Optical Communication

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Unit – 3
Revision

Unit – 4
OPTICAL SOURCES

The principal light sources used for the fiber optic communication applications are :

1. Light Emitting Diodes(LEDs).

2. Hetero-junction structured semi conductor LASER diodes (which are also called as injection LASER diodes or ILDs)

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A hetero junction consists of two adjoining semiconductor materials with different band-gap energies.

Advantages

- They have adequate output power for a wide range of applications .
- Their optical power output can be directly modulated by varying input current to the device.
- They have high efficiency and their dimensional characteristics are compatible with those of the optical fiber.

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- The major difference between LEDs and LASER diodes is that optical output from an LED is incoherent whereas from a LASER diode is coherent.

- The output beam of coherent source is highly directional.

- The output radiation from an incoherent source has broad spectral width.

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- Various characteristics of optical fiber such as attenuation, group delay ..etc are to be considered while choosing an optical source which is compatible with the waveguide.

Energy bands

- Conduction properties of a semi conductor can be interpreted with the help of energy band diagrams.

- In a semi conductor the valence electrons occupy a band of energy levels called valence a band.

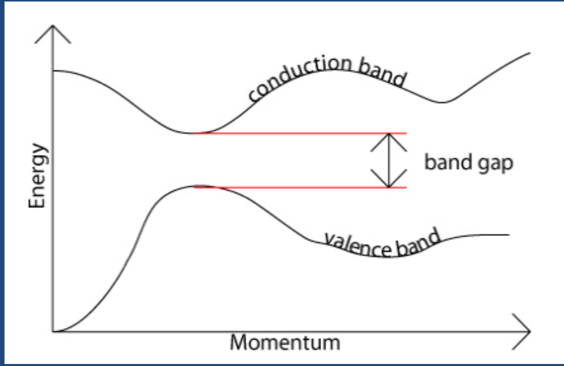
- In a pure crystal at low temperatures the conduction band is completely empty and valence band is completely full.

- These two bands are separated by an energy gap or band gap in which no energy levels exist.

Direct and Indirect band gap Semiconductors

Semiconductors are classified as direct and indirect band gap materials based on the shape of the band gap as a function of the momentum.

In a direct band gap semiconductor, the top of the valence band and the bottom of the conduction band occur at the same value of momentum, as in the schematic below.



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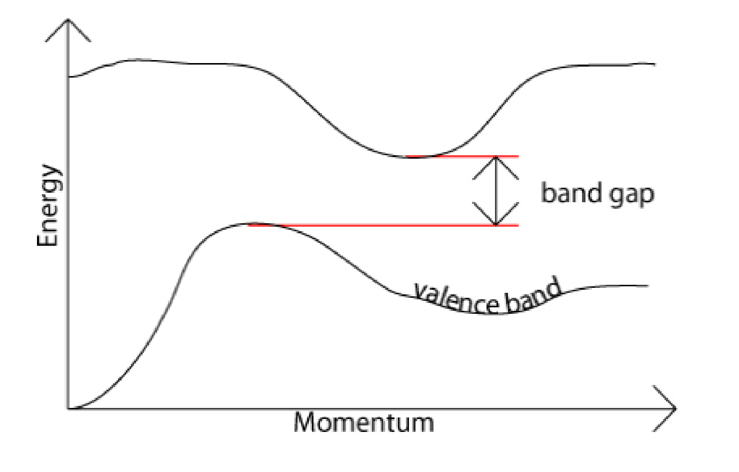
In an indirect band gap semiconductor, the maximum energy of the valence band occurs at a different value of momentum to the minimum in the conduction band energy:



LEDs

LEDs are used as light sources

(i) When the required bit rates are less than 100-200Mb/s

(ii) When the required optical power is in the order of tens of micro watts.

Advantages

- Simpler fabrication
- Low cost
- Reliability
- Generally less temperature dependence
- Simpler drive circuitry

LED Structures

To be useful in fiber transmission applications LEDs must have

(i) High radiance output

(ii) Fast emission response time

(iii) High quantum efficiency

Radiance is the optical power radiated into a unit solid angle per unit area.

Emission response time is the delay between the application of a current pulse and the onset of optical emission.

Quantum efficiency is related to the fraction of injected electrons-hole pairs that recombine radiatively.

LED Structures

LED configurations such as homo junctions , single and double hetero junction structures are generally used to achieve high radiance and quantum efficiency.

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LED Structures

Homo Jn LED	Hetero Jn LED
A **homojunction** is a semiconductor interface that occurs between layers of similar semiconductor material, but typically have different doping.	A **heterojunction** is an interface that occurs between two layers or regions of dissimilar semiconductors.
These materials have equal band gaps .	These semiconducting materials have unequal band gaps.
Advantage: Low terminal impedance **Disadvantage:** Quantum efficiency is less due to non- directional emitting of light.	**Advantage:** 1. Fine light spot. 2. Light emitting area is small , so easy to launch into fiber. 3. High data rate is possible.

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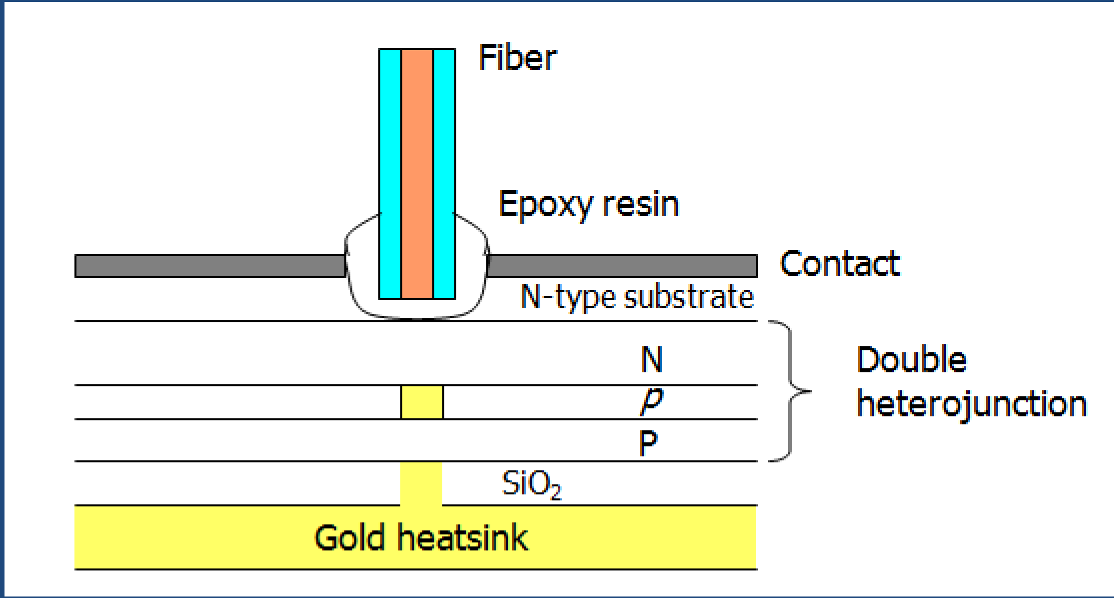
Surface Emitting LED



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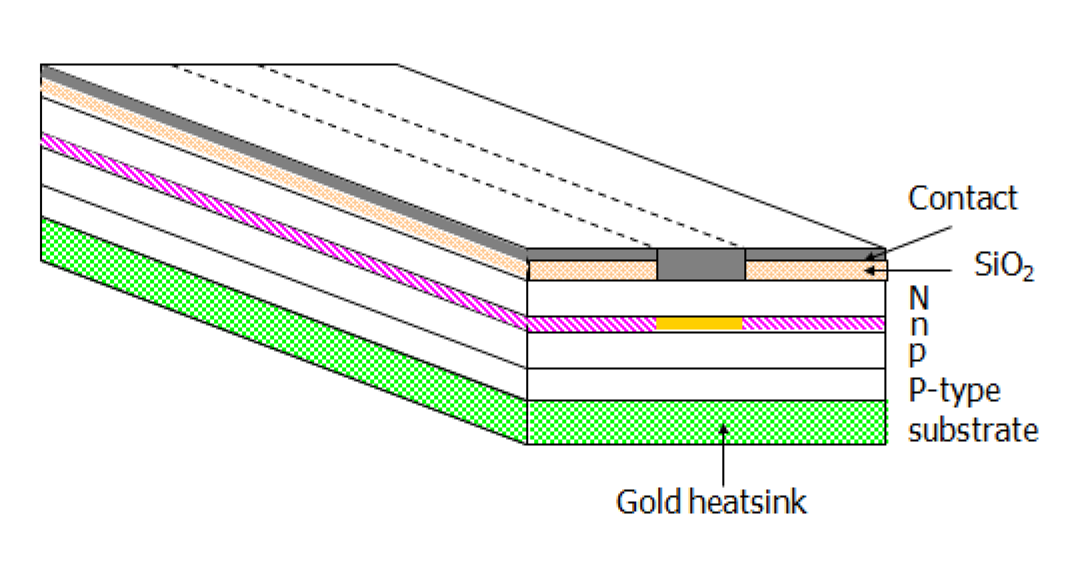
Edge Emitting LED



LED Structures

Surface Emitting LED	Edge Emitting LED
Surface emitter radiate more power than edge emitters.	Edge emitters radiate less power.
Surface emitters couple more optical power into large NA	Edge emitters couple more optical power into low NA.
Modulation BW is less.	Modulation BW is in the order of hundreds of Megahertz.
It is less temperature dependent.	It is more temperature dependent.

Light Sources Materials

In a direct band gap material radiative recombination rate is high to produce adequate level of optical emission.

III and V group elements are direct band gap materials.

III group elements are Al,Ga and In.
V group elements are P,As and Sb.

GaAlAs alloy is used to operate in 800-900nm spectrum.

Quantum Efficiency

Practically all LEDs do not radiate since all electrons and holes do not recombine.

If the radiative recombination rate is Rr and non-radiative recombination rate is Rnr then the internal quantum efficiency is given as ,

$$\eta_{int} = R_r/(R_r + R_{nr})$$

or $$\eta_{int} = \tau/\tau_r$$

Where τ_r = radiative recombination lifetime

τ = non- radiative recombination lifetime

Modulation of an LED

Modulation BW is defined as point where electrical power has dropped to half its constant value resulting from modulated portion optical signal.

Modulation BW depends on

- Doping level
- Injected carriers
- Parasitic capacitance of the device

Output electrical power = 10 Log [(P(ω)/P(0)]

Bandwidth = 0.35/Tr

Modulation of an LED

Where $P(\omega)$ = output power of the device.

$P(0)$= power emitted at zero modulation frequency.

Tr = Rise time

LASER DIODE
(Light Amplification by Stimulated Emission of Radiation)

LASER light has the following characteristics:

1. Monochromatic - single frequency
2. Coherent – Inphase
3. Collimated – high directivity
4. High energy

LASER DIODE

- LASER exists in different forms with dimensions ranging from the size of the salt crystal to that which occupy an entire room.

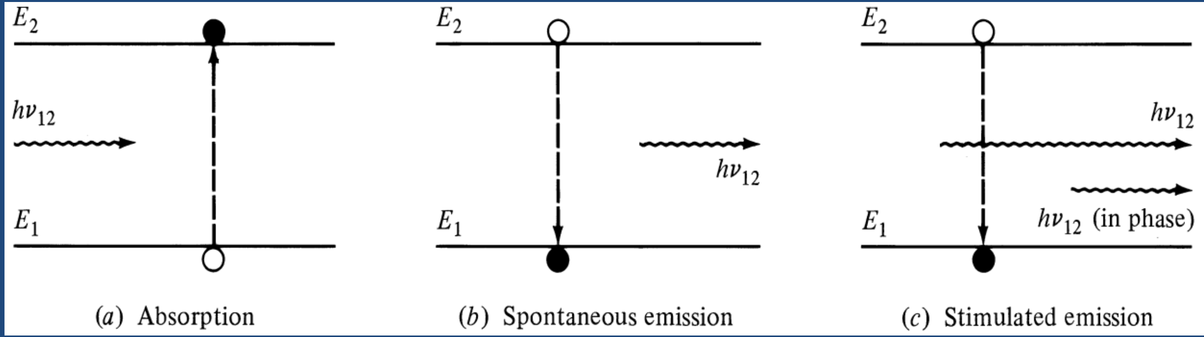
- LASERs can be a gas, liquid or a semiconductor.

- For optical fibers the LASERs used generally of semiconductors.

Principle of Operation

LASER action is the result of three key processes.

1. Absorption
2. Spontaneous Emission
3. Stimulated Emission



Principle of Operation

- ✓In thermal equilibrium the stimulated emission is essentially negligible, since the density of electrons in the excited state is very small, and optical emission is mainly because of the spontaneous emission.

- ✓Stimulated emission will exceed absorption only if the population of the excited states is greater than that of the ground state. This condition is known as **Population Inversion**.

- ✓Population inversion is achieved by various **pumping** techniques.

- ✓In a semiconductor laser, population inversion is accomplished by injecting electrons into the material to fill the lower energy states of the conduction band.

LASER diode features:

- For optical communications requiring bandwidth greater than 200MHz , semiconductor injection LASER diodes are preferred than LEDs.
- The LASER diode emission response time is less than 1ns.
- The width of the spectral component is less than 2nm.
- All LASER diodes are made up of heterojunction structures.
- The construction of LASER diode is more complicated because of the additional requirement of the current confinement in the small lasing cavity.

Fabry-Perot Resonant Cavity

1. The radiation in laser diode can be generated using Fabry-Perot cavity.
2. This laser diode consists of two flat partially reflecting mirrors which are directed towards each other.
3. The purpose of mirrors is to establish a strong optical feedback in the longitudinal direction.
4. As the light reflects back and forth within the fabry perot cavity the electric fields of the light interfere on successive round trips.
5. The optical frequencies at which constructive interference occurs is called resonant frequencies of the cavity.

Fabry-Perot Resonant Cavity

6. Consequently, spontaneously emitted photons that have wavelengths at these resonant frequencies reinforce themselves after multiple trips through the cavity so that their optical field becomes very strong.

7. Condition to reach the lasing threshold is the point at which the optical gain is equal to total loss in the cavity is given as,

$$\Gamma g_{th} = \bar{\alpha} + \frac{1}{2L} \ln\left(\frac{1}{R_1 R_2}\right)$$

Fabry-Perot Resonant Cavity

Where R1, R2 are called mirror reflectivities

$\bar{\alpha}$ is the effective absorption coefficient of the material

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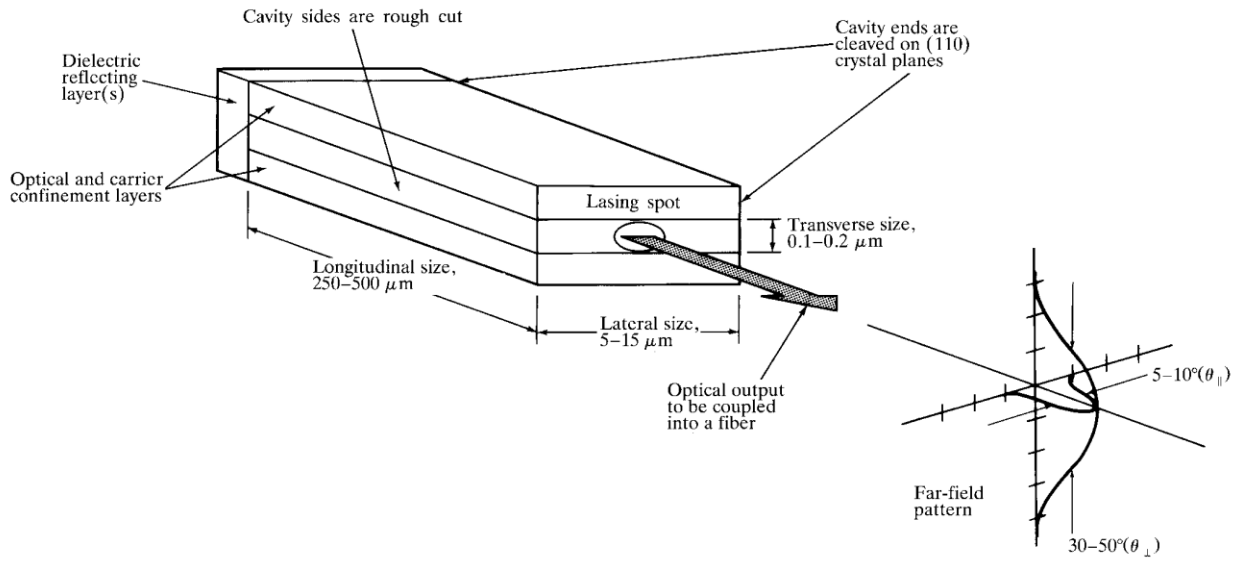
Fabry-Perot Resonant Cavity



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Laser diode rate equation

Rate equations relate the optical output power, or # of photons per unit volume, Φ, to the diode drive current or # of injected electrons per unit volume, *n*. For active (carrier confinement) region of depth *d*, the rate equations are:

$$\frac{d\Phi}{dt} = Cn\Phi + R_{sp} - \frac{\Phi}{\tau_{ph}}$$

Photon rate = stimulated emission + spontaneous emission + photon loss

$$\frac{dn}{dt} = \frac{J}{qd} - \frac{n}{\tau_{sp}} - Cn\Phi$$

electron rate = injection + spontaneous recombination + stimulated emission

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Laser diode rate equation

C : Coefficient expressing the intensity of the optical emission & absorption process

R_{sp} : rate of spontaneous emission into the lasing mode

τ_{ph} : photon life time

J : Injection current density

External Quantum Efficiency

The external quantum efficiency is defined as the no.of photons emitted per radiative recombination of electron hole pairs above threshold value.

$$\eta_{ext} = \frac{\eta_i (g_{th} - \bar{\alpha})}{g_{th}}$$

η_i – internal quantum efficiency.

$\bar{\alpha}$ – effective absorption coefficient of the material

g_{th} – threshold optical gain.

Reliability Considerations

The operating lifetimes of LEDs and LASER diodes are affected by both operating conditions and fabrication techniques.

Lifetime tests of optical sources are carried either at room or at high temperatures.

There are methods to test the lifetime of an optical source.

1. Keeping the drive current constant and monitoring the output level.
2. Increasing the drive current suddenly and monitoring the output level.

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Degradation of optical sources is due to three reasons:

1. Internal damage – Crystal defects.
2. Ohmic contact degradation – increase of thermal resistance.
3. Damage of facets – mechanical damage during fabrication.

Optical Detectors

- At the output of the optical transmission line, there must be a receiving device which interprets the information contained in the signal.

- The first element of this receiver is a photodetector.

- Photodetector senses the luminescent power falling upon it and converts the variation of this optical power into a correspondingly varying current.

Optical Detectors

Types of photodetectors:

1. Photomultipliers
2. Pyroelectric detectors
3. Semiconductor based photo detectors
4. Phototransistors
5. Photodiodes

Optical Detectors

Out of various semiconductor based photodetectors , the photodiode is used almost exclusively for fiber optic systems because of its

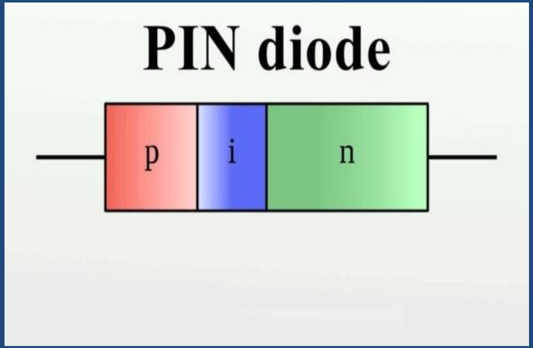
- Small size
- Suitable material
- High sensitivity
- Fast response time

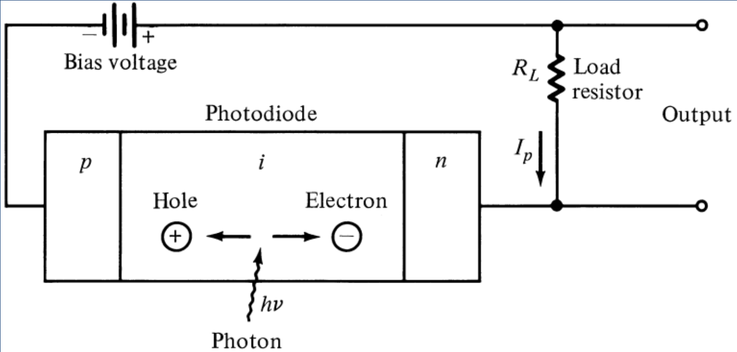
Optical Detectors

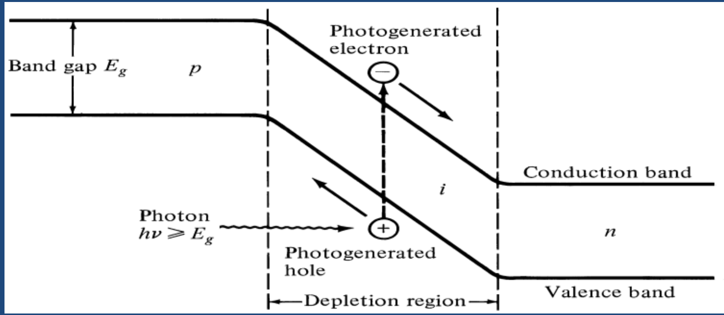
Two types of photodiodes are generally used

- PIN photodetector
- Avalanche photodiode

PIN photodetector







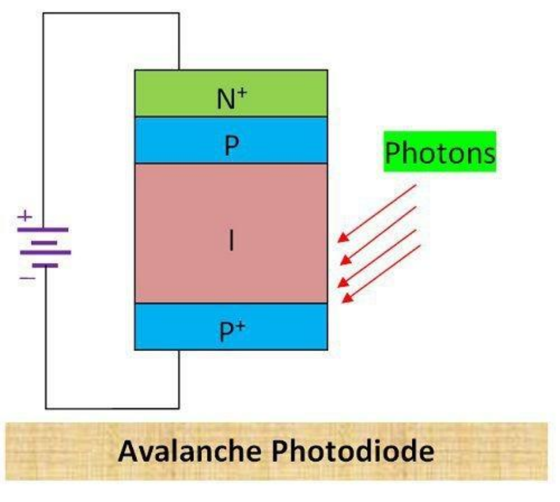
Optical Detectors

When the device is reverse biased, there is a minute leakage current. If light (photons) hit the Intrinsic Layer, electrons are dislodged and this leaves a hole. The electrons migrate towards the Anode (positive) and the holes migrate towards the Cathode (negative). So light shining on the device increases the leakage current.

If the PIN diode is reverse biased with a very high voltage, when an electron is dislodged, it accelerates towards the anode and this dislodges more electrons which also accelerate. This causes an avalanche effect and quite a large current pulse flows even if only one photon triggered the avalanche.

Avalanche Photodetector(APD)

Avalanche photodiode internally multiply the primary signal photocurrent before it enters the input circuitry of the following amplifier.



Avalanche Photodetector(APD)

This multiplication increases receiver sensitivity, since photo current is multiplied before encountering the thermal noise associated with the receiver circuit.

Detector Response Time

It is the amount of time taken by the detector to produce current when the light fall on it.

It depends mainly on:

1. Transit time
2. Diffusion time
3. RC time constant

Detector Response Time

Transit time of the photodiode is the time taken by the carriers to travel across the depletion region.

$T_r = W/V_d$

W = width of the depletion layer

V_d = Drift velocity

Detector Response Time

To have high a high speed photo diode , the photocarriers should be generated in the depletion region or so close to it that the diffusion times are less than or equal to the carrier drift times.

A reverse biased photodiode exhibits a voltage dependent capacitance caused by the variation in the stored charge at the junction.

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Detector Response Time

Comparison:

Sr. no.	PIN diode	APD (Avalanche photodiode)
1	PIN does not have high intensity electric field region.	APD has high intensity electric field region.
2	Photo current (I_p) generated is less compared to APD $I_p = qN_e$ q = electron charge N_e= carrier number	Photo current (I_p) generated is more compared to PIN $I_p = qN_e \cdot M$ q = electron charge N_e= carrier number M = multiplication factor
3	Responsivity of PIN is limited.	Responsivity of APD can have much larger values.
4	They exhibit lower noise levels.	They exhibit higher noise levels as compared to PIN due to impact ionization and photocurrent multiplication.
5	Response time of PIN is half that of APD.	Response time of APD is almost double that of PIN.

Thank you