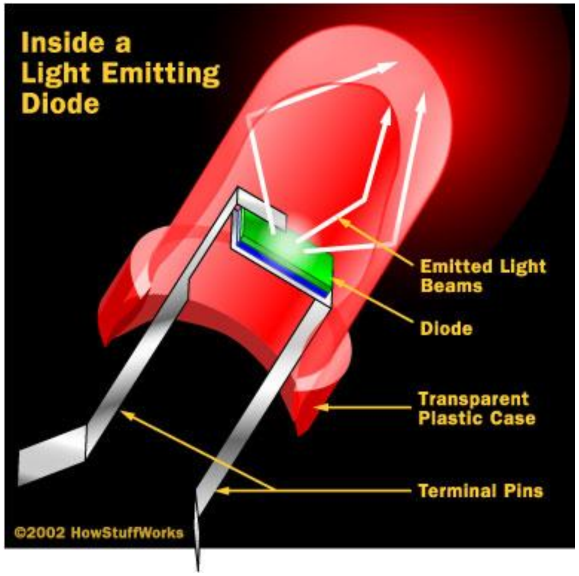
# Engineering Physics

(PHY1701)

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# Module-7: Optoelectronic Devices & Applications of Optical fibers

## *Contents*

- Introduction to Semiconductors,
- Sources-LED & Laser Diode,
- Detectors, Photodetectors- PN & PIN (AG 209, 235, 238),
- Applications of fiber optics in communication, and
- Endoscopy*

***: Self Study**

❖ Introduction to Fiber Optics, Ajoy Ghatak and K. Thyagarajan, Cambridge University Press, 2010 (AG)

# Responsivity (R) and Quantum efficiency (η)

- The ratio of the number of produced electrons, $N_e$, to the number of falling photons, $N_p$, shows how efficiently the semiconductor material converts light into current. This ratio is called the *quantum efficiency*, η, of a photodiode.

$$\therefore \qquad \eta = \left(\frac{N_e}{N_p}\right)$$

- The quantum efficiency of a regular photodiode ranges from 50% to almost 100%.

- The input for a photodiode is a light power (P). The output is current, which is usually called photocurrent ($I_p$) because it is caused by light.

$$\therefore \qquad I_p \propto P$$

$$\therefore \qquad I_p = RP$$

where 'R' is a constant, called *responsivity*, measured in A/W.

# Responsivity (R) and Quantum efficiency (η)



- We know that photocurrent is the number of electrons ($N_e$) times the electron charge (e) per unit time.

$$\therefore \qquad \mathrm{I_p} = (\mathrm{e.N_e})/\mathrm{t}$$

where $N_e$ represents the no. of electrons generated and e, the electronic charge.

- On the other hand, light power is light energy per unit of time, where light energy is equal to the energy of the photon ($E_p$) times the number of the photons ($N_p$).

$$\therefore \qquad \mathrm{P} = \left(\mathrm{N_p E_p}\right)/\mathrm{t}$$

- Substituting $\mathrm{E}_p = \left(\frac{hc}{\lambda}\right)$ and dividing $I_p$ by P, we have,

$$R = \frac{\mathrm{I_p}}{\mathrm{P}} = \left(\frac{\mathrm{N_e}}{\mathrm{N_p}}\right)\left(\frac{\mathrm{e}\lambda}{\mathrm{hc}}\right)$$

$$\therefore \qquad \mathrm{R} = \eta\left(\frac{\mathrm{e}\lambda}{\mathrm{hc}}\right)$$

This eq. connects responsivity and quantum efficiency of a photodiode.

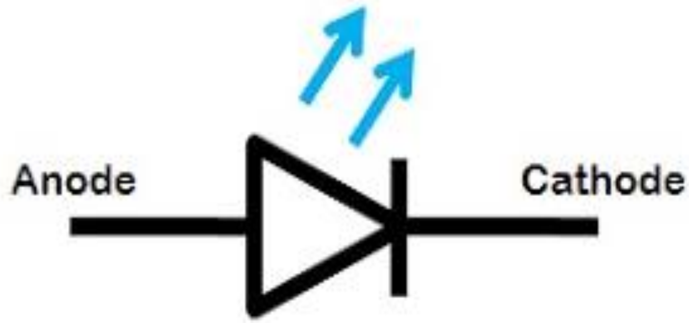
# Light Emitting Diode (LED)



- A light-emitting diode is a two-lead semiconductor light source. It is a p–n junction diode that emits light when activated.
- When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons.
- The color of the light (corresponding to the energy of the photons) is determined by the energy required for electrons to cross the band gap of the semiconductor. White light is obtained by using multiple semiconductors or a layer of light-emitting phosphor on the semiconductor device.
- They come in diverse colors and some LEDs even contain multiple elements and are therefore capable of emitting light with different colors.

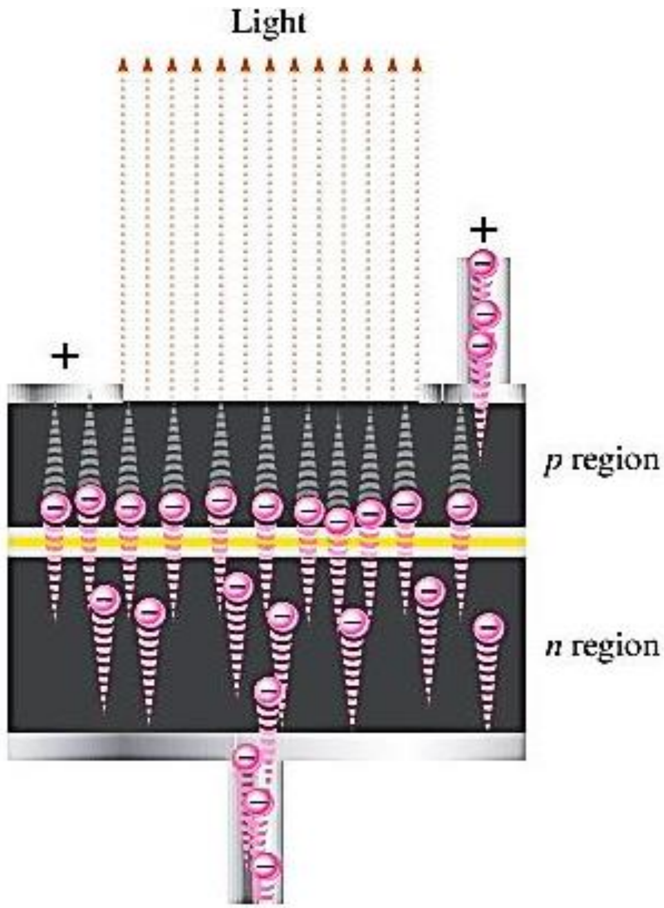
# Symbol and Principle of LED

## LED symbol




- LED (light emitting diode) is an optoelectronic device which works on the principle of electro luminance. Electro luminance is the property of the material to convert electrical energy into light energy and later it radiates this light energy. In the same way, the semiconductor in LED emits light under the influence of electric field.

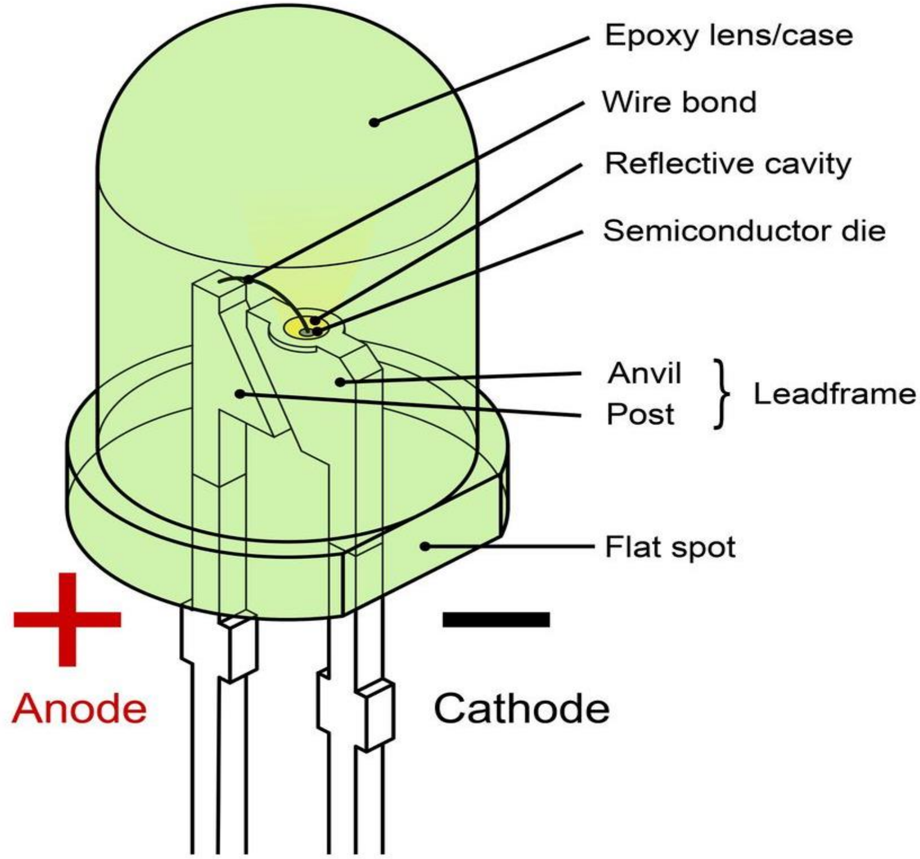
## Electroluminescence in a forward biased LED




- The symbol of LED is formed by merging the symbol of p n.

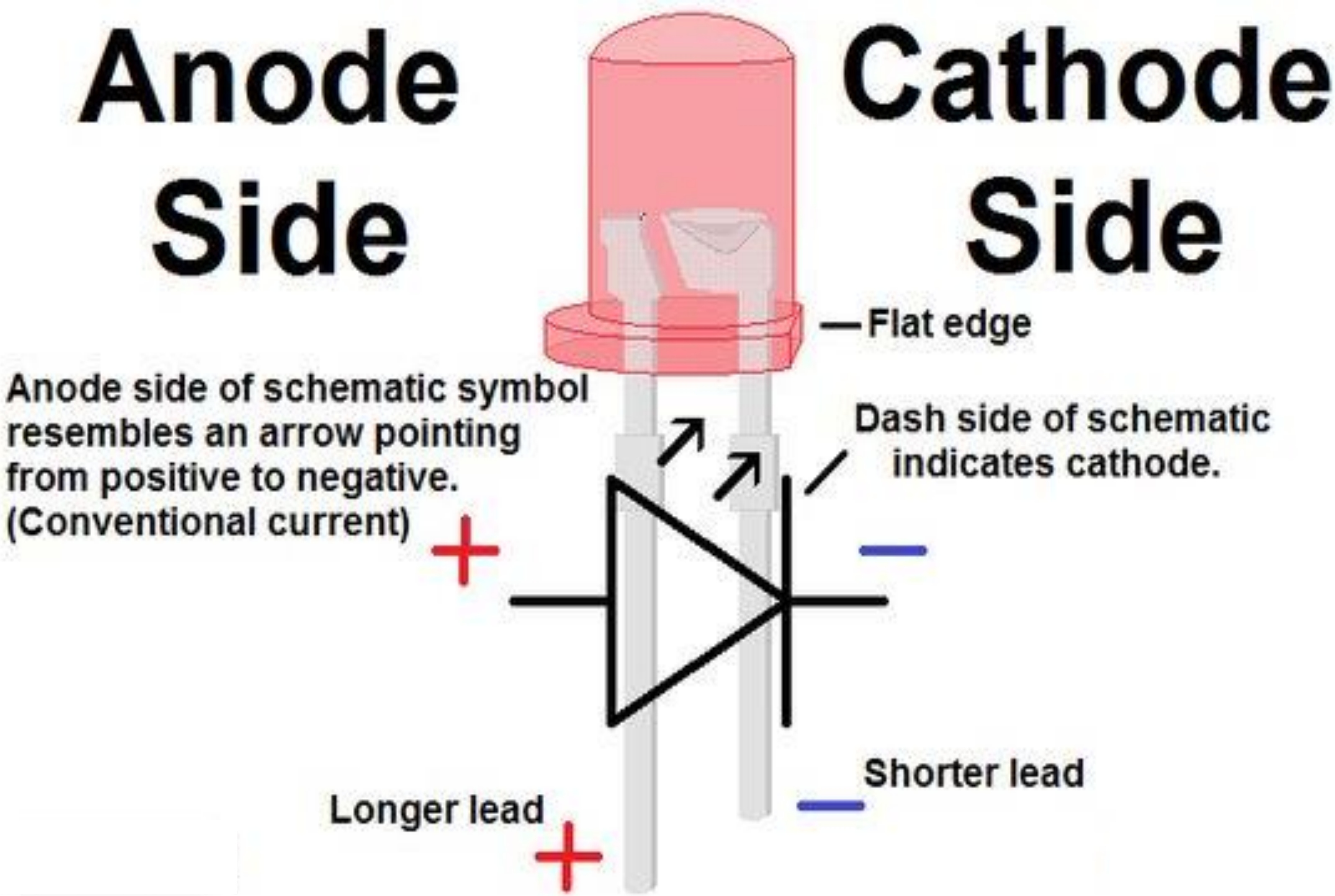
# Construction of LED

- The LED consists of a chip of semiconductor material doped with impurities to create a PN junction.
- The chips are mounted in a reflecting tray order to increase the light output.
- The contacts are made on the cathode side by means of conductive adhesive and on the anode side via gold wire to the lead frame.
- The plastic case encloses the chip area of the lead frame.



# Construction of LED





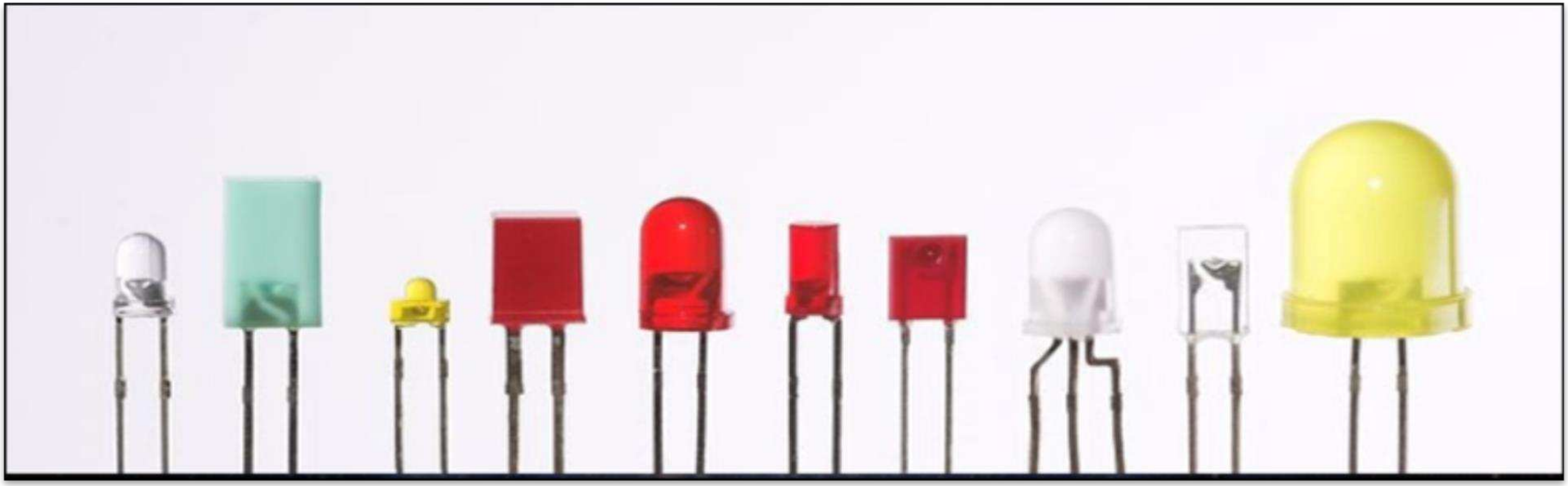
# Main LED materials

- The main semiconductor materials used to manufacture LEDs are:
  - Indium gallium nitride (InGaN): blue, green and ultraviolet high-brightness LEDs.
  - Aluminum gallium indium phosphide (AlGaInP): yellow, orange and red high-brightness LEDs.
  - Aluminum gallium arsenide (AlGaAs): red and infrared LEDs.
  - Gallium phosphide (GaP): yellow and green LEDs.

# LED TYPES



- LEDs are produced in a variety of shapes and sizes. The color of the plastic lens is often the same as the actual color of light emitted.
- purple plastic is often used for infrared LEDs.
- most blue devices have colorless housings.
- Modern high power LEDs such as those used for lighting and backlighting are generally found in surface-mount technology.



# LED BENIFITS

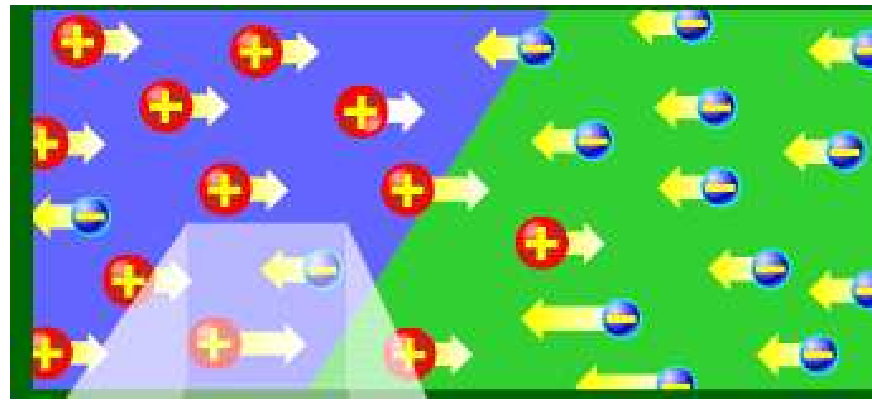


- Efficiency: LEDs emit more light than incandescent light bulbs. The Efficiency of LED lighting is not affected by shape and size, unlike fluorescent light bulbs or tubes.
- Color: LEDs can emit light of an intended color without using any color filters as traditional lighting methods need. This is more efficient and can lower initial costs.
- Size: LEDs can be very small (smaller than 2mm and are easily attached to printed circuit boards.
- On/Off time: LEDs light up very quickly. LEDs used in communications devices can have even faster response times.
- Cycling: LEDs are ideal for uses subject to frequent on-off cycling, unlike fluorescent lamps that fail faster when cycled often.
- Slow failure: LEDs mostly fail by dimming over time, rather than the abrupt failure of incandescent bulbs.
- Lifetime: LEDs can have a relatively long useful life.

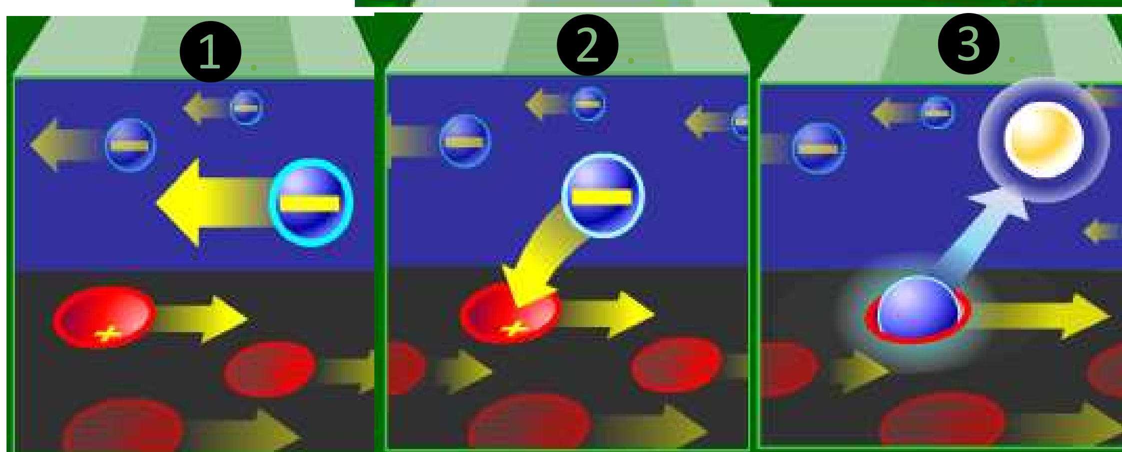
# WORKING

① When current flows across a diode. Negative electrons move one way and positive holes move the other way

② The wholes exist at a lower energy level than the free electrons. Therefore when a free electrons falls it losses energy



③ This energy is emitted in a form of a photon, which causes light. The color of the light is determined by the fall of the electron and hence energy level of the photon.

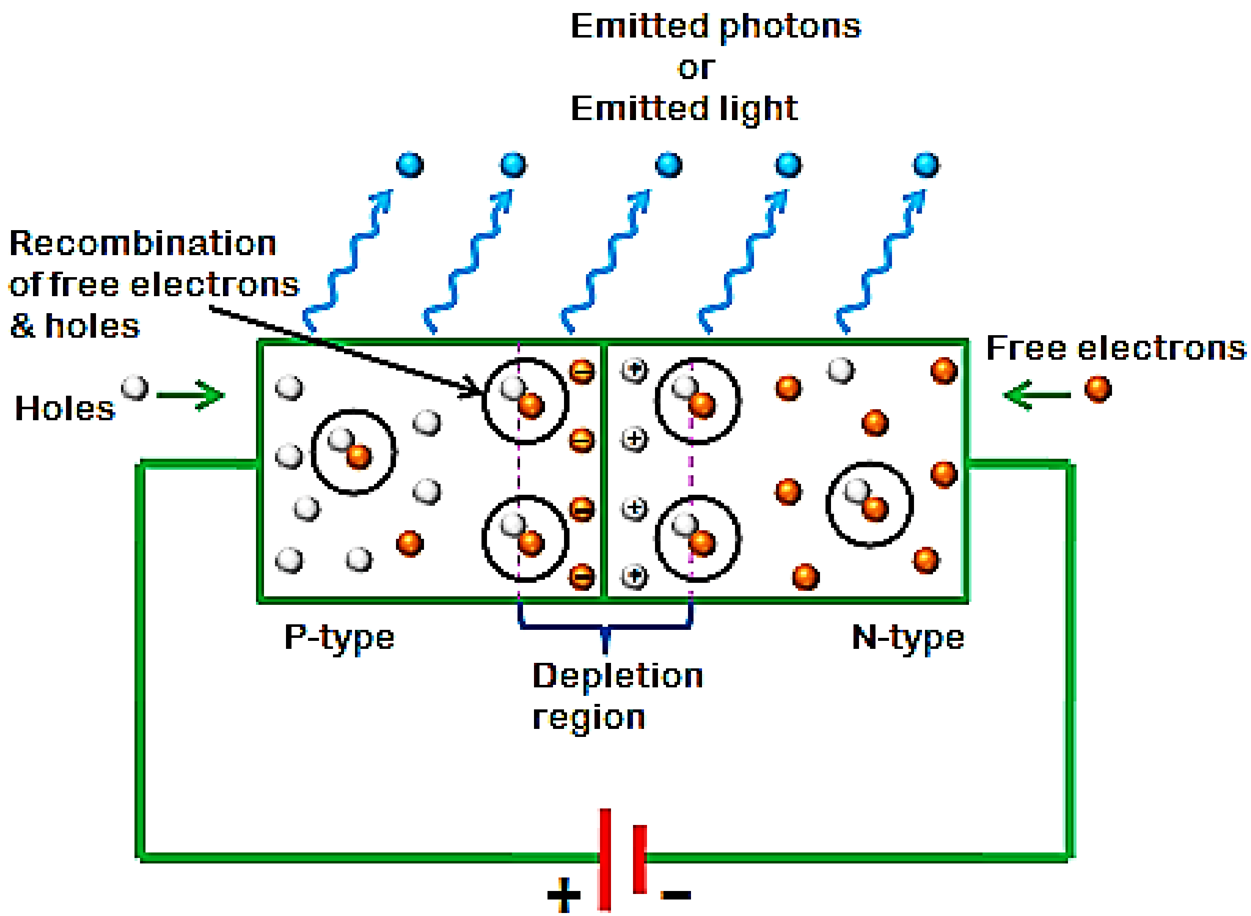


# WORKING



- When LED is forward biased as shown in figure, the electrons from the n-type material cross the pn junction and recombine with holes in the p-type material.

- Recall that these free electrons are in the conduction band and at the higher energy level than the holes in the valence band.



# WORKING

- When recombination takes place, the recombining electrons release energy in the form of heat and light.
- In germanium and silicon diodes, almost the entire energy is given up in the form of heat and emitted light is insignificant.
- However, in materials like gallium arsenide, the number of photons of light energy is sufficient to produce quite intense visible light.

# ADVANTAGES

- Energy efficient (produce more light per watt)
- Long lifetime (60,000 Hours or more)
- Rugged (made-up of solid material, no breakage like filament)
- No warm-up period (achieve full bright light in nanoseconds)
- Not effected by cold temperature (used in sub zero weather)
- Directional (direct the light where you want)
- Environment Friendly (contains no mercury)
- Controllable (brightness and color can be controlled)
- Can sustain over frequent on-off cycle

# DISADVANTAGES

- Very expensive than other lighting technologies
- Requires accurate voltage & constant current flow
- Can shift colour due to age & temperature
- Cannot be used in high temperature(Lead to device failure)

# APPLICATIONS

- Vehicle indicator lights and brake lights.
- Currently Audi & BMW integrate high power LEDs.
- Mobile phone flash lights.(Surface Mount Diode)
- LED screens for advertising & information.
- Due to low power consumption, small size & long life LEDs are used in many electrical equipments.(indicator)
- Now a days airports, hotels, subways, shopping centers and some homes feature LEDs.
- LED based traffic signal has been successful & is also growing rapidly