Parul® University

ENGINEERING PHYSICS
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Chapter - 5

OPTOELECTRONICS DEVICES

Aim of Optoelectronics Devices

Optoelectronic is the technology that combines optics and electronics and the devices based on this technology are known as Optoelectronic Devices.

Contents:

Contents:

5.1.1 Introduction

- Optoelectronics is the branch of science and technology concerned with the combined use of electronics and light.

- It can be defined as the study and application of electronic devices that act as sources, detectors, and controllers of light.

- Optoelectronics can be considered as the subfield of “**PHOTONICS**”.

- Photonics includes generation, emission, transmission, modulation, signal processing, amplification, detection, and sensing of light.

5.1 Introduction

- The basic working process of optoelectronics deals with the optical interaction on the electronic responses in some specific optically active semiconducting (SC) materials.

- The semiconducting materials are preferred as the natural choice, due to the variation in their electrical conductivity over orders of magnitude by changing in temperature, optical excitation and the presence of impurity content in them.

- The devices which support that type of interaction are known as **TRANSDUCERS**, usually accompanied by energy conversion from optical energy to electrical energy or vice versa, as shown in Fig. 5.1-1.

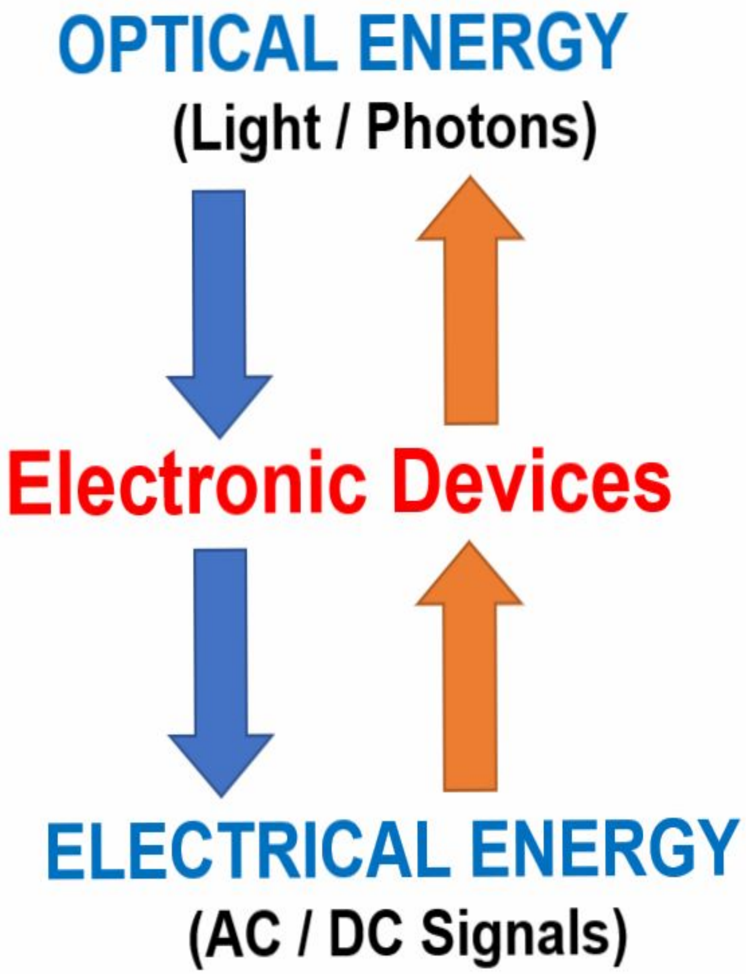


Fig 5.1-1 Energy conversion by using optoelectronics devices

Classification of Optoelectronics Devices

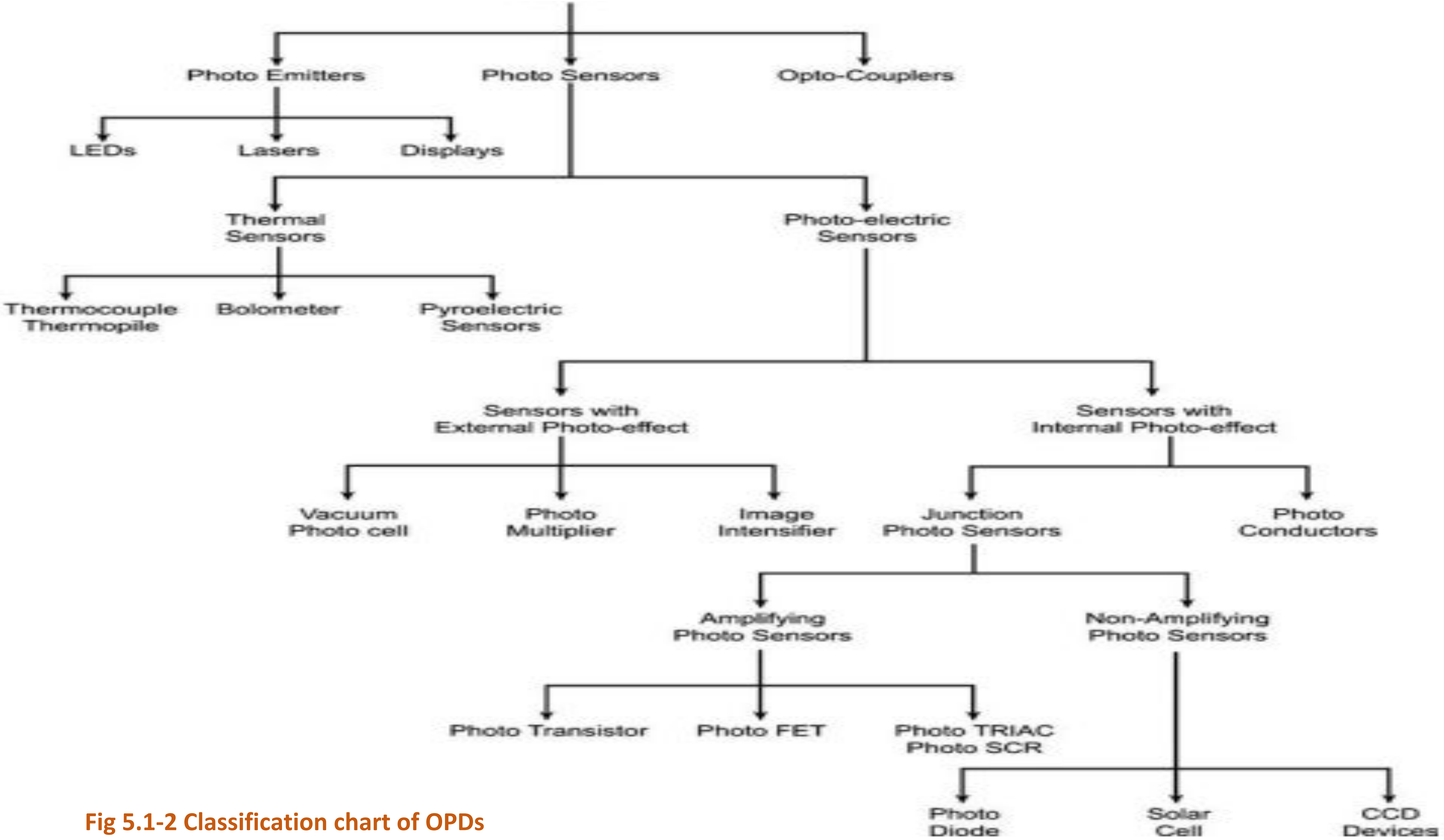


Fig 5.1-2 Classification chart of OPDs

5.1.2 Optoelectronic Materials

- Elements of a Group- IV of the periodic table especially Germanium (Ge) and Silicon (Si) are the two most common and well-studied semiconductors (SC) at an elemental level.

- But they have very limited uses in optoelectronics due to some shortcomings or drawbacks.

- Both Si & Ge are indirect Bandgap structures material. These material devices show poor light emission as well as absorption properties.

- Devices that are made from elemental SC's are not good for energy production.

- To overcome this problem, we have to dopped with such materials (i.e. to form compounds or alloys made from different group elements like II-VI, IV- IV, III - V in form of binary, ternary, quaternary composite semiconducting materials).

5.1.2 Optoelectronic Materials

- **For example;**

1). **III-V GROUP COMPOUND MATERIALS:**
a). **Binary form:** GaN, GaP, InSb, etc
b). **Ternary form**: AlGaAs, InGaP, InGaAs, etc
c). **Quaternary form:** AlGaInP

2). **II-VI GROUP COMPOUND MATERIALS:**
a). **Binary form:** ZnS, GdSe, PbTe, ZnO, CdS, etc
b). **Ternary form:** HgCdTe, GdZnS, etc
c). **Quaternary form:** ZnSnSiBr

3). **IV-IV GROUP COMPOUND MATERIALS:**
a). **Binary form:** SiC, SiGe etc.

5.1.2 Optoelectronic Materials

- **For device efficiency:**
  The semiconducting (SC) materials enclose a wide range of light spectrums. Starting from the infrared, visible, and ultraviolet regions.
  Therefore, it covers more degrees of the spectrum means more energy conversion is done by the device.

- **For synthesizing material:**
  Modern semiconducting (SC) growth techniques like Molecular Beam Epitaxy (MBE), Chemical Vapor Deposition (CVD) along with band gap engineering are used to create various composite compounds or alloys.
  It is possible to fabricate numerous solid-state devices like LEDs, LASERs, Solar cells, and Photo-diodes which are active in Visible, IR, and UV regions of the spectrum as shown in fig-5.1.2-1.

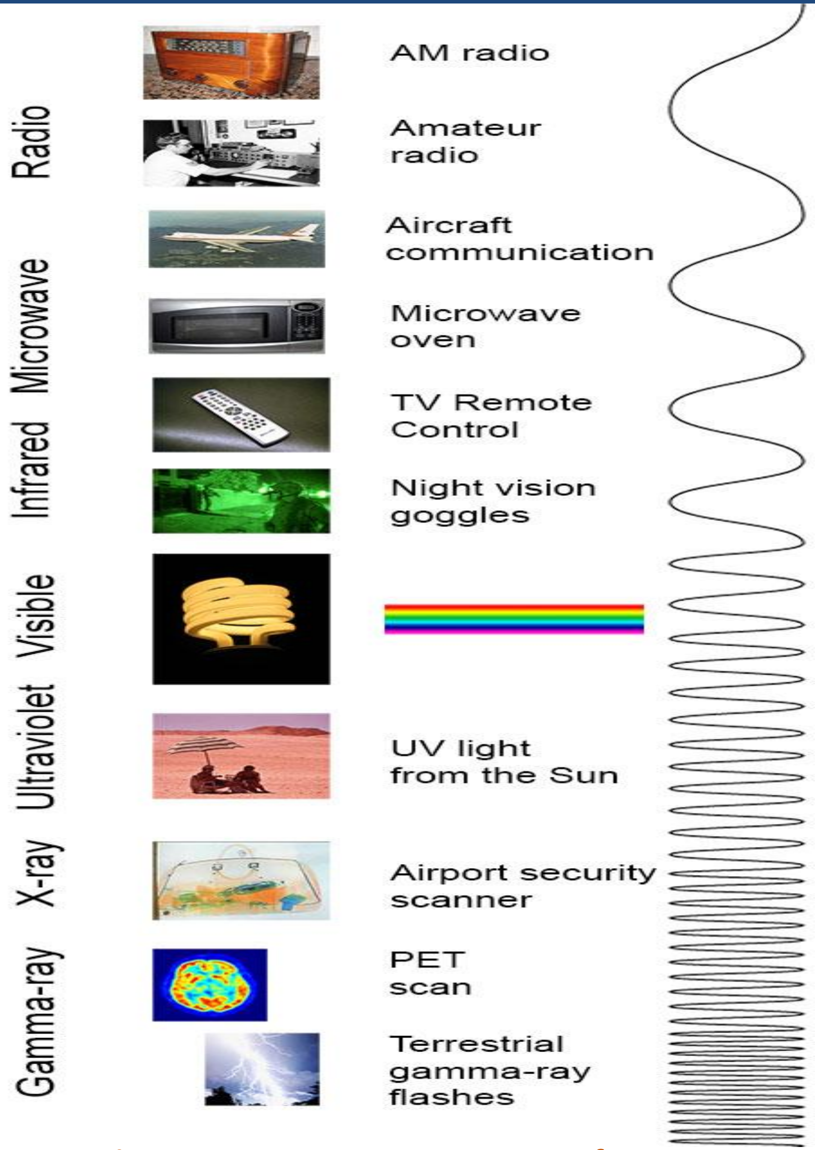


Fig-5.1.2-1: EM Wave Spectrum for EDC.

https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html

5.1.3 Light-Material Interactions:

- In all optoelectronic devices, the main manifestation is the interaction of optical radiations or photons or electromagnetic waves with the semiconducting material. As shown in fig-5.1.3-1.

- Generally, we see these types of interaction of lights with optoelectronics devices or semiconducting materials are;
  a). Reflection (**A%**)
  b). Absorption (**B%**)
  c). Transmission (**C%**)

- The law of conservation of energy:

Incident light energy = Reflected energy (A%)
(100%) + Absorbed energy (B%)
+ Transmitted energy (C%)

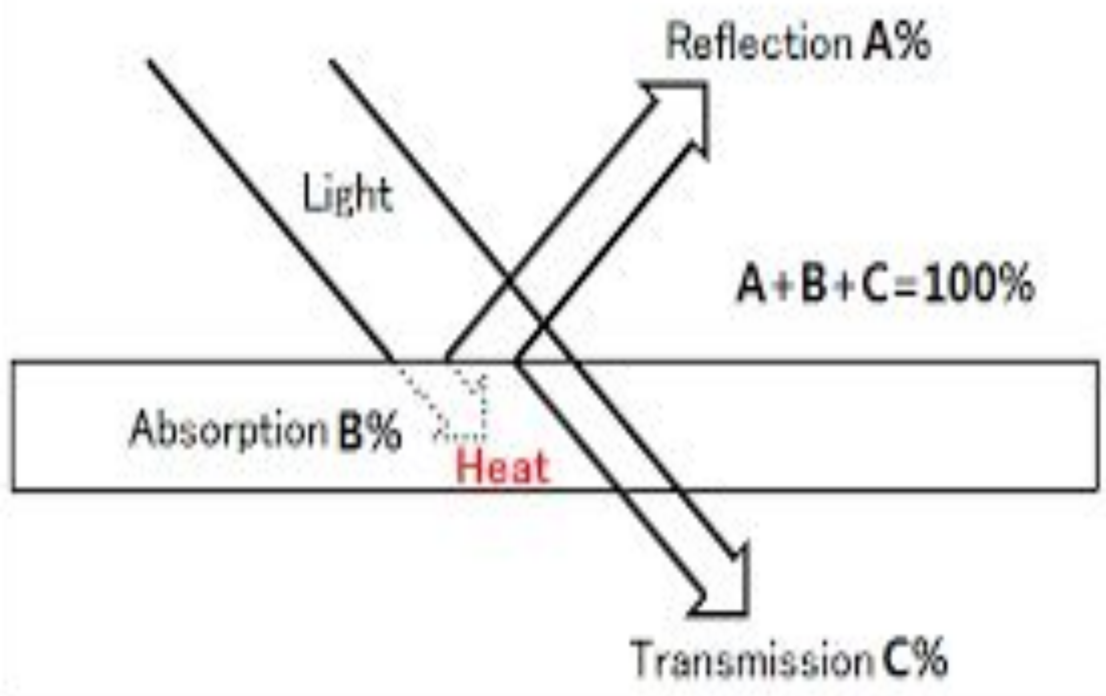


Fig-5.1.3-1: Type of interactions of light with materials .

https://heater.heat-tech.biz/halogen-point-heater/basic-knowledge-of-halogen-heater/physics-of-light-heating/12444.html

5.1.4 Optical Absorption and charge carrier generation in SC material:

- The excess charge carriers (i.e electron-hole in pair form) are created in the device via the absorption of suitable light energy.

- The amount of light absorption determines the number of charge carrier generation rates and device efficiency.

- This energy will be absorbed by the valence band electron, then get excited goes into conduction band while they leave a vacancy in valance band is known as Hole as shown in figure-5.1.4-1.

- Since, during the light absorption process, both energy and momentum are conserved.

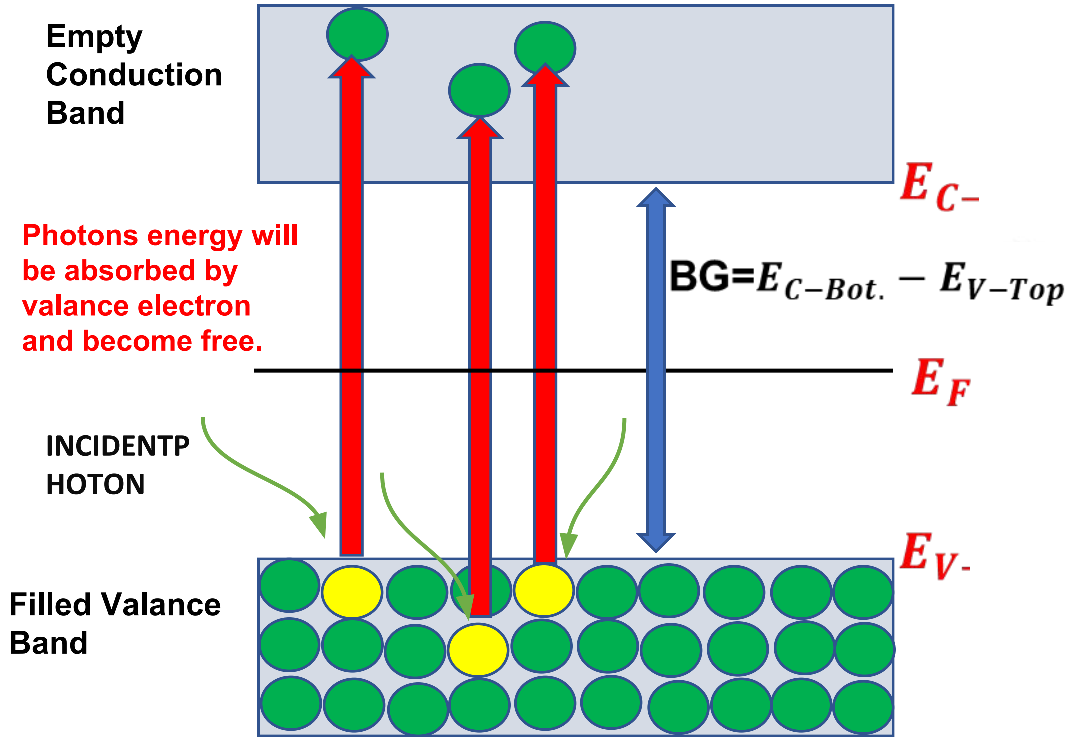


Fig-5.1.4-1 EHPs Generation via absorbing Incident Light.

5.1.5 Optical Emission and Carrier Recombination in SC material:

- In the light emission process, the energy quanta or Photon will be emitted by the SC material.
- This energy is released when the excited state electron from the conduction band goes to the valance band. It combines with a hole to fill the vacancy in the valence band. So, in this process recombination of the charge carrier will take place.
- During this process, electrical energy is converted into optical energy due to the electron-hole pair recombination process. It is most commonly observed in optical sources like LED, LASER, etc. As shown in fig-5.1.5-1.
- Since, during the light emission process, both energy and momentum are conserved.

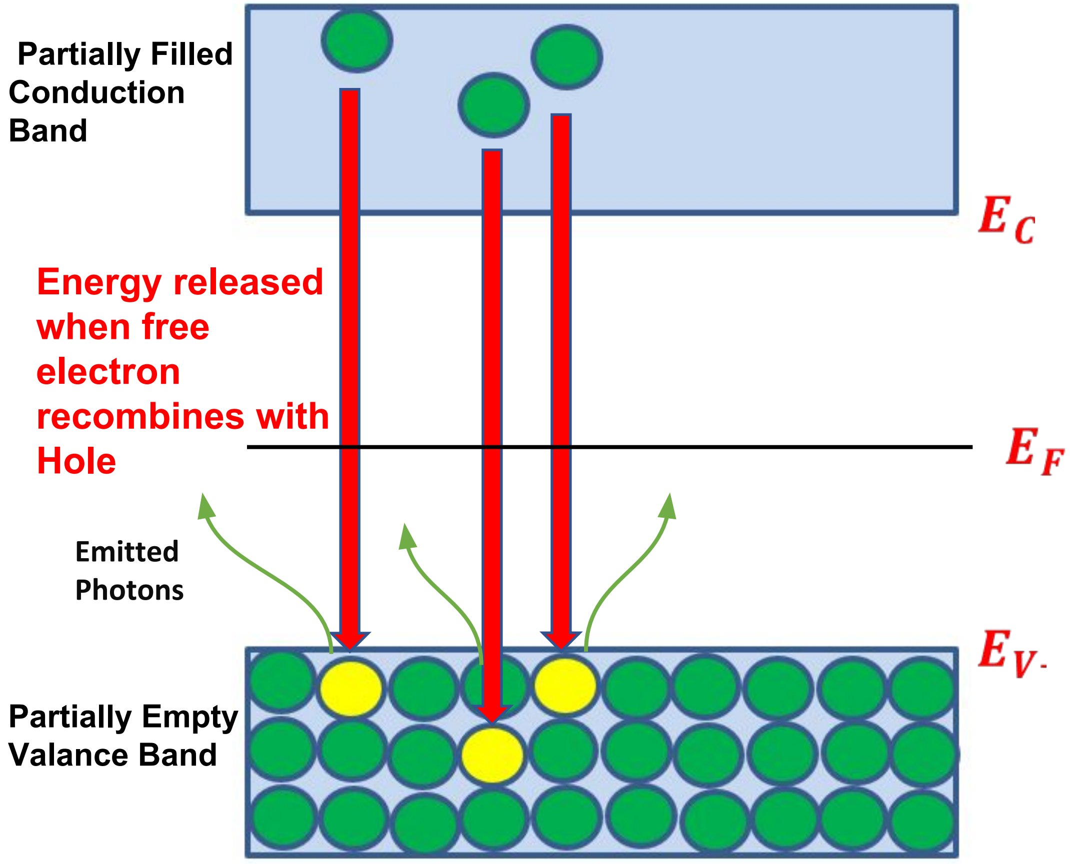


Fig-5.1.5-1 EHPs Recombination via Emitting Light (photons).

5.2 Photo-detectors or Photo-sensors:

- In optical communication systems, the photo-detectors or photo-sensors play a crucial role.
- Such as photo-conductors, photo-diodes photo-transistors, etc in which energy conversion is typically achieved due to the generation or annihilation of free electron-hole pairs (EPHs) by the absorption of energetic photons (i.e. changes optical energy into electrical energy by the means of changing the electronic properties of SC materials).
- Due to EHPs generation, its drift motions within material create photocurrent within the device under external applied Electric force as shown in fig.-5.2-1. This is the basic physical mechanism of photo-detectors or photo-sensor.
- The creation of photocurrent in photoconductors cells or photovoltaic detectors.

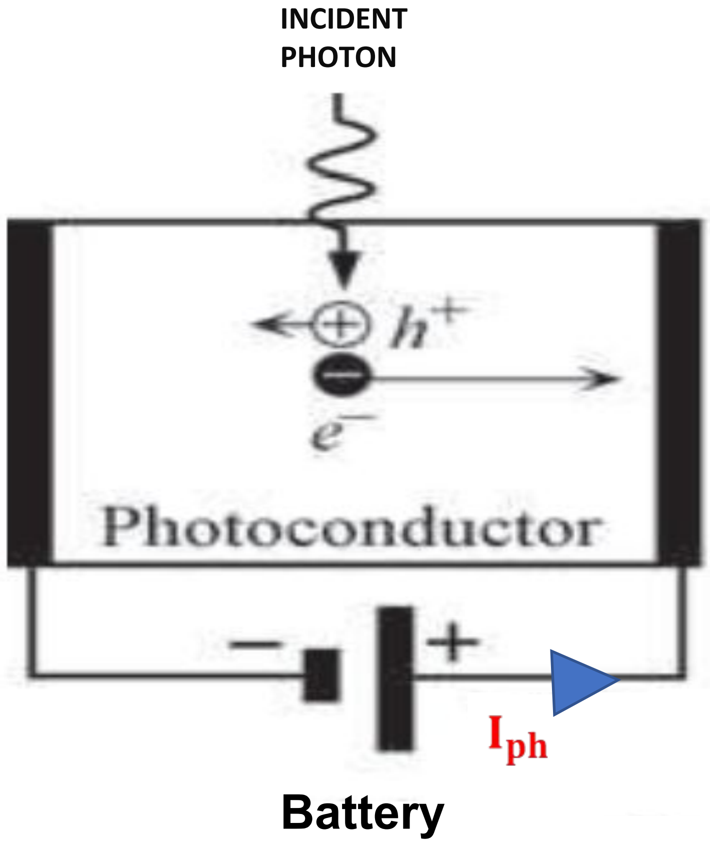


Fig-5.2-1 EHP Generated is drifted in external Electric field.

5.2 Photo-detectors or Photo-sensors:

 The performance of these photodetectors depends upon the following points;

a). The magnitude of the optical absorption process.

b). The charge career transportation of these EHPs after generation depends upon the material doping and designing of the detector.

c). The interaction with the main circuitry system.

5.2 Photo-Detectors (PDs) or Photo-Sensors (PSs):

Various types of PDs:

1). **Based on illumination type:**

a. Horizontal illuminated (Edge illuminated detector)

b. Vertically illuminated (Planar or Surface illuminated).

2). **Based on Device Gain:**

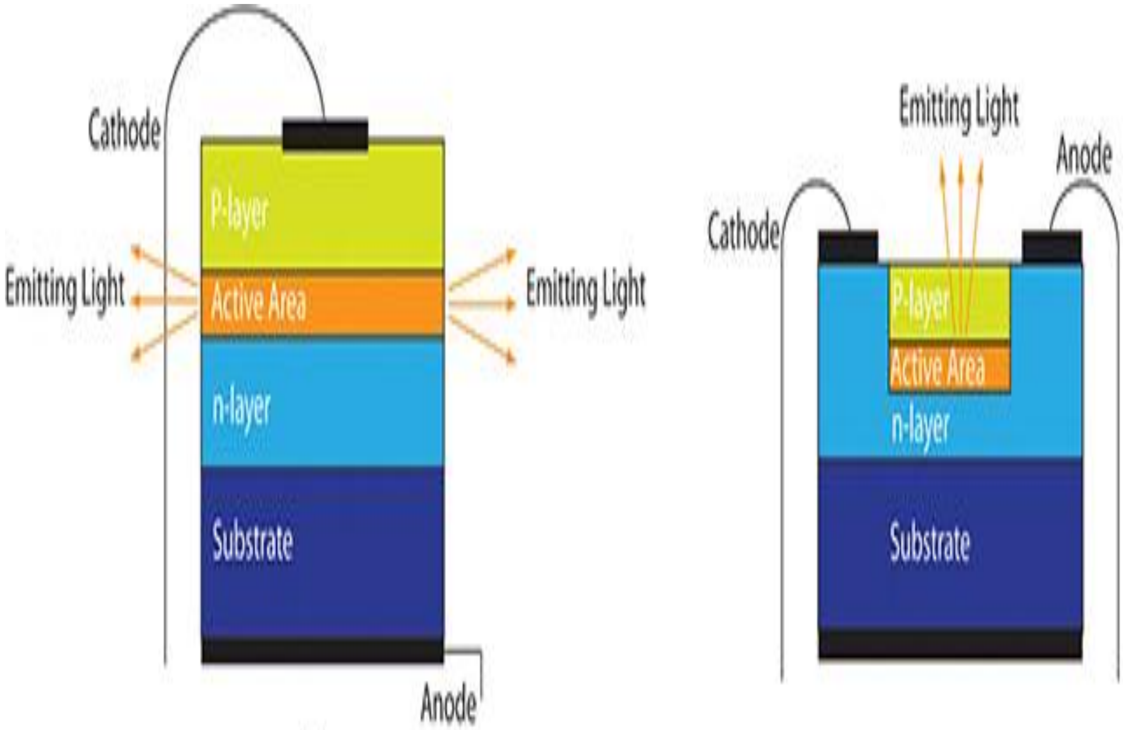
a. Without gain (PN Junction PD and PIN PD).

b. With gain (Avalanche PD and Phototransistor)

3). **Based on SC material type:**

a. Intrinsic

b. Extrinsic



a. Edge type b. Surface type

Fig-5.2-2 Based On Illumination type PDs.

8). https://marktechopto.com/technical-articles/improved-accuracy-and-resolution-using-point-source-emitter-technology

5.2.1 Junction Photodiode (PN Diode, PIN Diode, Avalanche Diode)

- Junction photodiode is also known as Photodiodes (PD).
- In this, light energy is converted to electrical energy via using incident Photon.
- Photodiodes always work in reverse biased conditions (RBC).
- To understand the working of the SC Junction photodiode it is necessary to have a clear and good prior knowledge of charge carrier concentration in the SCR or Depletion region (when we join two different metals or SC materials) as shown in fig-5.2.1-1 & fig-5.2.2-2.

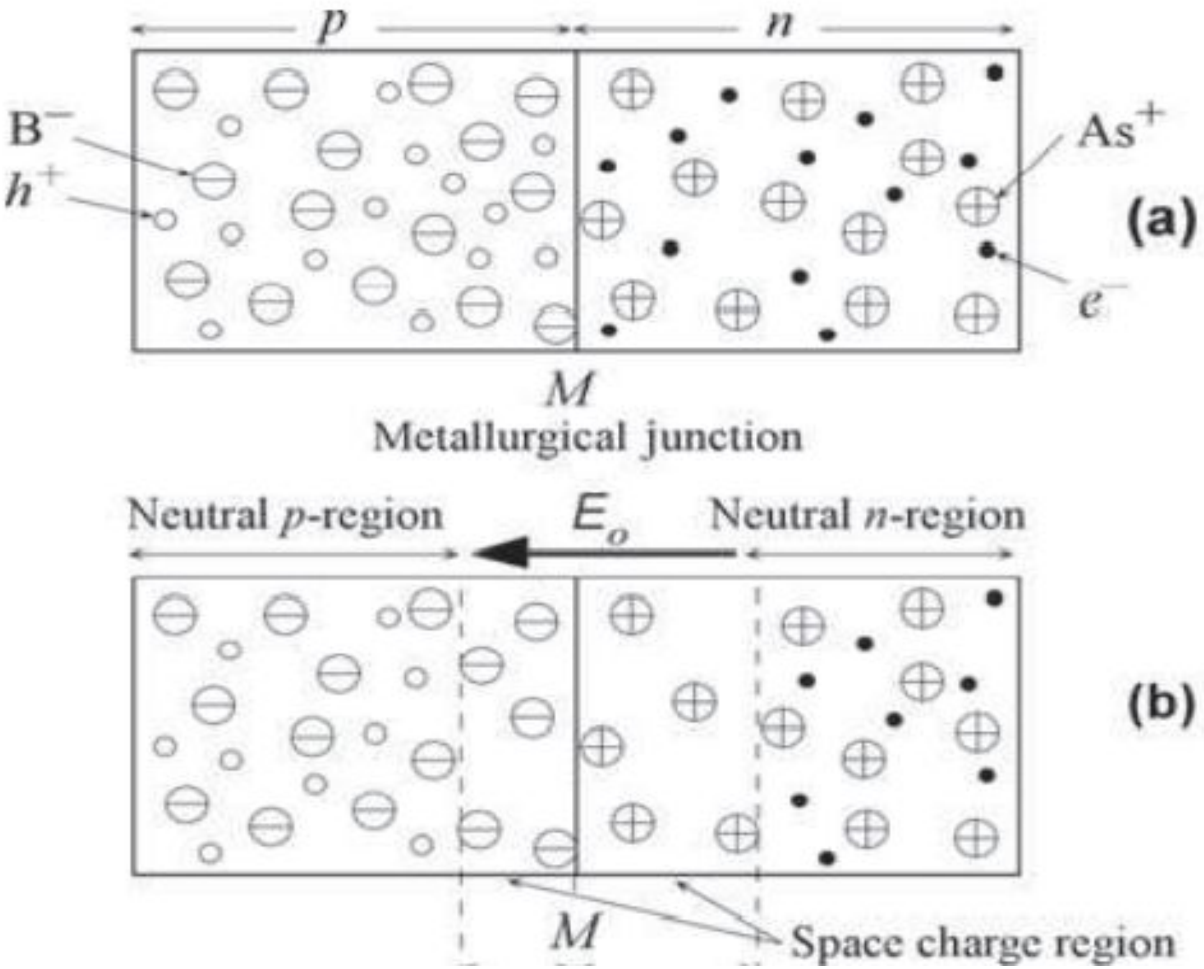


Fig- 5.2.1-1 Metallurgical junction formed when P & N type SC material (a), Depletion Region and Electric field(b).

5.2.1 Junction Photodiode (PN-Junction, PIN, Avalanche)

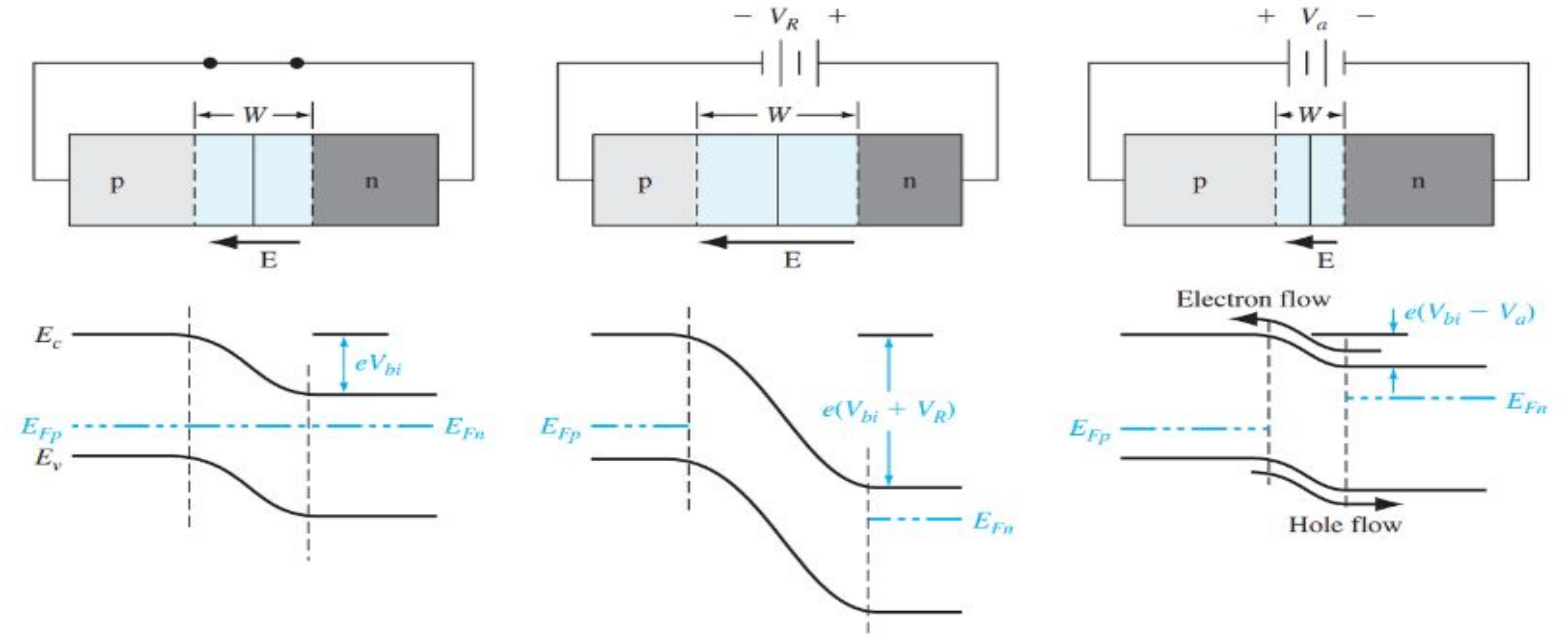


Fig- 5.2.1-2 PN Junction diode with Zero Biasing (a), Reversed Biasing (b), and Forward Biasing (c). And their energy band diagram variation with various biasing.

5.2.1 Junction Photodiode (PN Diode, PIN Diode, Avalanche Diode)

□ The important features are;

1). Boundaries of an n-type and p-type material.

2). Width of the Depletion Region or Space Charge Layer(SCL). Photodetection occurs within this region of a device fig- 5.2.1-3.

3). Diffusion length

4). Doping and profile index of charge carrier concentration.

5). Absorption Area(AA) or Exposure Area.

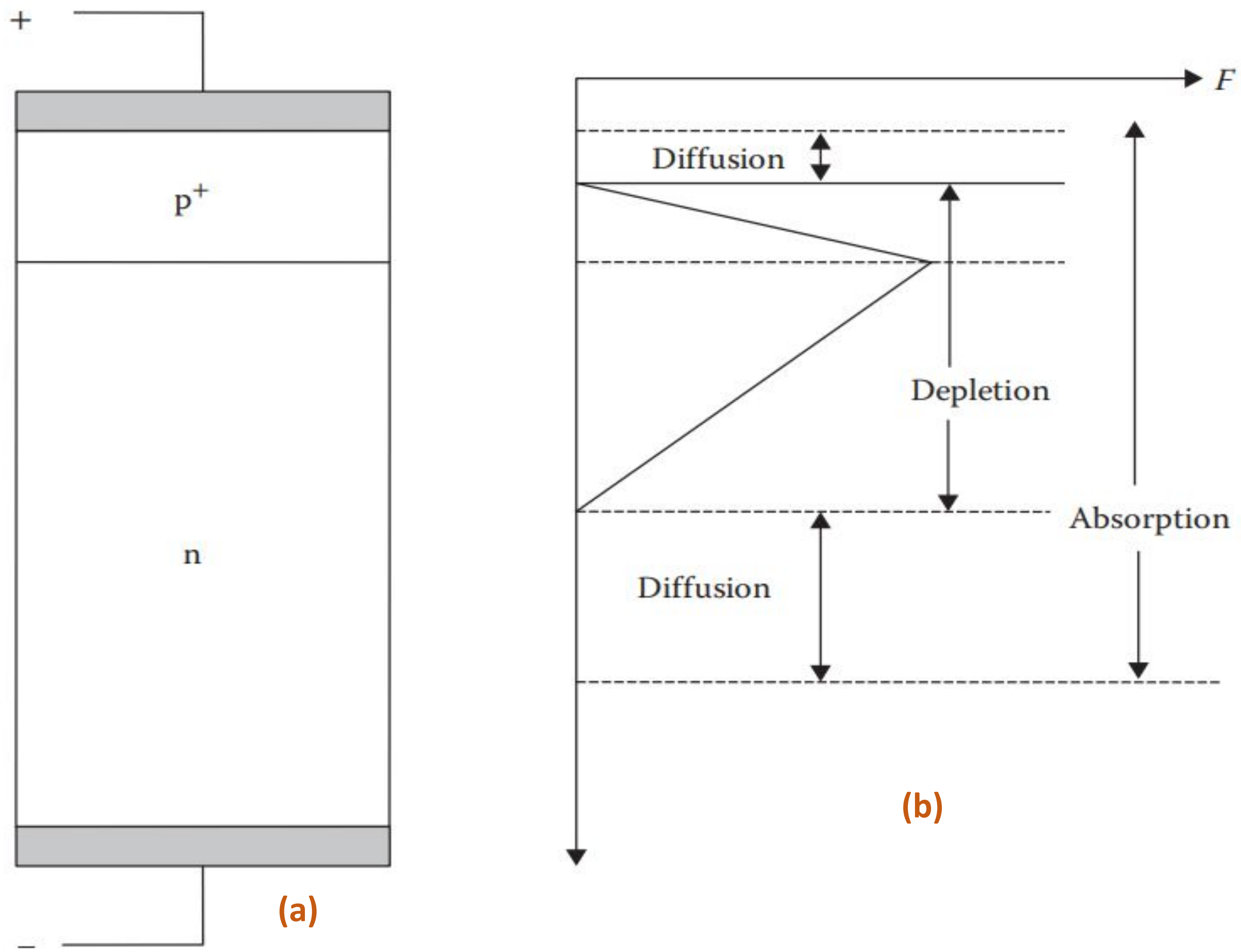
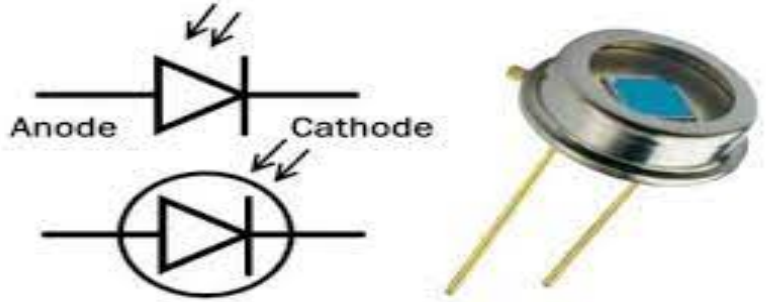


Fig- 5.2.1-3 PN junction structure (a), Electric field profile across the depth of the device in which Depletion, Diffusion Length and Absorption Area as shown (b).

5.2.1.A Junction Photodiode (PN Junction Photodiode)

PN Junction Photodiode:



Symbol of PN Junction Photo-diode

- The simplest photodiode without internal gain is operated in reverse biased condition as shown in the fig-5.2.1-4 in which both depletion and diffusion regions are shown.

- The electric field profile along with mobile and immobile charge carrier concentrations is shown in the fig-5.2.1-1.

- EHPs are generated in both the depletion and diffusion regions. It's with is made as large as possible by using less doping.

- Due to the strong depletion region, electric field and external applied electric field (i.e power supply) increase the drift of velocity of the minority charge carriers generated in the depletion region will cross the PN junction before they recombine with atoms.

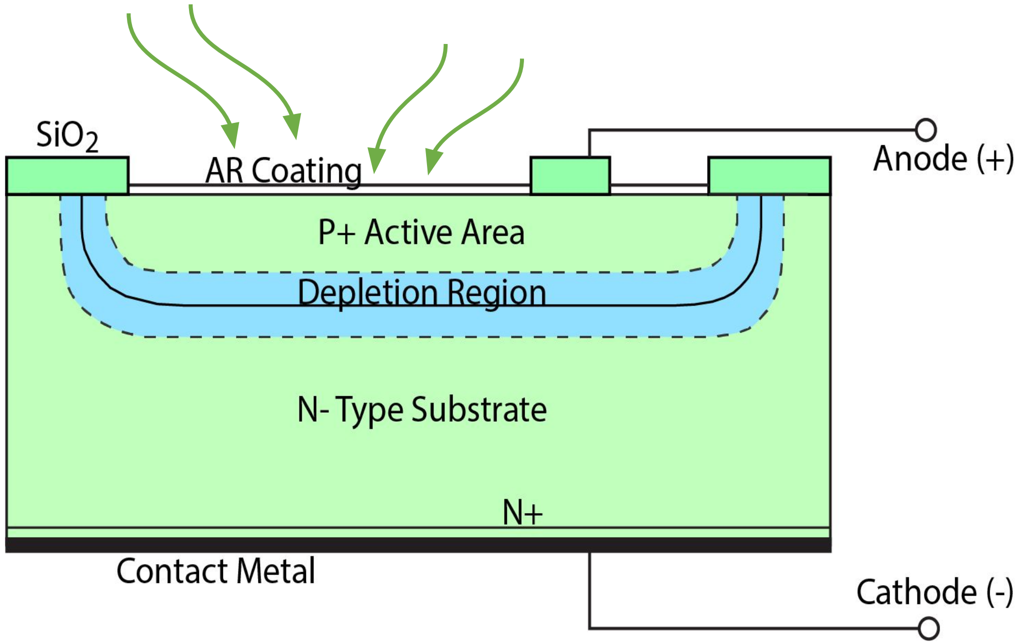


Fig-5.2.1-4 Cross sectional view of PN Junction Photodiode structure.

5.2.1.A Junction Photodiode (PN Junction Photodiode)

PN Junction Photodiode:

- Due to the strong depletion region, electric field and external applied electric field (i.e power supply) increase the drift of velocity of the minority charge carriers generated in the depletion region will cross the PN junction before they recombine with atoms.

- When an external circuit is connected across the diode terminal the minority carriers return to the original side via the external circuit.

- Thus the flow of minority carriers tends to reduce the barrier potential.

- Energy band diagram with the variation of depth of charge carrier movement as shown in fig-5.2.1-5.

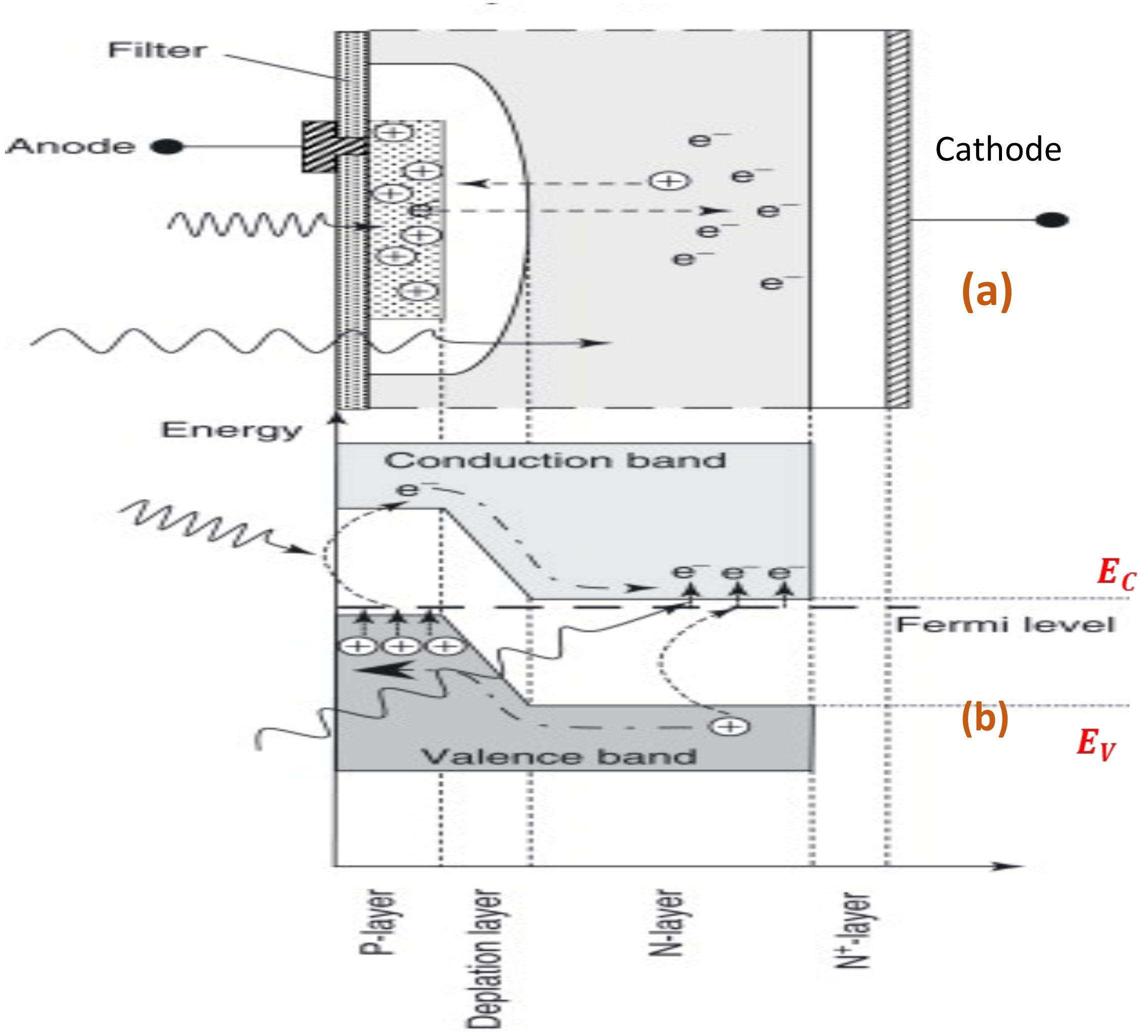


Fig-5.2.1-5 PN Junction Photodiode, interaction with light (a) and energy band diagram (b).

https://elprocus.com/technical-articles/improved-accuracy-and-resolution-using-point-source-emitter-technology

5.2.1.A Junction Photodiode (PN Junction Photodiode)

Drawback:

1). Depletion layer is very small.

2). The limiting factor for the bandwidth of PN junction photodiodes is the presence of a diffusive component in the photocurrent as shown in fig-5.2.1.6.

Application:

Light detection circuits, demodulation, switching, logic circuits that need stability and high speed, character recognition, optical communication equipment etc.

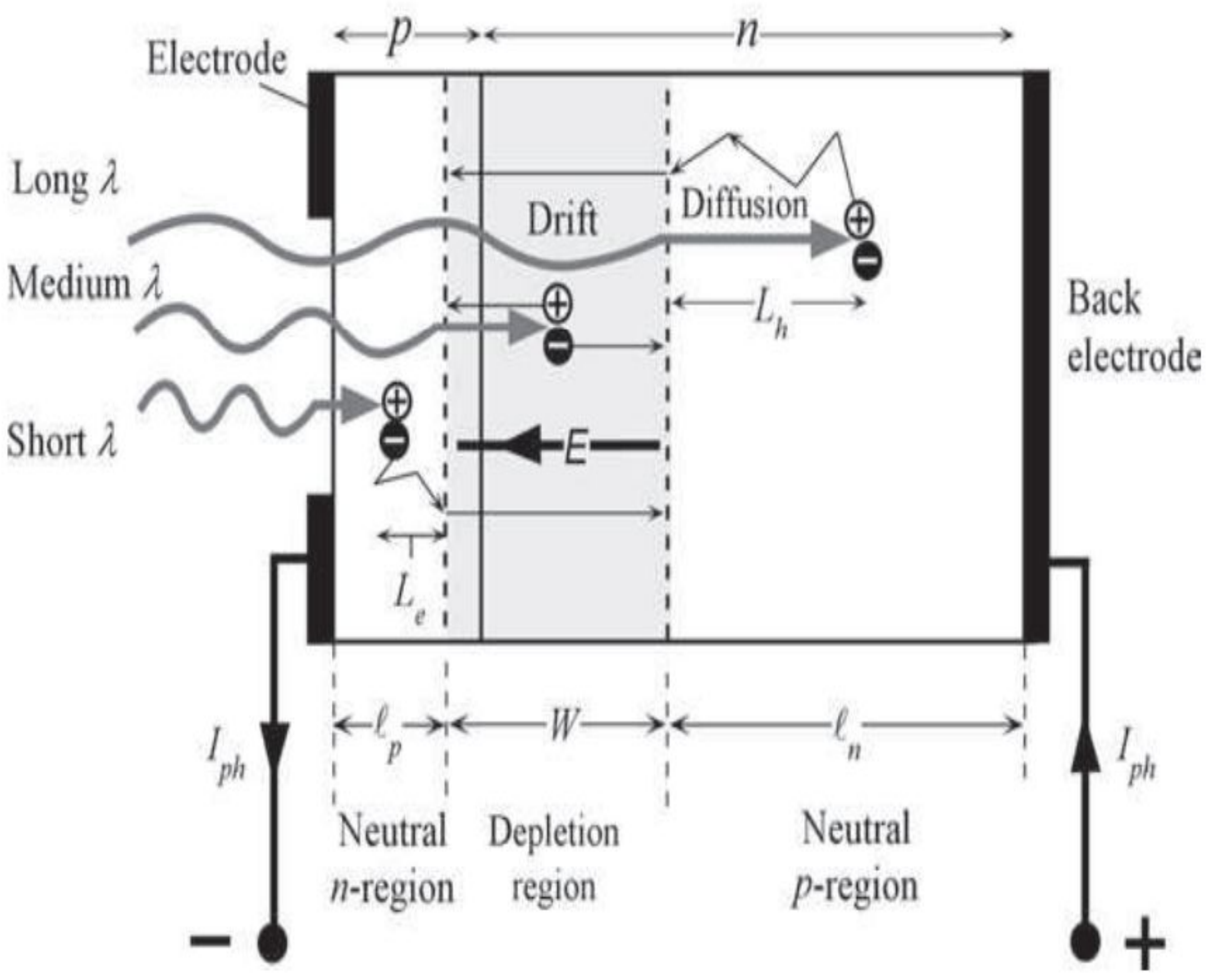
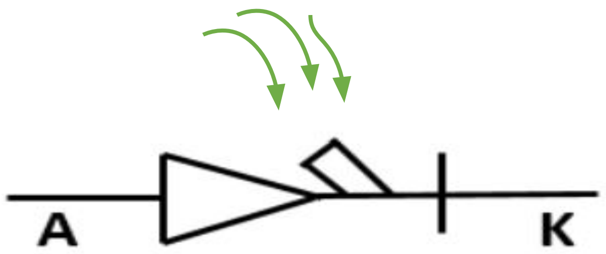


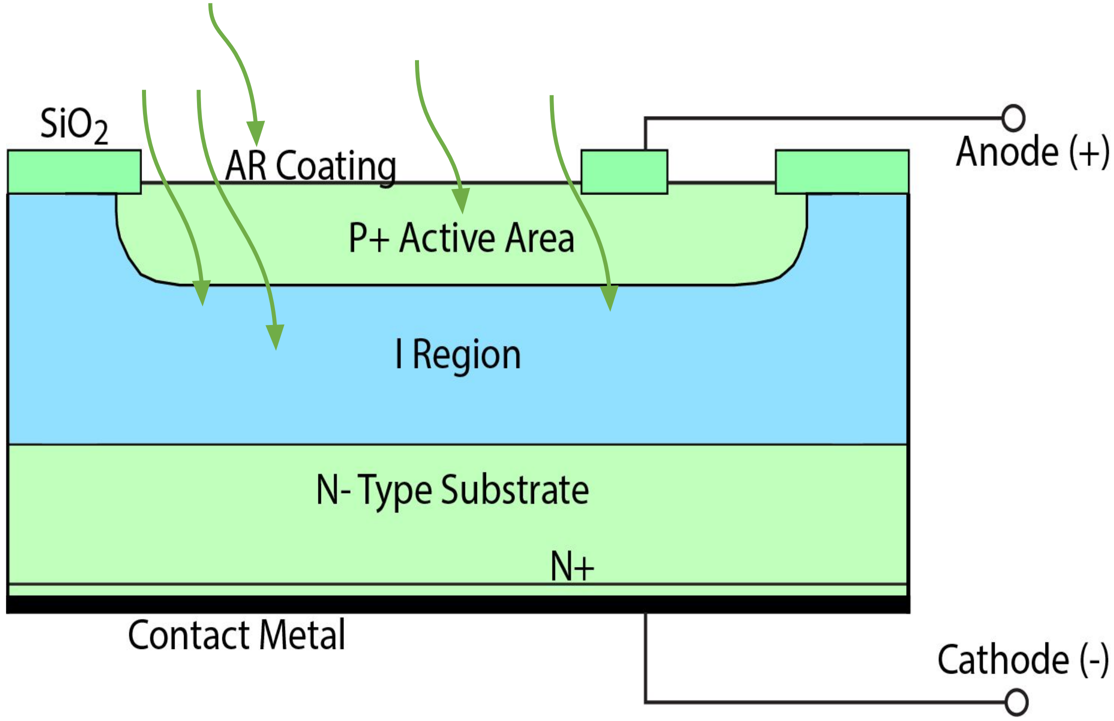
Fig-5.2.1-6 Diffusive length of photon of different wavelength within PN junction photodiode.

PIN Photo-diode:

- It's developed from the PN junction photodiode to improve its response time and bandwidth spectrum.
- For better functioning of PD, we have made small changes in the normal PN junction photodiode.
- In the construction of a PIN photodiode, an intrinsic layer is placed between two different extrinsic (highly doped) material layers as shown in fig-5.2.1-7.
- This intrinsic layer is highly resistive and increases the electric field strength within the device. It means the width of the depletion region increased. As a result of it, the device has high quantum efficiency.



(a) Symbol of PIN Photodiode



(b) Cross Sectional View pf PIN Photodiode.
Fig-5.2.1-7 PIN photodiode.

5.2.1.B Junction Photodiode (PIN Photo-Diode)

- When there is no bias applied to the diode, there will be diffusion of charge due to concentration gradient across the junction. Diffusion HOLES and ELECTRONS across NI junction from very thin depletion layer in I region and a relatively thicker depletion layer in I region containing equal and opposite fixed charges.

- When a reverse bias is applied and gradually increased, the thickness of the depletion layer increases until the entire I-region is swept free of mobile carriers. Thus, with a reverse bias applied to the PIN photodiode, the space charge region extends completely through the I-region as shown in fig-5.2.1-8.

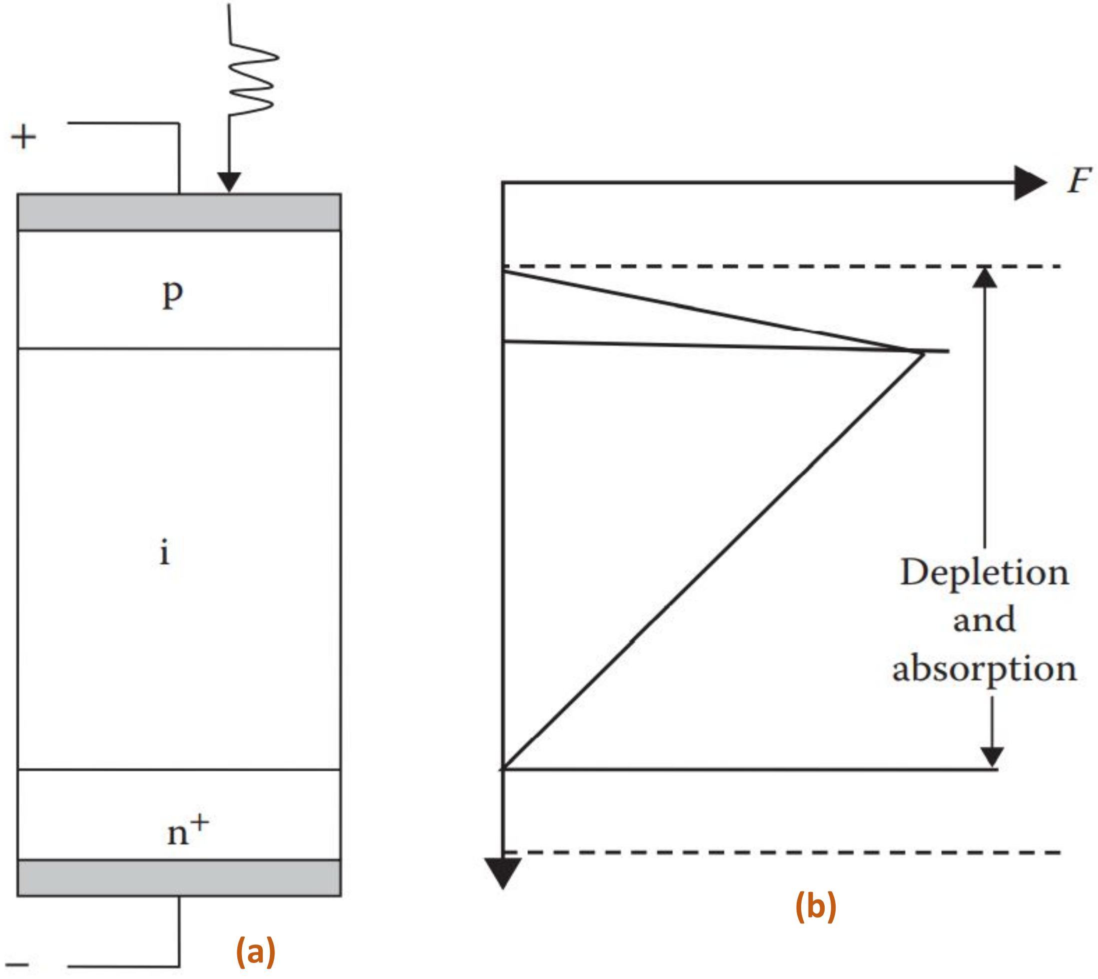


Fig- 5.2.1-8 PIN photodiode structure, Electric field profile across the depth of the device in which Depletion (a), Diffusion Length and Absorption Area as shown (b).

5.2.1.B Junction Photodiode (PIN Photo-Diode)

Drawback:

The optimum value of width (W) depends on a compromise between speed and sensitivity.

Advantage:

They are capable of processing very signals.

Inexpensive and ultrafast having a response time of nanosecond.

Generate very low noise and have broad spectral response.

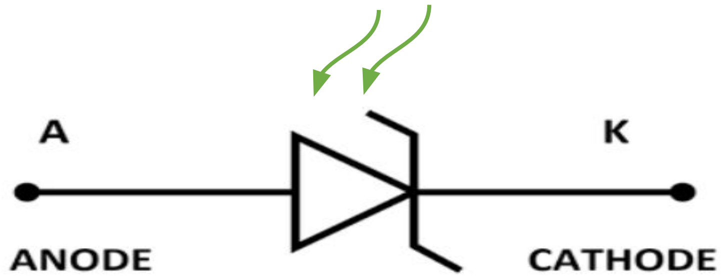
Application:

Audio CD players, DVD drivers, nuclear radiation detectors, optical communication equipment, demodulation etc.

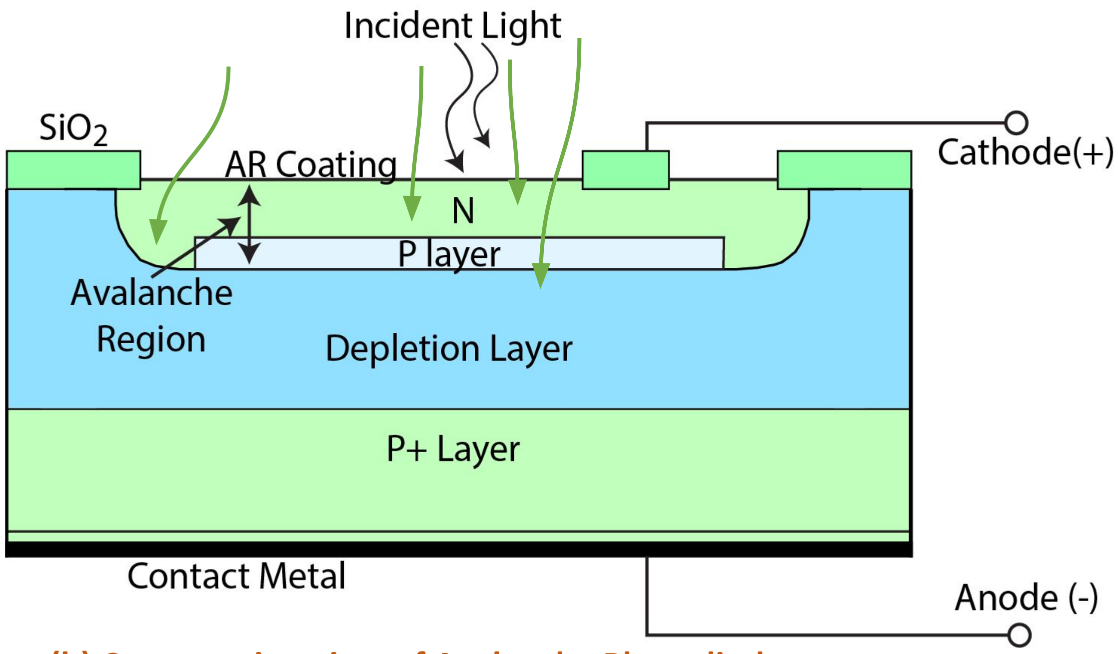
5.2.1.C Junction Photodiode (Avalanche Photo-Diode)

Avalanche Photodiode (APD):

- APDs are based on Impact ionization to create an internal current gain.
- For avalanche effect, it requires high reverse biased condition for operation near applied reverse biased voltage as shown in fig-5.2.1-9.
- When Incident photon on material it generate EHP which is known as Primary generate electron.
- Under these conditions, an accelerating electron can acquire sufficient K.E to generate new EHPs.
- These generated charge carriers get sufficient K.E due to the established Electric field in the SCL or Depletion Region and External applied voltage.



(a) Symbol



(b) Cross section view of Avalanche Photodiode

Fig- 5.2.1-9 Avalanche Photodiode

5.2.1.C Junction Photodiode (Avalanche Photo-Diode)

- It act as solid state photomultiplier as shown in fig-5.2.1-10.
- When the bias is high enough to fully deplete the junction, the following three factors contribute to the response time:

1. Transit time of the carriers across the absorption layer of width W.
2. The time taken by the carriers to create EHPs by avalanche multiplication
3. The RC time constant, where R is the device and load resistance and C is the junction capacitance.

- These two limit the value of bandwidth.
- When the gain is large, avalanche multiplication time becomes dominant and the bandwidth is reduced.
- APDs are therefore characterized by a constant gain bandwidth product.

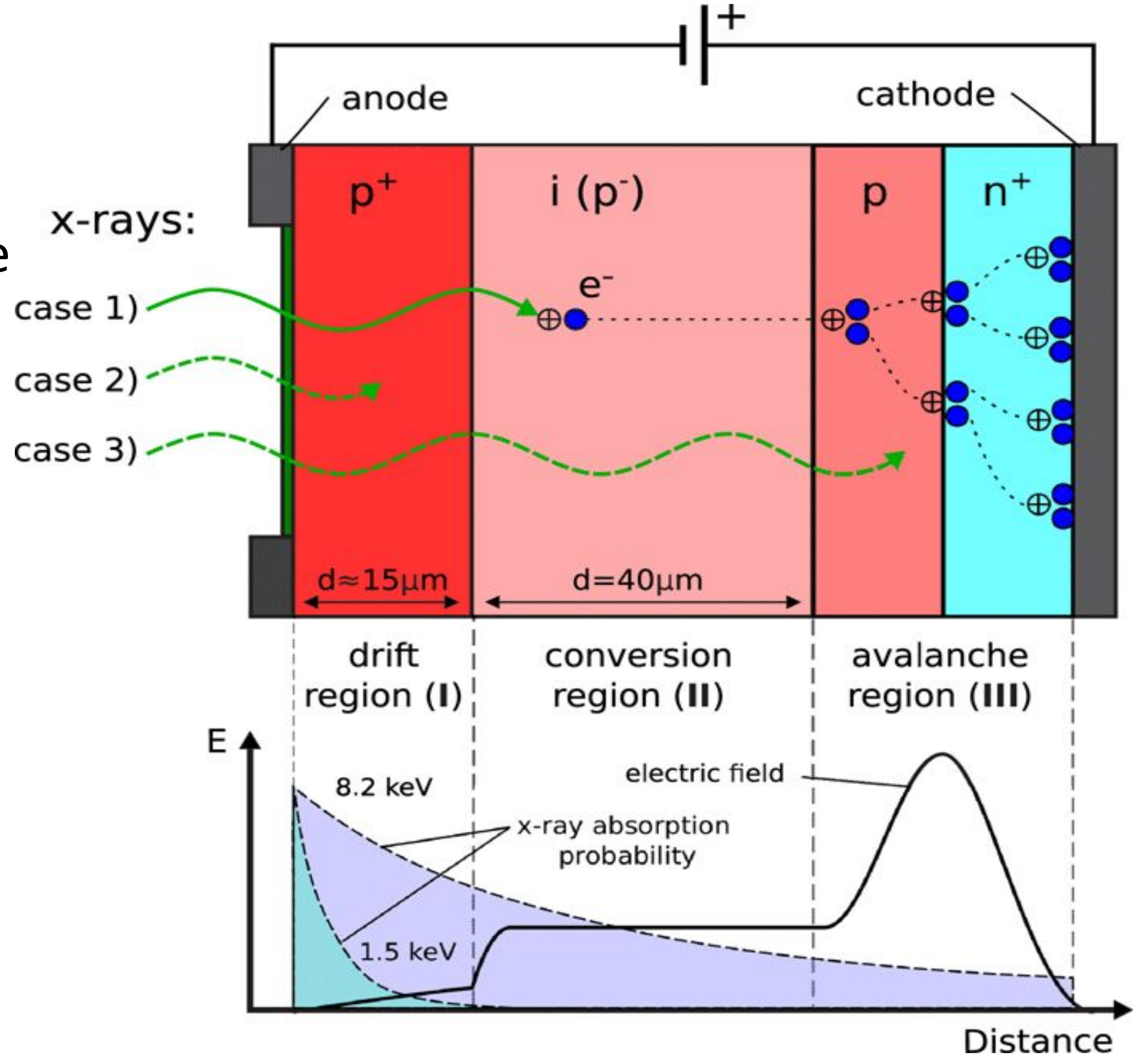


Fig-5.2.1-10 Avalanche photodiode, Incident photon Energy verse distance within the device.

https://aip.scitation.org/doi/10.1063/1.4921195

5.2.1.C Junction Photodiode (Avalanche Photo-Diode)

Applications of avalanche photodiodes:

Receivers in optical fiber communications, range finding, image, high speed LASER scanners, LASER microscopy, and optical-time domain reflectometers (OTDR).

Disadvantages:

- Much higher operating voltage may be required.
- Avalanche photodiode produces a much higher level of noise than a PN photodiode
- Avalanche process means that the output is not linear.

Advantages:

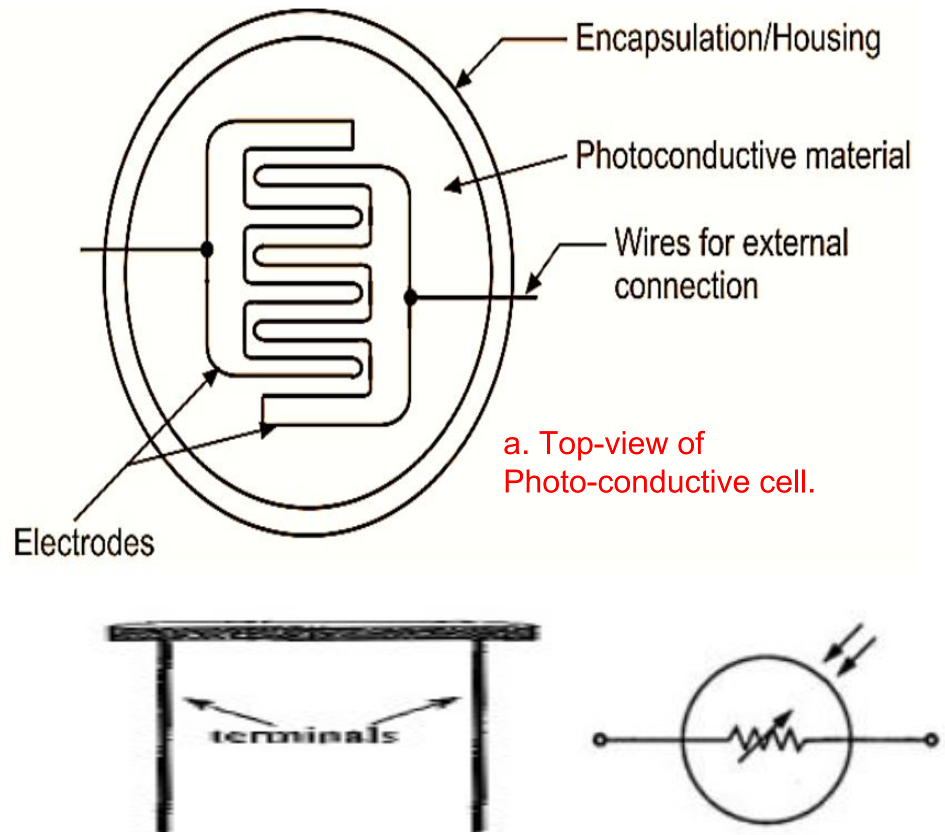
- High level of sensitivity as a result of avalanche gain

5.2.2 Photo-Conductive Cell

- The photoconductive cell (PC) is two terminal light sensitive SC devices. It is also referred as a Light Dependent Resistor LDR) or Photo-resistor.
- Working principle based on the principle of photo conducting effect that is a process in which the conductivity or resistivity o a SC material changes as per the wavelength and intensity of the radiation incident on it.

Construction:

- Photoconductive detectors have a sample structure schematically shown in figure-5.2.2-1.
- The essential elements are the ceramic base, a layer of photo conducting material, metallic electrodes to connect the device into the main circuit and silica capsule for enclosure as shown in fig-5.2.2-1.
- Most frequently used include cadmium sulphide (CdS) and cadmium selenide (CdSe) This material is arranged in the form of a long strip side from across a disc shape like base.



a. Top-view of Photo-conductive cell.

b. Front-View of Photo-conductive cell.

c. Symbol of Photo-conductive cell.

Fig-5.2.2-1 Construction of Photoconductive.

https://mediatoget.blogspot.com/2011/09/photo-conductive-cell.html

5.2.2 Photo-Conductive Cell

Working:

In photo conductive SC material are connected with two electrodes of a voltage V is applied across it which are used to separate the EHPs generated by the absorption of incident photon.

As a result of it, conductivity of the SC material increases and enhance/increase the external current in main circuit.

Generated EHPs are drift in opposite direction due external and internal E-field.

Here electrons drift much faster as compared to holes due to the mobility difference of these two charge carriers.

Sample will be neutral at any instant of time t (i.e the number of is equal to number of electrons) as shown in Fig-5.2.2-3.

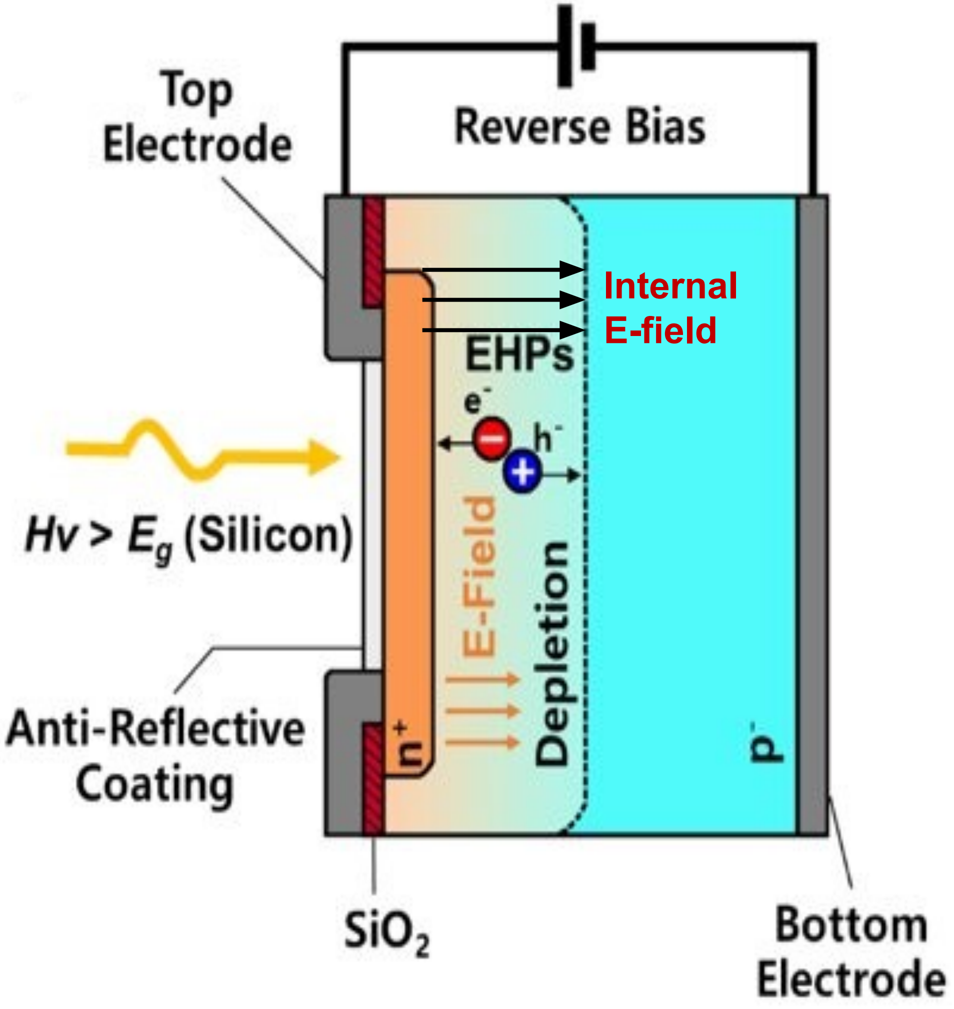


Fig-5.2.2-3: Generation of charge carriers in PC cells.

https://techxplore.com/news/2019-11-hourglass-shaped-silicon-photodiodes-near-infrared-photoresponse

5.2.2 Photo-Conductive Cell

1). At any time (t) the number of electrons concentration is **n** (i.e photogenerated electron included) and the thermal equilibrium electrons concentration is $\mathbf{n_0}$ (i.e in the dark), then the excess electrons concentration is $\mathbf{\Delta n = n - n_0}$.

But photogenerated of EHPs, $\mathbf{\Delta n = \Delta p}$

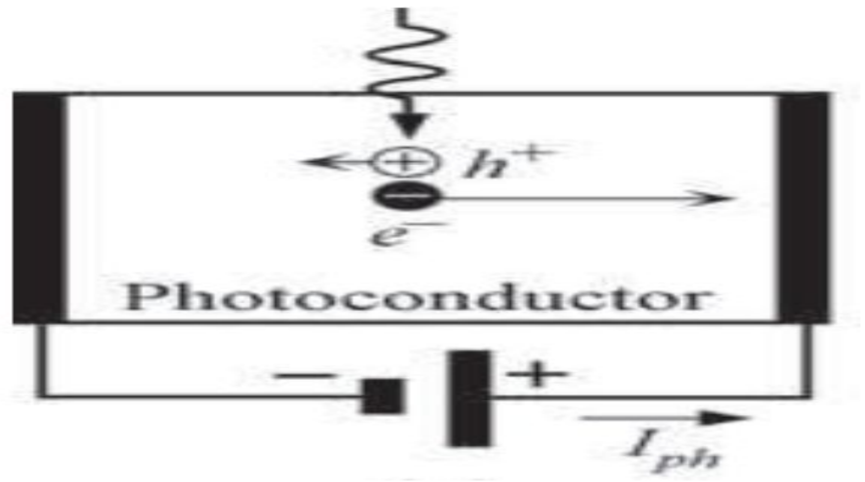


Fig-5.2.2-3 EHP Generated is drifted in external E-field.

- For electrons, $\mathbf{n = n_0 + \Delta n}$
- For holes, $\mathbf{p = p_0 + \Delta p}$

2). In the Sample,

The rate of increase in the excess electron concentration

= Rate of photo generation of excess electrons

- Rate of recombination of excess electrons.

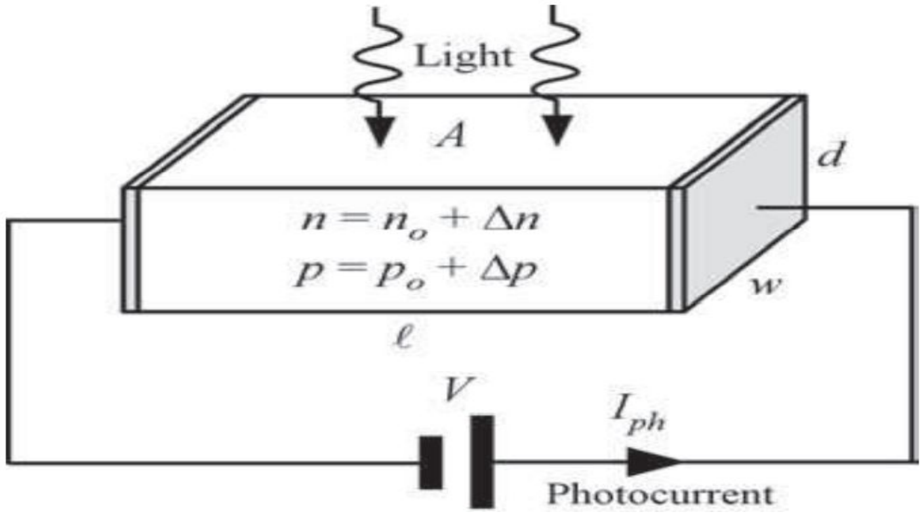


Fig-5.2.2-4: Generation of charge carriers in PC cells.

5.2.2 Photo-Conductive Cell

Application:

- It is inexpensive and simple type of detector which is widely used in OFF/ON circuits, light intensity measurement and light detecting circuits etc.

Drawbacks:

- Temperature variation causes substantial variation in resistance. This variation will enhance by the light absorption. Material is not useful for analog application.

Photo-Voltic Cell:

When PN junction photodiode is operated in Reversed Biased condition then its known as PHOTOCONDUCTIVE CELL or DEVICES.

PN Junction photodiode operated without any external power supply but connected in series with resistive load or with power storge device, then its known as PHOTO-VOLTIC CELL or DEVICES.

Incident photon illumination can generate EHPs in the SCL that will generate photocurrent, in that circuit connect without bias as shown in fig-5.2.3-1.

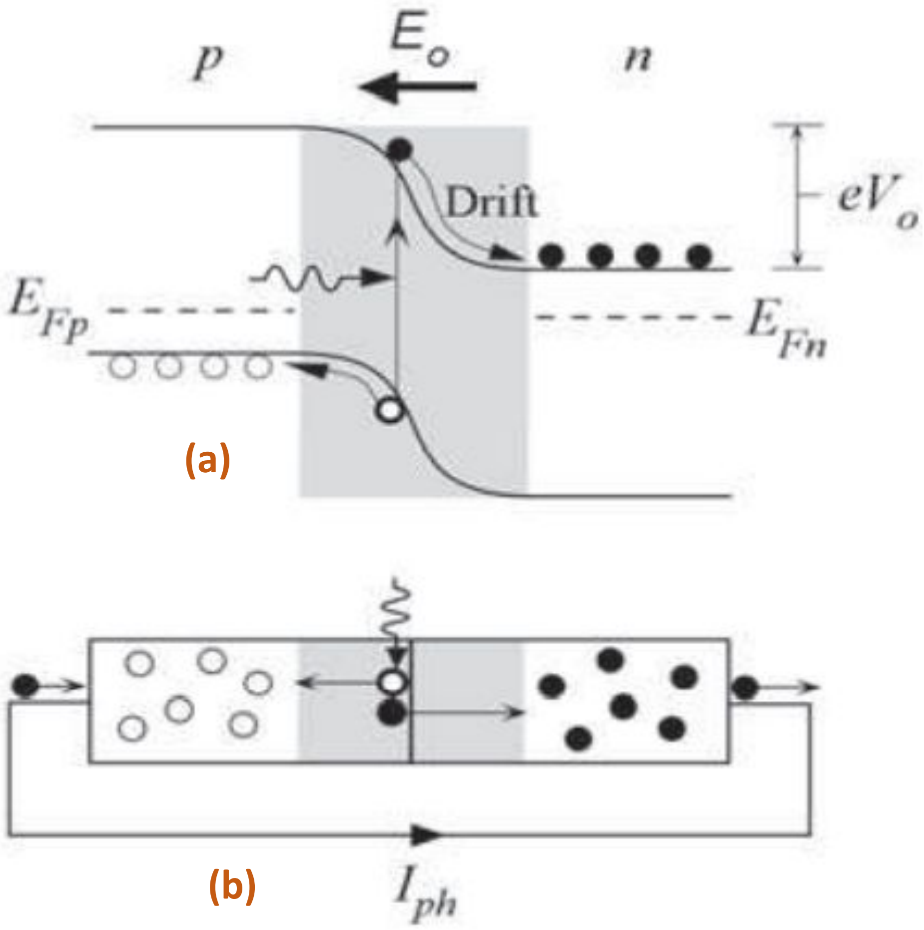


Fig-5.2.3-1 Photo - Voltic cell: Energy band diagram (a), Generation of EHPs in the SCL (b).

Disadvantage of Photo-Voltic Cell:

Without gain, Less bandwidth, low response time, temperature dependent efficiency, conversion rate is low (Light energy to Electrical energy).

Advantage of Photo-Voltic Cell:

Less complex circuit.

Application of Photo-Voltic Cell:

Its used in Solar panels.

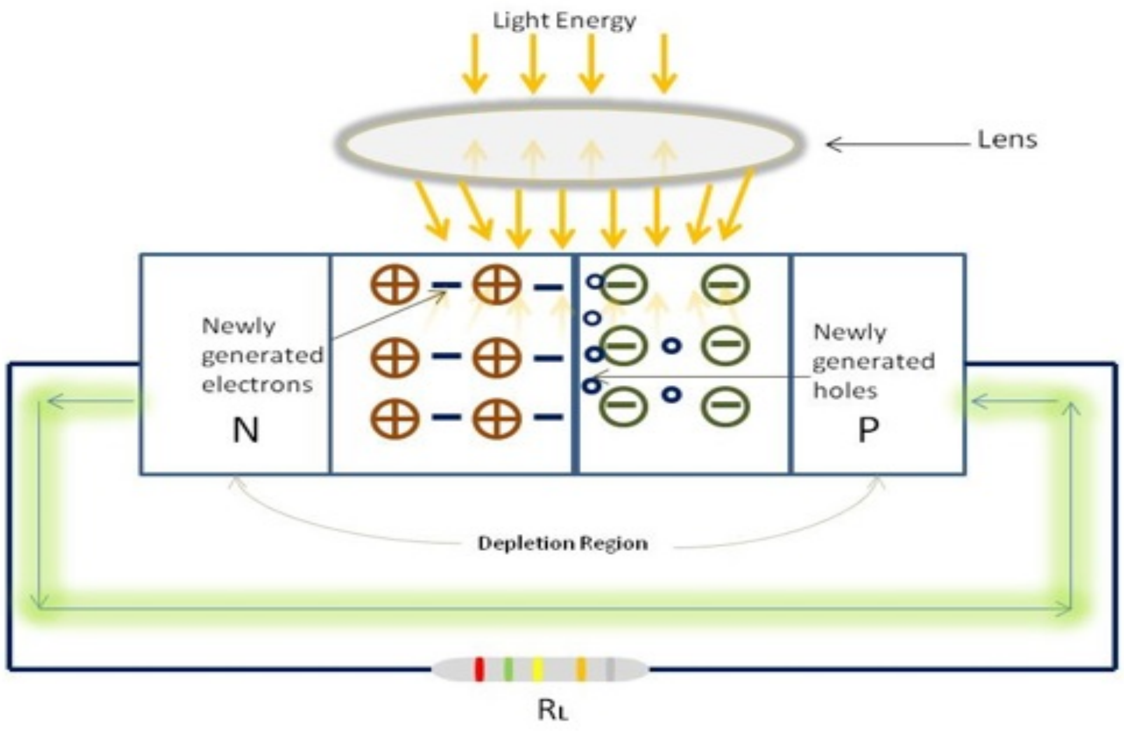
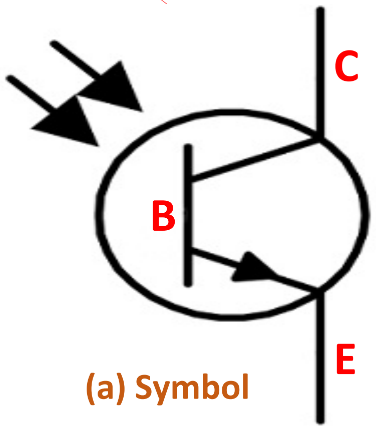


Fig-5.2.3 Generation of charge carriers in SCL.

Phototransistor:

- A phototransistor is similar to a regular BJT in that the base current is produced and controlled by incident light.
- Which has 3 layers with a light-sensitive base region and the other two are emitter and collector. There is no electrical connection to the base as shown in the figure.
- Here base current is produced when an incident photon strikes the photosensitive SC base region as shown in the fig-5.2.4-1.
- It also offers a current gain.



(a) Symbol

(b) Cross section view of Phototransistor

Fig- 5.2.4-1 NPN - Phototransistor

5.2.4 Phototransistor

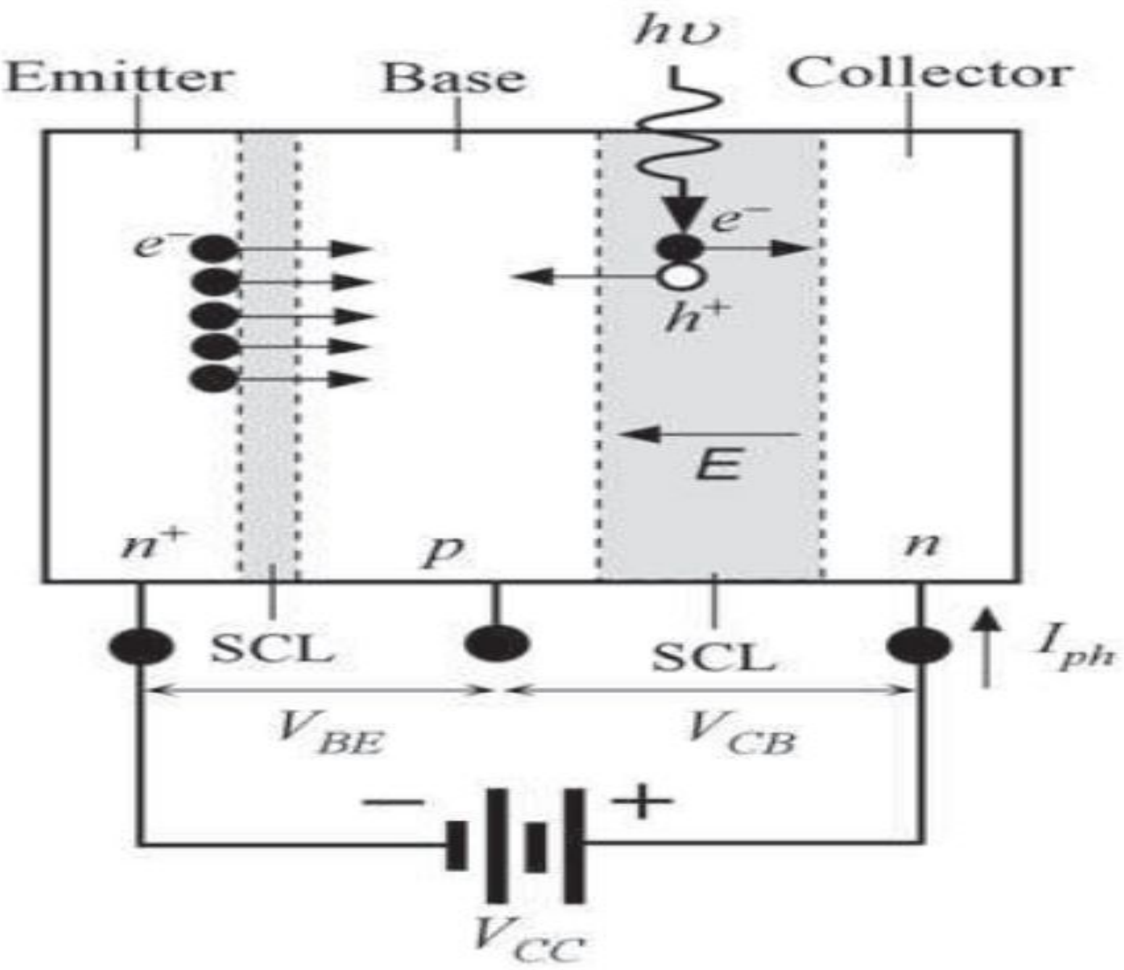


Fig-5.2.4-2 Movements of charge carriers within the device.

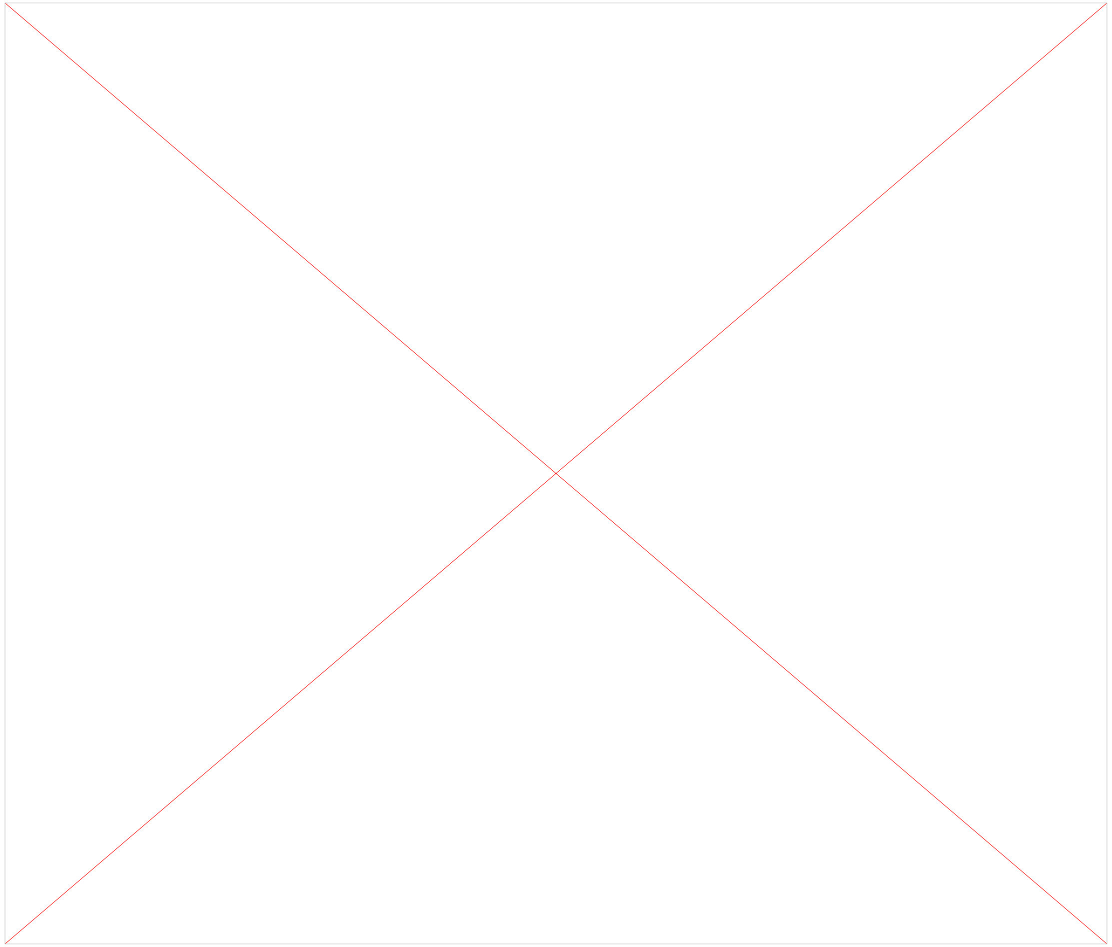


Fig-5.2.4-3 Output characteristics of NPN phototransistor.

5.2.3 Photo - Transistor

Advantages of Phototransistor:

It is more sensitive; it allows more current. So, it's used in high power consumption applications, Noise interference is more immune etc.

Disadvantages:

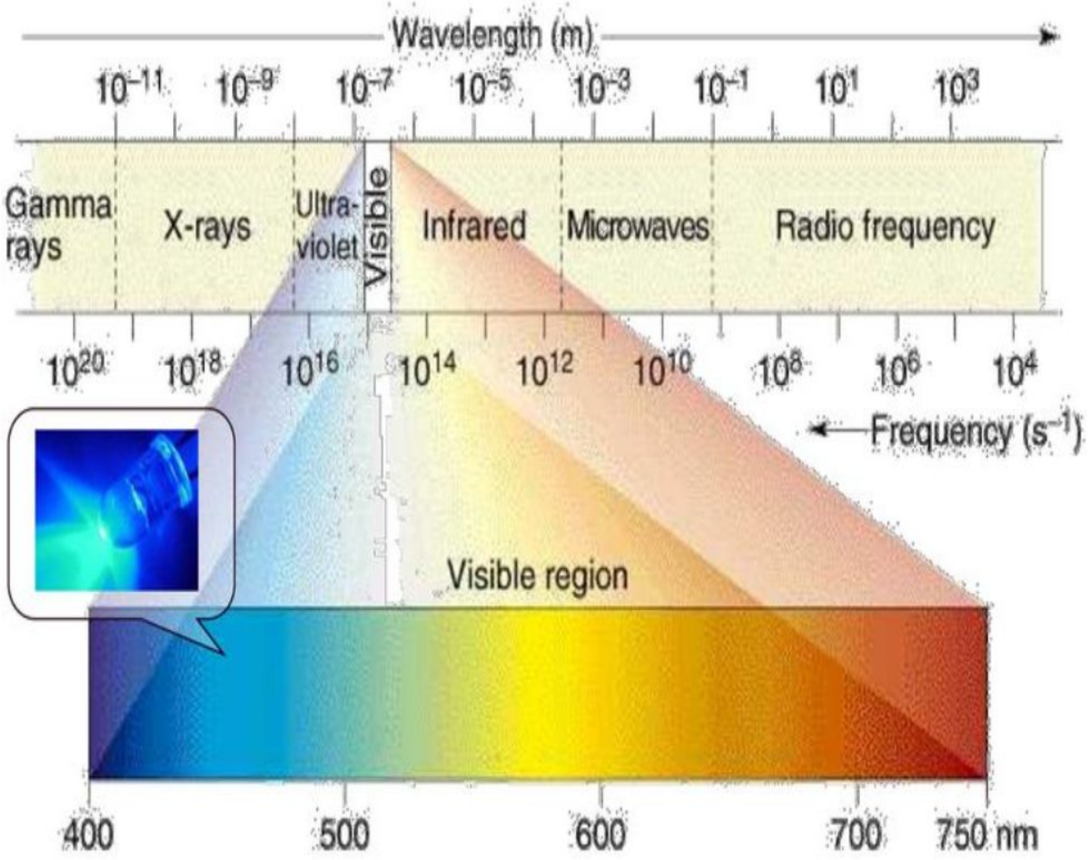
Output response is low, Operational speed is low, Dark current is high, It is not responsive more to incident light, The High-frequency response of this PD gives poor results etc.

5.3 Photo-Emitter Devices

- A photo-emitter device that emits noncoherent optical radiation at photon energy close to the bandgap of the junction.
- According to QM theory, light is a wave packet of energy that is called photons. This energy depends upon the frequency and the relation given by

  E = hf = hv

  whereas h is Planck's constant & f is the frequency.
- As per the above relation, photon energy is directly proportional to the frequency. But frequency is inversely proportional to the wavelength of photons. Indirectly, talks about the range of the spectrum like visible, IR, UV, X-ray region, etc.
- Various photo emitters are based on the light emission range as shown in fig-5.3.1.



$$E_{ph} = h\nu$$

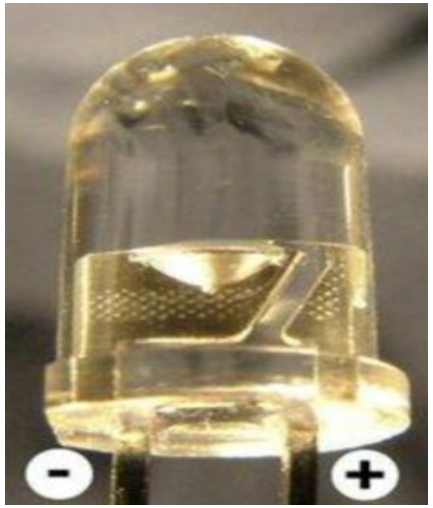
$$\lambda = \frac{c}{\nu} = \frac{hc}{h\nu} = \frac{hc}{E_{ph}}$$

$$\lambda[\mu m] = \frac{1.24}{E_{ph}[eV]}$$

Fig-5.3.1 Spectrum of light for visible range of LED.

5.3.1 Light Emitting Diode (LED)

- The operation of LED is based on the phenomenon of electro luminance, which is the emission of light from an SC under the influence of an electrical field.
- The current is primarily electron flow and the main recombination region is the edge of the depletion region on the p-side. The optical output increases with forward-bias diode current.
- These electrons give up energy in form of photons and thermal energy.



(a)

(b)

Fig-5.3.4: White LED

- Generally, in a regular junction diode: recombination release energy thermal (heat) - Nonradiative recombination but in LED: recombination releases the light (photons) radiative recombination. Both types of recombination occur in a LED but a majority of combinations are radiative types.
- Energy band diagram for LED is shown in fig-5.3.6.

5.3.1 Light Emitting Diode (LED)

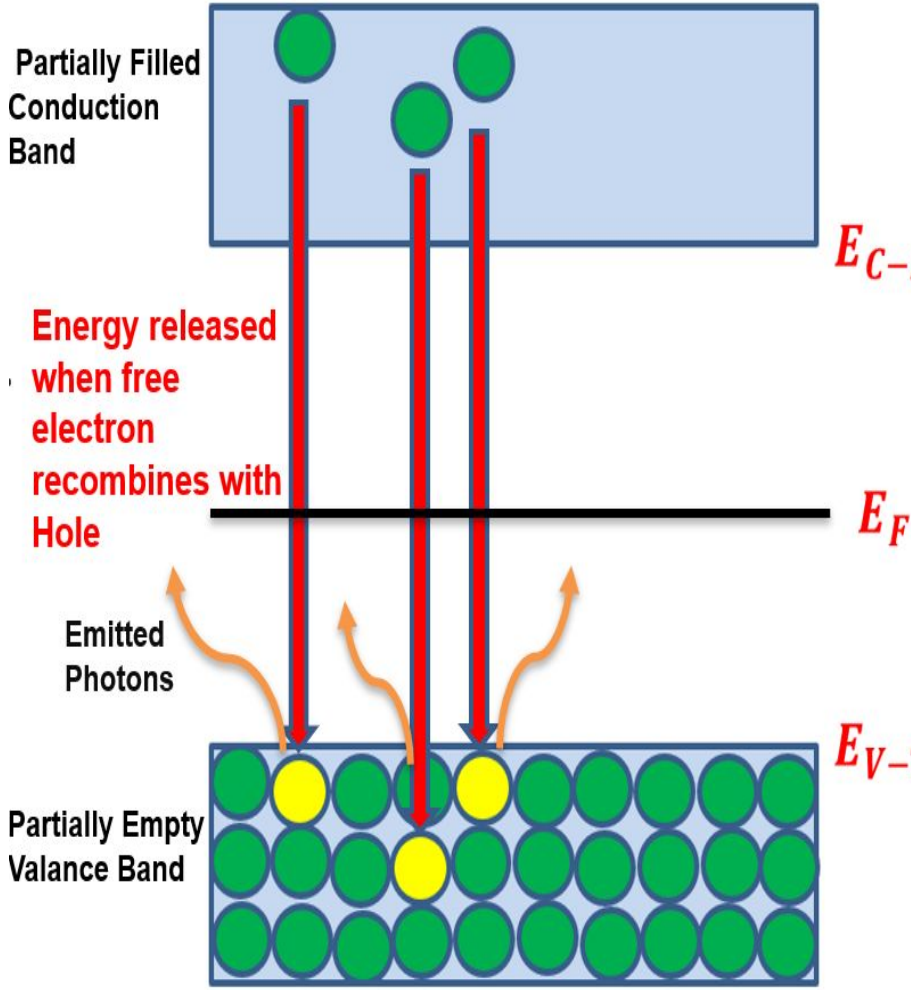


Fig-5.3.5 EHPs Recombination via Emitting Light (photons).

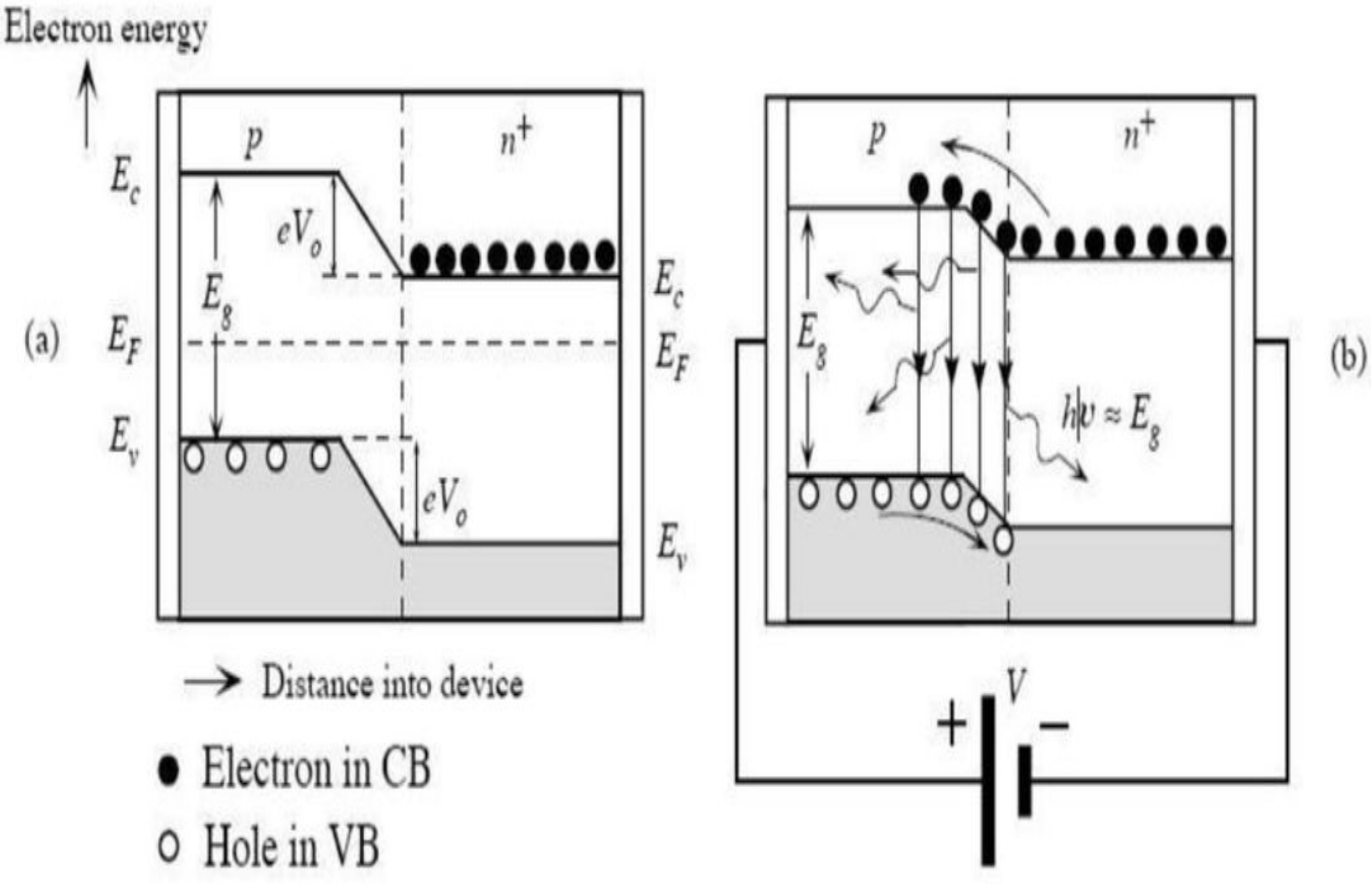
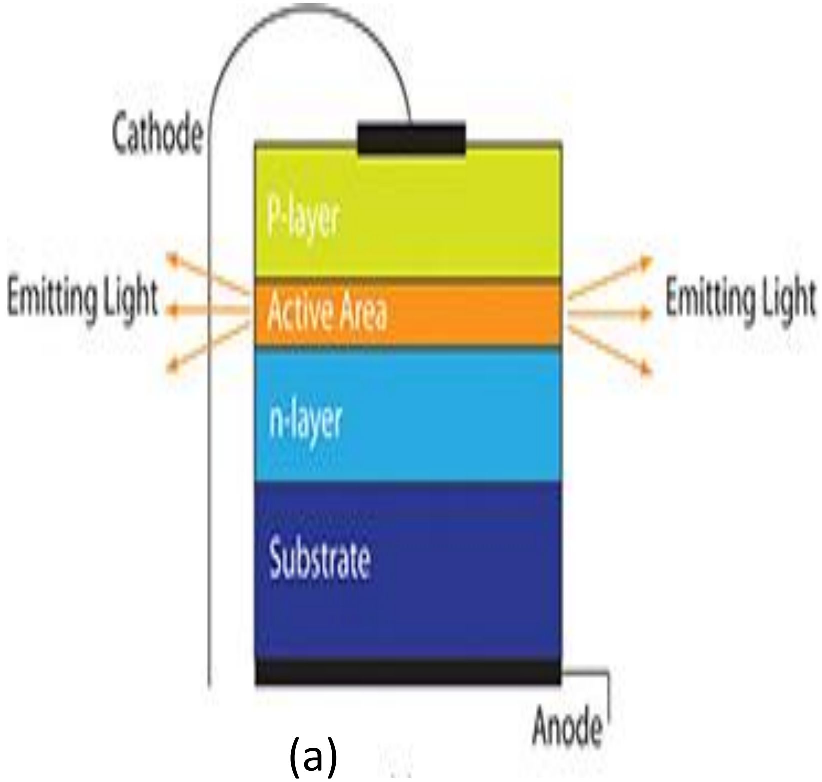
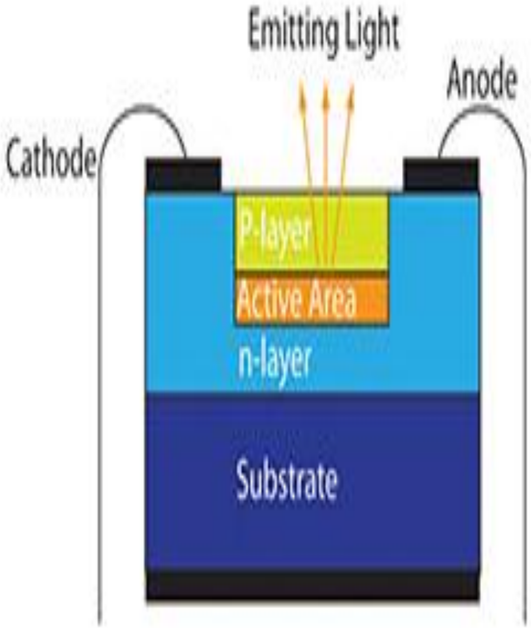


Fig-5.3.6: PN Junction Diode, (a) Energy Band formation when P and N-type join without applying any potential across the device and (b) Alteration of Energy band when it connected with power supply in FB condition. When recombination of charge carriers across the SCL region takes place it generates light with a particular wavelength.

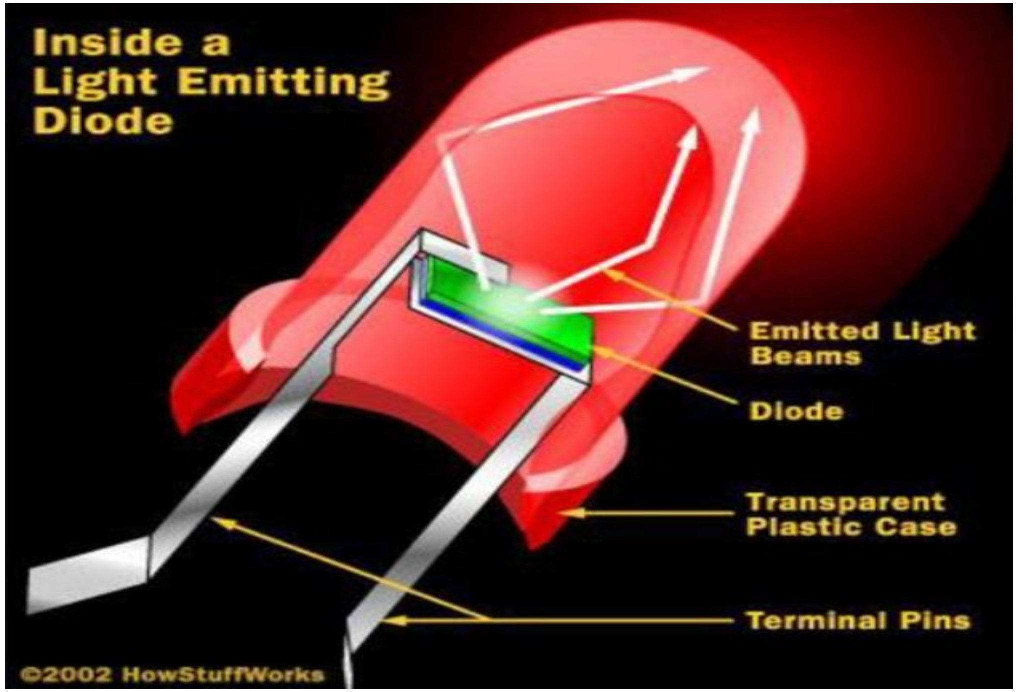
5.3.1 Light Emitting Diode (LED)



(a)



(b)



(c)

Fig-5.3.3: Types of LED based on light emission through the device, (a) Edge-Emitting LEDs, (b) Surface-Emitting LEDs, and (c) Cross-sectional view of Surface-Emitting LEDs. Typically a p+n or n+p diode such that the main transitions occur on the n-side or p-side respectively of the depletion region.

Construction: The LED structures can be divided into two categories;

1. **SURFACE-EMITTING LEDs**: These LEDs emit light in a direction perpendicular to the PN junction plane. Recombination of charge carriers occurs in the P-region. So, this region is required to be kept at the top. This, the P-region becomes the device's surface.
2. **EDGE-EMITTING LEDs**: These LEDs emit light in a direction parallel to the PN junction plane.

5.3.1 Light Emitting Diode (LED)

Application: Emitting visible light is widely used in instrument display panels, panel indicators, digital watches, calculators, telephone switchboards, etc.

Advantages: Small area, low power required, available in different colors, mainly smooth control of the light intensity, operated over a wide range of temperatures, rugged in construction, etc.

Disadvantages: Get damaged by over-voltage or over-current, their temperature depends on the radiant output power and wavelength.

5.3.2 Infrared (IR) Diode

- Infrared emitting diodes are solid state device made of Gallium Arsenide that emits a beam of light flux when forward biased.
- The basic construction of the IR emitter diode is similar to LED but the spectrum of light emitted will be different due to the bandgap of the material is large.
- When the junction is forward biased, electrons from the N-type will reach P-type and recombine with an excess hole of the P-type of a material.
- Its special design recombination region (i.e sandwiched in between N & P-type materials).

- **Application:** Burglar Alarm circuit, Card and paper-tape readers, shaft encoders, data-transmission systems, high-density mounting application.
- **Disadvantages:** High energy loss, the range is limited, less data transmission, get damaged by over-voltage or over-current.

5.4 Opto-Couplers

- An optocoupler or an optoelectronic coupler is an interface between two circuits that operate at different voltage levels.
- The most common industrial use of the optocouplers or optically coupled isolators is as a signal converter between high voltage pilot devices or limit switches, and low voltage solid state logic circuits as shown in fig-5.4-1.
- Optical isolators can be employed in any situation where a signal must be passed between two circuits that have no conductors in common is often necessary to prevent noise generated in one circuit from being passed to the other circuit as shown in fig-5.4.1-(a).

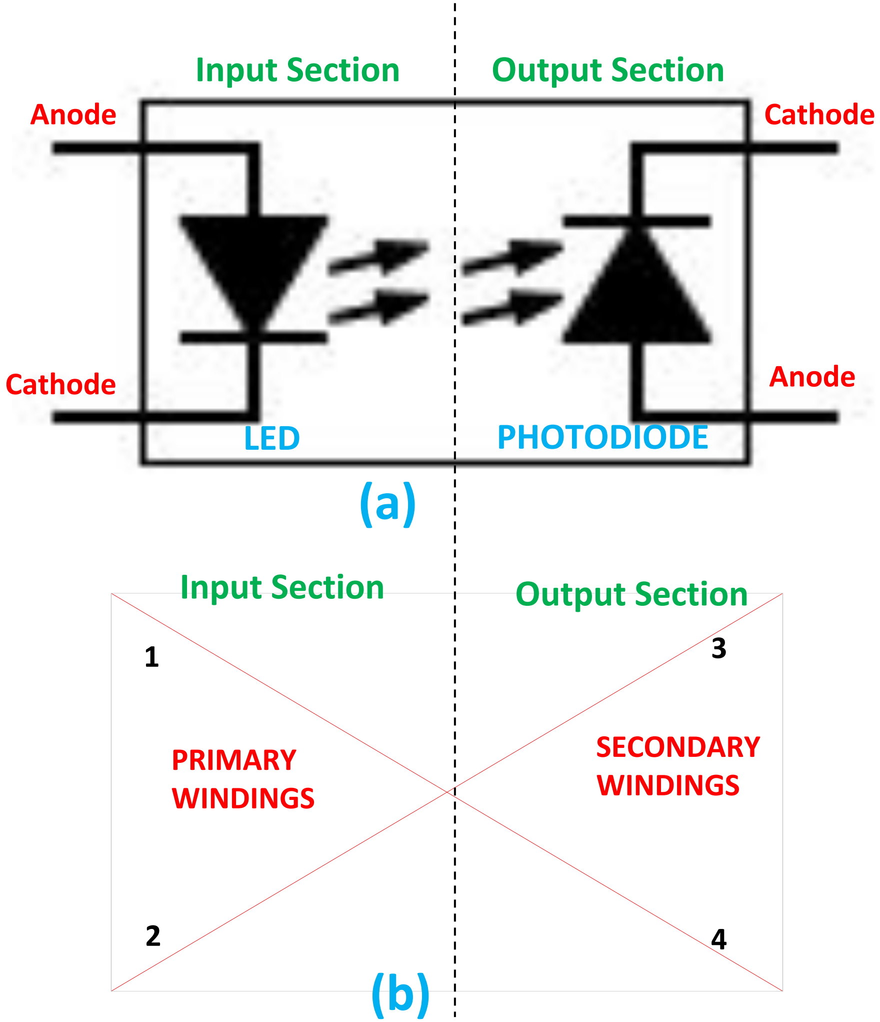


Fig-5.4.1 Optoelectronic coupler (LED & Photodiode) (a) and electrical signal coupler - transformer (b)

https://www.electrical-symbols.com/electric-electronic-symbols/optocoupler-symbols.htm

5.4 Opto-Couplers

- Nowadays, optoelectronic couplers are commonly used. In the input & Output section, the electrical component may vary due to application based as shown in fig-5.4.2.
- The ideal isolation scheme should only allow signal flow in 1-D, should respond to DC levels, and should offer an extremely large resistance between the inputs and output circuits.
- They work on both AC and DC high voltage signals. For this reason, signals converters employing optical coupling are sometimes referred to as the UNIVERSAL SIGNAL CONVERTERS.
- The information circuits are almost badly exposed to noise sources and the logic circuits cannot tolerate noise signals.

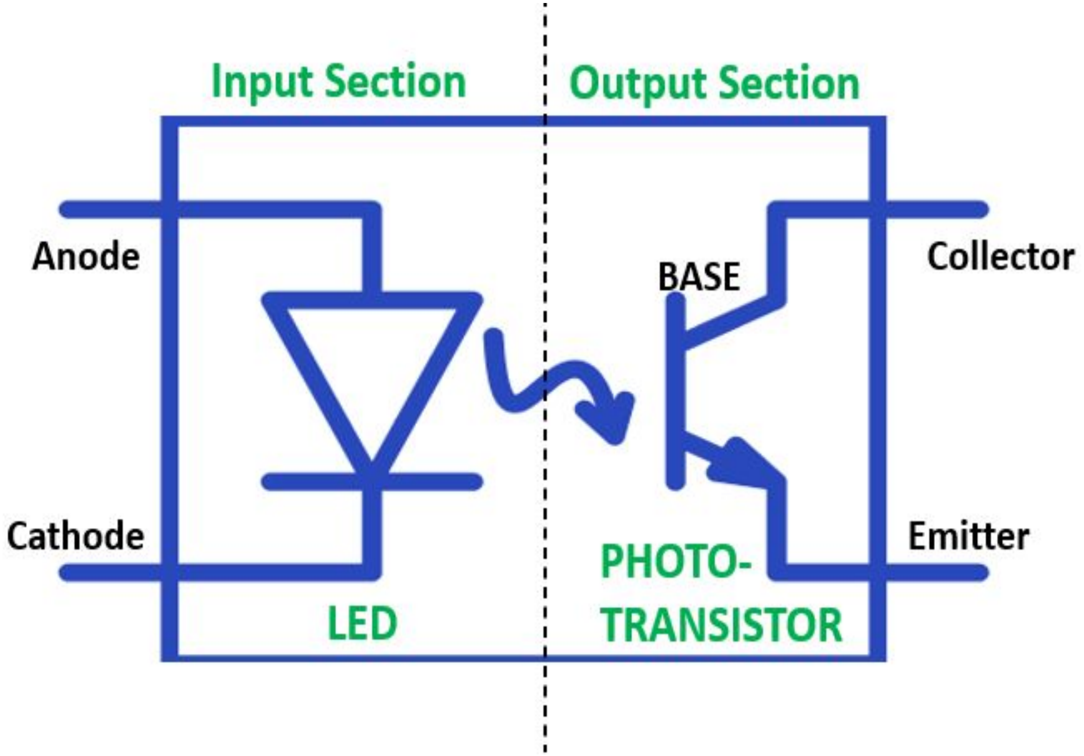


Fig-5.4.2- Optoelectronic coupler (LED and Phototransistor)

5.4 Opto-Couplers

- **Advantages:**

  It offers a very good response at lower frequencies.
  Compact and cheaper optocoupler devices are available.
  Less maintenance is required.
  No moving part or mechanical part.

- **Disadvantages:**

  Optocoupler needs external biasing voltage for its operation.
  Higher frequency response is poor.

- **Application:**

  Microprocessor input/output switching.
  Pulse Code communications.
  DC and AC power control and transmissions.
  Signal isolation and power supply regulation suffer from current ground loops, etc.

5.5 X-ray Diffractometer

- An X-ray diffractometer is a device for analyzing and measuring the structure of materials.
- X-rays have high energy and short wavelength when compared to visible light making them ideal for probing the interplanar distances in crystalline materials. An experimental setup is shown in fig-5.5.1.
- X-rays are produced within an X-ray tube

1. Heated filament emits electrons by thermionic emission.
2. Electrons are accelerated by a high voltage.
3. Electrons hit a metal target and produce X-rays.

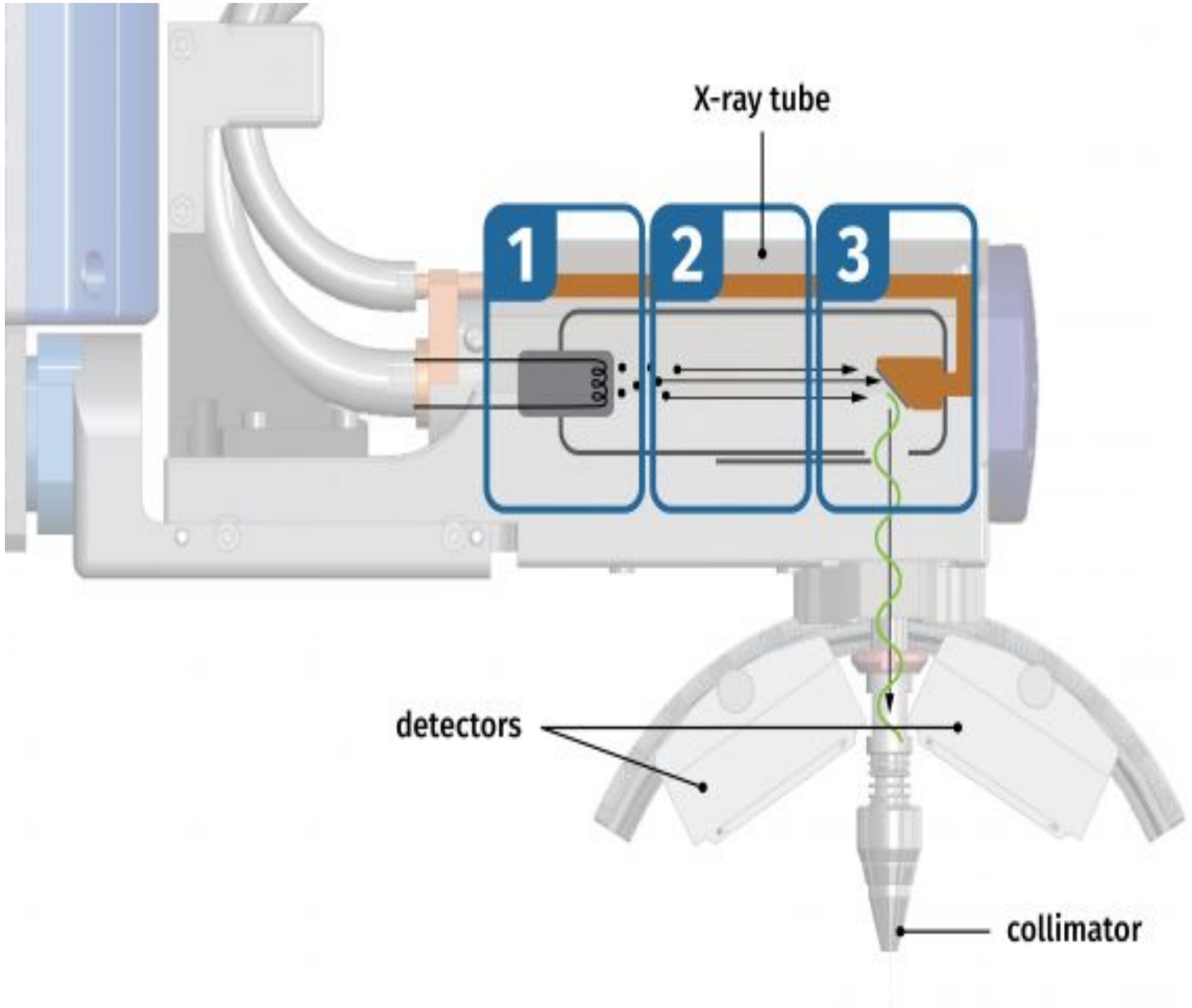


Fig-5.5.1 Various parts of X-ray diffractometer for analysis of materials.

5.5 X-ray Diffractometer

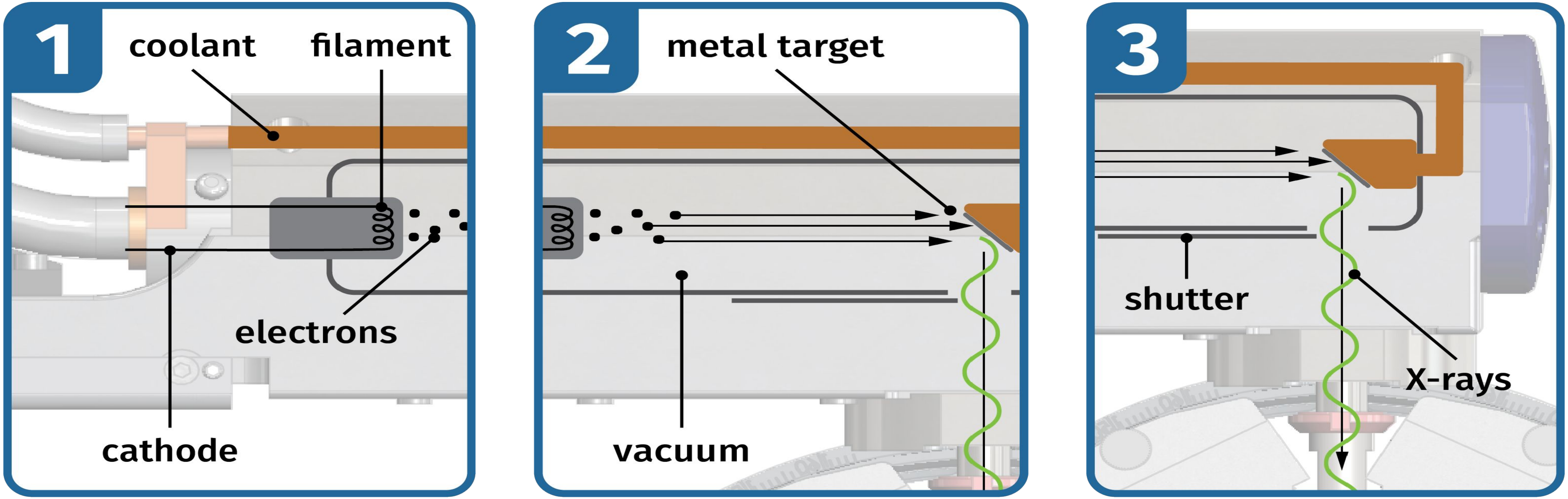


Fig-5.5.2 X-ray Diffractometer: from the generation of an electron (1) to the creation of characteristics of X-ray (2) and then incident on the target material (3) for analysis.

5.5 X-ray Diffractometer

- **Advantages:**

Technique for identification of an unknown mineral
Minimal sample preparation is required
Data interpretation is relatively straightforward.

- **Disadvantages:**

Homogeneous and single-phase material is best for the identification of an unknown
For mixed materials, the detection limit is ~ 2% of the sample
Peak overlay may occur and worsens for high angle 'reflections’

- **Application:**

Characterization of crystalline materials
Determination of unit cell dimensions
Measurement of sample purity
Determining the thickness, roughness and density of the film using glancing incidence X-ray reflectivity measurements

5.6 Quantum Devices and their Applications.

5.6.1) 2 D QD

5.6.2) 1 D QD

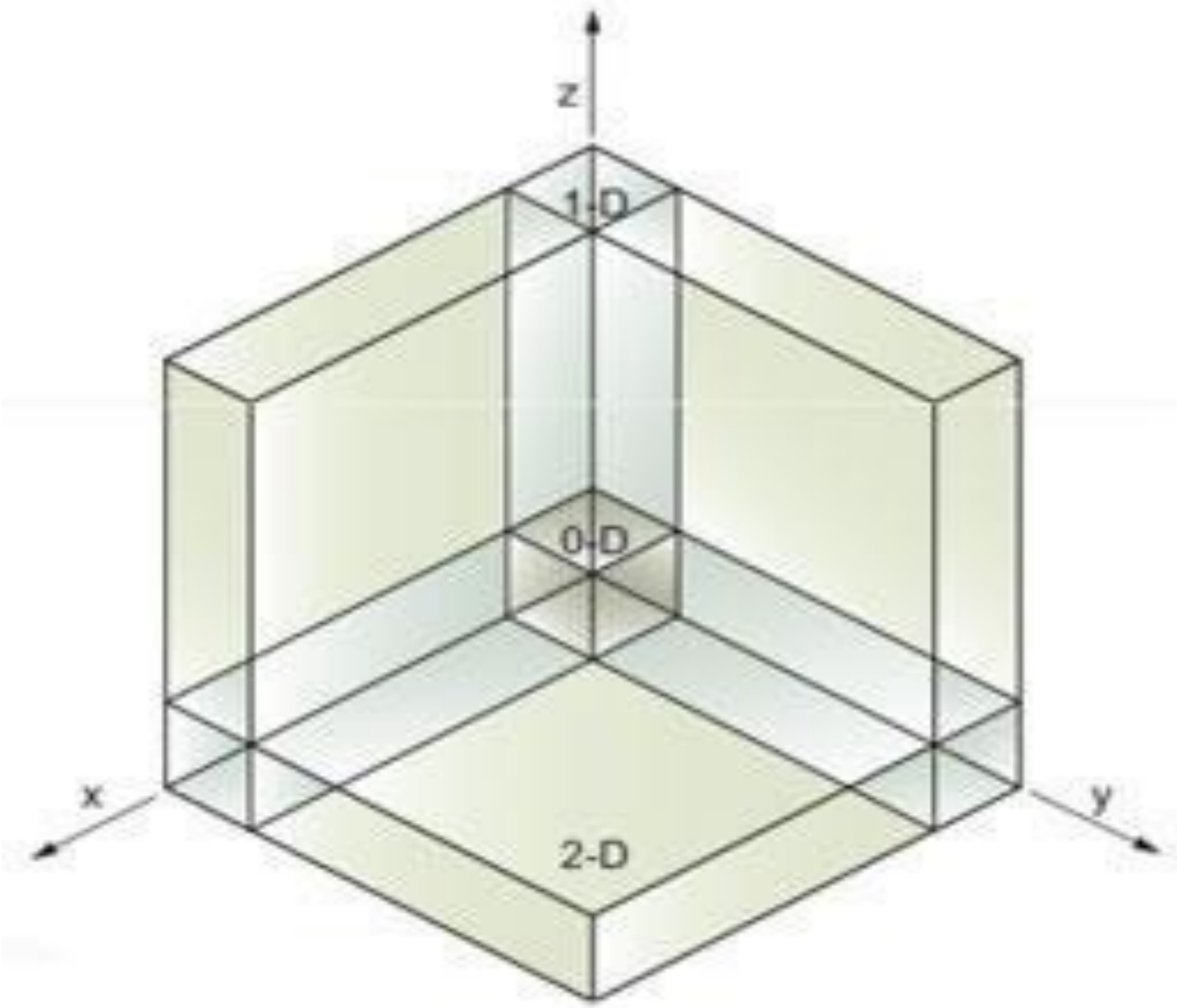
5.6.3) 0 D QD

Low dimensional materials

- **When the size drops below 100 nm, new structure of the material is formed called nanostructure.**
- The quantum wells, quantum wires and quantum dots are nothing but nanostructures of the material.
- These nanostructures are explained through quantum mechanics so they are called quantum wells, quantum wires and quantum dots.
- They are different from classical wells, wires and dots. They are also called low-dimensional structures.

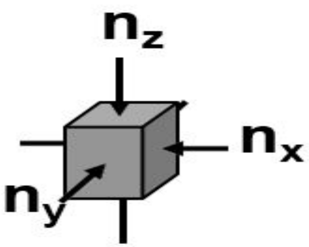
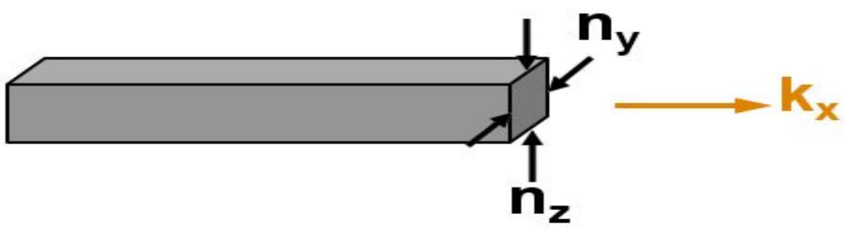
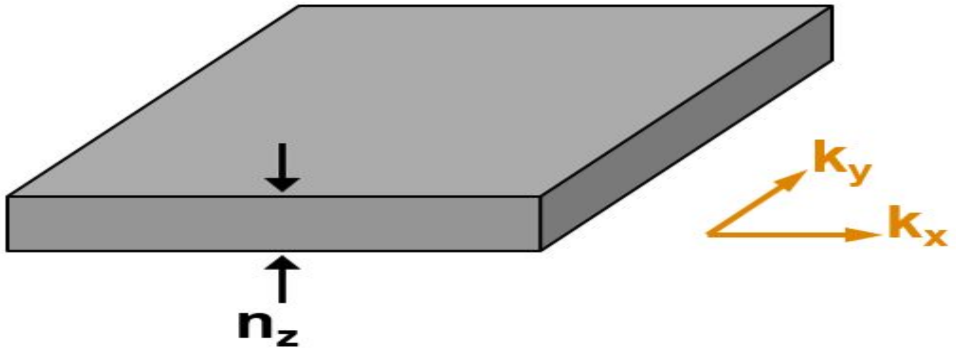
Low-dimensional materials
Zero-dimensional materials • Nano powders, Nano particles, precipitates, colloids and quantum dots
One-Dimensional materials • Nano wires, Nano fibers, Nano tubes, Nano rods
Two-dimensional materials • Nano layers, thin films, platelets and surface coatings.

Low dimensional materials

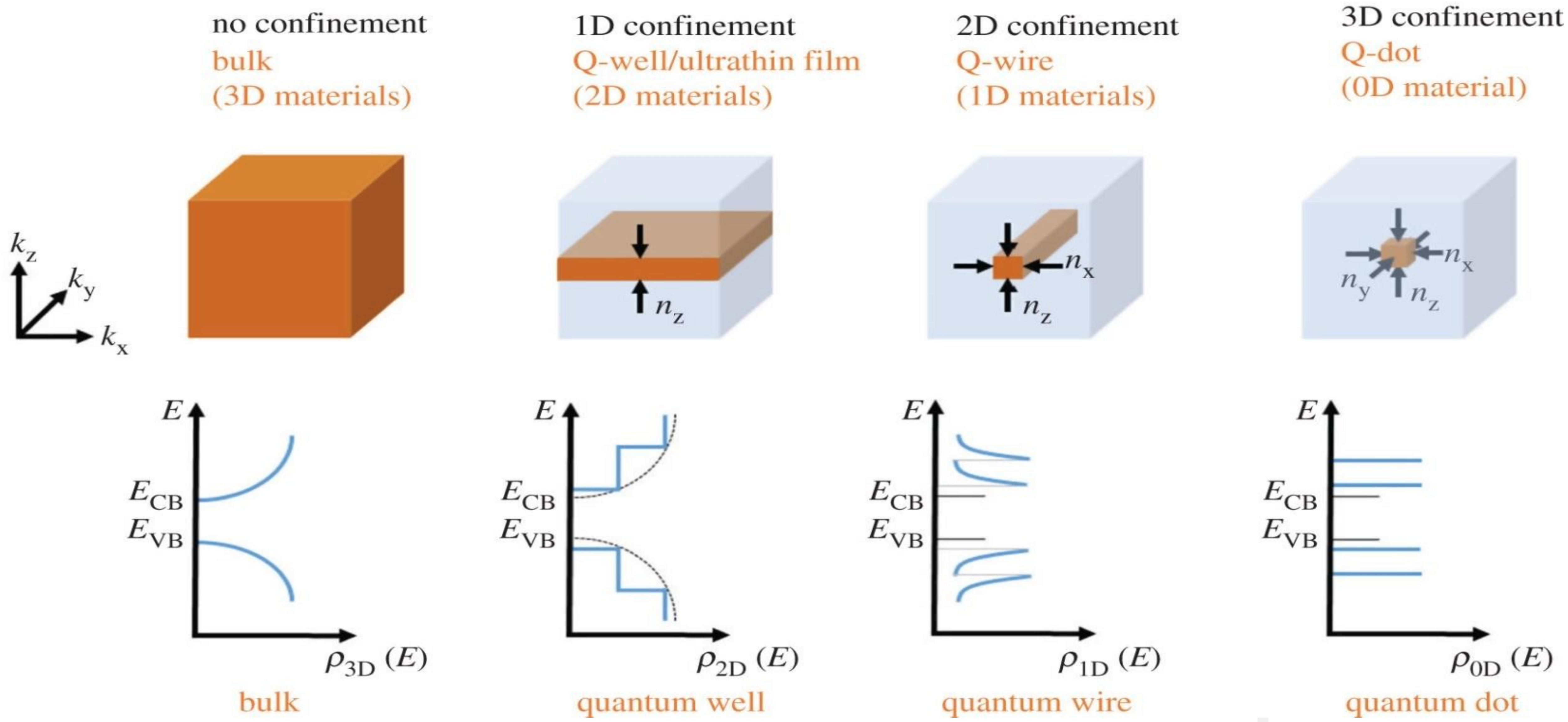


0-D:	All dimensions at the nanoscale
1-D:	Two dimensions at the nanoscale, one dimension at the macroscale
2-D:	One dimension at the nanoscale, two dimensions at the macroscale
3-D:	No dimensions at the nanoscale, all dimensions at the macroscale

Electron confinement and mobility

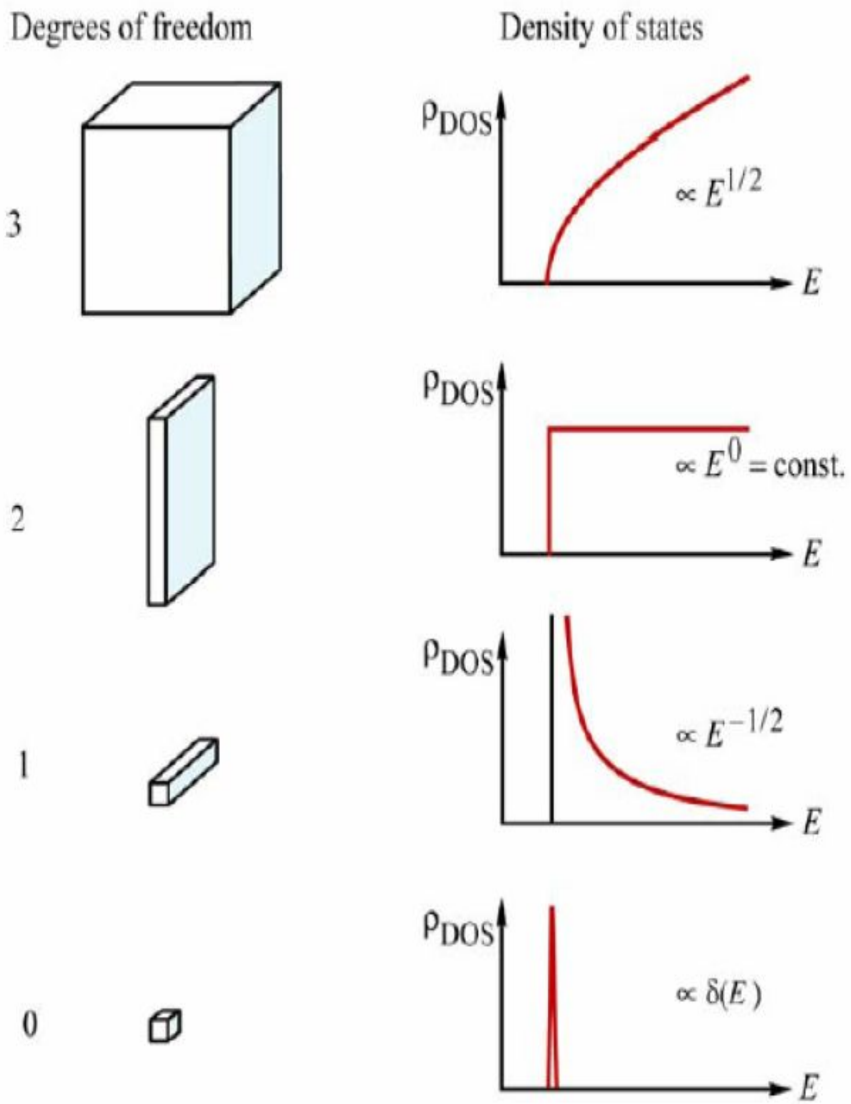
Material	Confinement	Mobility
	3	0
	2	1
	1	2

Density of states in different dimensions



Density of states in different dimensions

Degrees of freedom	Dispersion (kinetic energy)	Density of states	Effective density of states
3 (bulk)	$E = \frac{\hbar^2}{2m^*}(k_x^2 + k_y^2 + k_z^2)$	$\rho_{DOS}^{3D} = \frac{1}{2\pi^2}\left(\frac{2m^*}{\hbar^2}\right)^{\frac{3}{2}}\sqrt{E - E_C}$	$N_c^{3D} = \frac{1}{\sqrt{2}}\left(\frac{m^* kT}{\pi\hbar^2}\right)^{\frac{3}{2}}$
2 (slab)	$E = \frac{\hbar^2}{2m^*}(k_x^2 + k_y^2)$	$\rho_{DOS}^{2D} = \frac{m^*}{\pi\hbar^2}\sigma(E - E_C)$	$N_c^{2D} = \frac{m^*}{\pi\hbar^2}kT$
1 (wire)	$E = \frac{\hbar^2}{2m^*}(k_x^2)$	$\rho_{DOS}^{1D} = \frac{m^*}{\pi\hbar}\sqrt{\frac{m^*}{2(E - E_C)}}$	$N_c^{1D} = \sqrt{\frac{m^* kT}{2\pi\hbar^2}}$
0 (box)	–	$\rho_{DOS}^{0D} = 2\delta(E - E_C)$	$N_c^{0D} = 2$



5.6.2 Quantum Electronic Devices (QEDs)

The electronic devices that are capable to use these quantum phenomena are quantum electronic devices.

Classification of Quantum Devices:

1. Quasi-Equilibrium Devices
2. Far Form Equilibrium Devices

List of QEDs:

1. Quantum Dot Transistor
2. Quantum LASER
3. Quantum Wires
4. SQUID
5. Quantum Computers

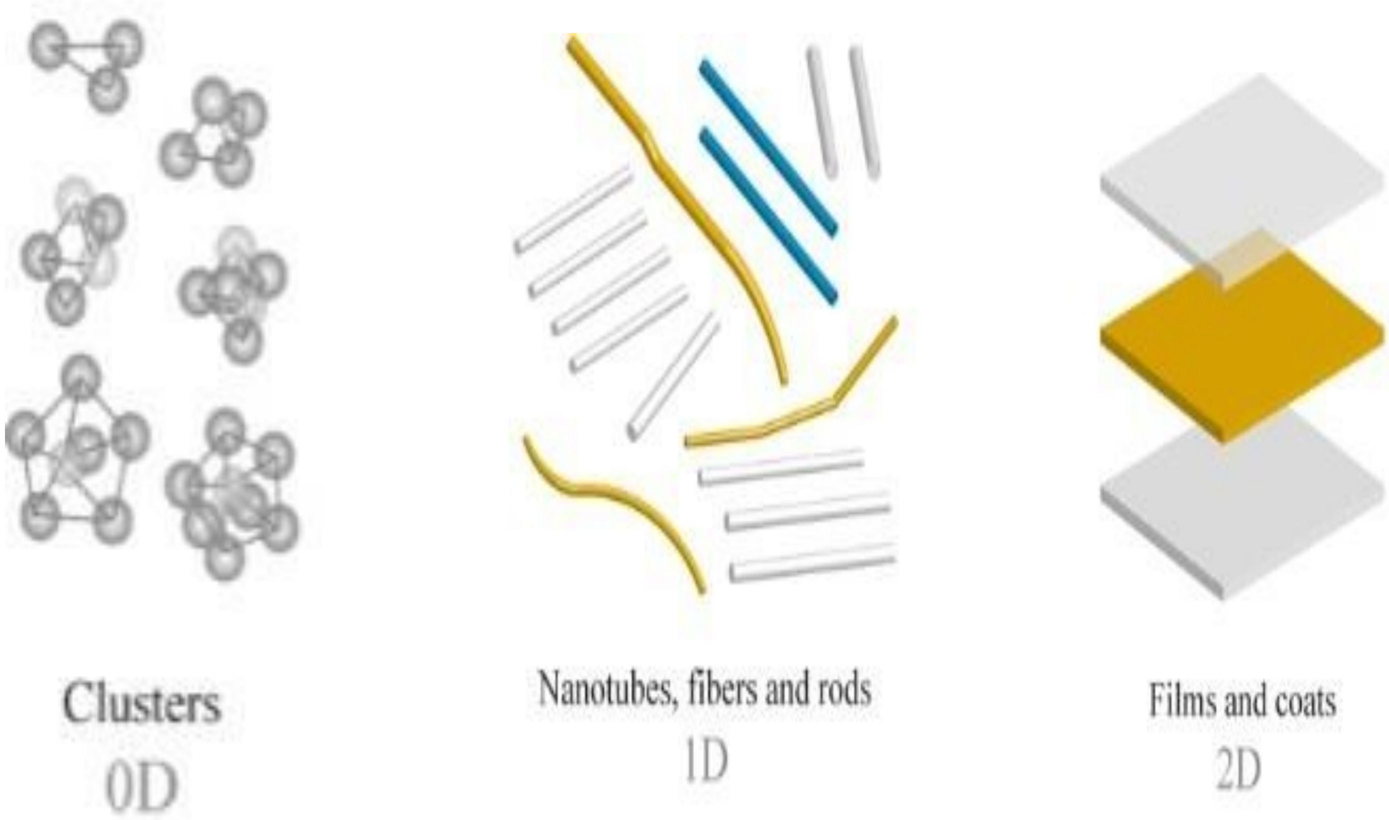


Fig-5.6.2.2 QED in low dimensional form.

5.6.2 Quantum Electronic Devices (QEDs)

Quantum Dot Transistor:

It's also called the Single Electron Transistor.

Its main advantage it is that has a high device integration level and ultra-low power consumption.

In this, we use the Coulomb Blockade phenomenon.

Quantum LASERS:

This type of SC LASERS generally used Quantum Dots and Quantum Wells as an active laser medium-sized for the emission of light.

It works in optical data transmission and metro access systems.

High operation rate.

5.6.2 Quantum Electronic Devices (QEDs)

Quantum Wires:

An electrical conducting wire in which quantum effects are used to explain the transport properties. These are known as Nano Wires.

These have high potential in density data storage.

SQUIDs:

It stands for "Superconducting Quantum Interface Devices".

It is a very sensitive magnetometer used to measure extremely subtle magnetic fields based on superconducting loops containing junctions.

Also used in cardiology for Magnetic field imaging (MFI).

5.6.2 Quantum Electronic Devices (QEDs)

Quantum Computers:

A quantum computer is device for computation that makes direct use of the distinctively quantum mechanical phenomenon.

It plays a vital role in quantum computing by using Q-bits.

It could handle problems more effectively than a classical computer using the SHORs algorithm.

Application QEDs:

1. Quantum computing
2. Cryptography
3. Imaging
4. Sensing
5. Metrology

5.6.2 Quantum Electronic Devices (QEDs)

Advantages:

1. Higher performance.
2. Avoid experimental and uncertainty measurement errors.
3. Reduces the number of experimental iterations.
4. Solves higher integration density problems.
5. Improves performance and functionality of ICs.

Limitations:

1. Conventional electronic circuit architecture may not work.
2. Need new fabrication technologies.
3. Order of magnitude of circuit integration beyond the present scale.

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Video Lectures

1. Online course: “Quantum electronic devices simulation” by K Thyagarajan on NPTEL.
2. Online course: “Semiconductor Optoelectronics” by M R Shenoy on NPTEL.
3. Online course: "Optoelectronic Materials and Devices" by Monica Katiyar and Deepak Gupta on NPTEL.

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