photons.

Quantum limit

The quantum limit defines the minimum achievable BER for a given optical power level. It depends on the modulation format and the received power, and it sets a lower bound on the system performance. To approach the quantum limit, sophisticated receiver designs, such as coherent detection and forward error correction (FEC), are employed.

Power Penalties

Power penalties refer to the degradation in system performance caused by various impairments in an optical link. These penalties are typically measured in terms of increased BER compared to the ideal case. Some common power penalties encountered in optical link design include:

a. Fiber Loss: Fiber optic cables exhibit loss, which leads to reduced signal power. It can be compensated using optical amplifiers or by increasing the transmitted power.

b. Chromatic Dispersion: Dispersion causes temporal spreading of the optical signal, leading to inter-symbol interference (ISI) and degradation of signal quality. Compensation techniques like dispersion compensation fibers or digital signal processing can be employed.

c. Polarization Mode Dispersion (PMD): PMD causes differential delay between different polarization states, resulting in signal degradation. Compensation methods include PMD compensators or polarization diversity techniques.