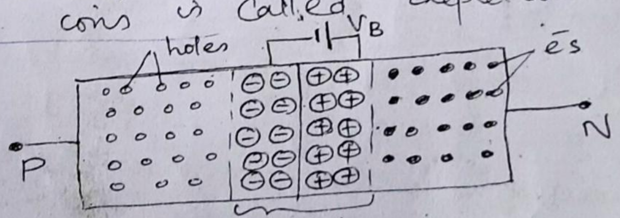
p-n Junction diode

A semiconductor having p-type impurity at one end and n-type impurity at the other end — PN junction diode. The junction, at which p-type and n-type semiconductors combine is called PN junction. (Semiconductor diode is basically a p-n junction provided with metallic contacts at the p & n ends)

Two important processes occur during the formation of p-n junction (i) Diffusion. (ii) Drift.

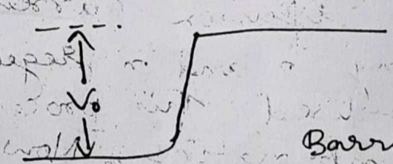
(i) **Diffusion** In n-type S.C, the concentration of ē's is much greater than that of holes, while in p-type, the concentration of holes is much greater than ē's. When a p-n junction is formed, due to this concentration gradient, holes diffuse from p-region to n-region and ē's diffuse from n region to p-region across the junction giving rise to diffusion current. The ē's and holes reaching p and n regions recombine and get neutralised. This process is called ē-hole recombination. Now the p-region near the junction is left with immobile -ve ions and n-region is left with +ve ions as shown in fig (i). The small region near the junction (of the order of μm) which is depleted of free charge carries and has only immobile ions is called depletion ~~region~~ layer.



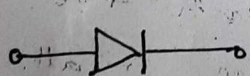
depleated of free charge carries & has only immobile ions.

The accumulation of negative charges in the p-region and +ve charges in the n-region across the junction sets up a potential difference which is called barrier potential (V_B).

Drift: Due to the built in barrier potential developed across the junction, an e^- on p-side of the junction moves to the n-side and a hole on the n-side moves to p-side. This motion of charge carriers due to the electric field is called drift due to which drift current flows opposite to direction of diffusion current. These processes continues until diffusion current equals drift current. Thus in a p-n junction, at equilibrium there is no net current. The polarity of the potential difference across the junction is such as to oppose further flow of carriers in the unbiased state – hence known as barrier potential.



Barrier potential under no bias.

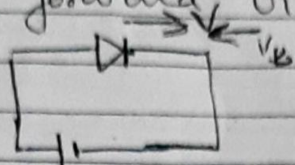


Symbol

[At the initial stage, the diffusion current is large but drift current is small. As the diffusion continues, the space charge regions on both sides of the junction increases & expands due to which, electric field increases and hence drift current also increases. This process continues until diffusion & drift current become equal]. * The movement of e^-s from n-region to p-region creates a p.d. across the junction & the polarity of this potential prevents further flow of charge carriers & equilibrium sustains.

Semi Conductor Devices

Forward biasing: positive terminal of the battery connected to p-side and negative terminal connected to n-side — pn junction is said to be forward biased.



forward biasing.

(i) the effective barrier potential $(V_B - V)$ decreases as they are opposite, as shown in fig.

(ii) majority charge carriers ie holes from p-side and ē's from n-side begin to flow towards the junction depending on the applied voltage. The barrier height will decrease as the applied voltage is increased significantly & hence current also will increase. In this process, actually holes reach the n-side, where they are minority carriers & ē's reach p-side & hence known as minority carrier injection. Due to this, charge carriers accumulate at the junction giving rise to concentration gradient which will make the charge carriers diffuse across the junction easily. This gives rise to current in forward bias (of the order of mA) – sum of hole current and ē current.

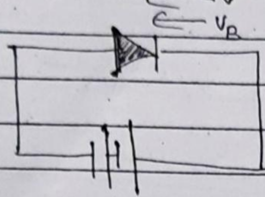
(iii) Width of depletion layer decreases due to diffusion of charge carriers.

(iv) Effective resistance decreases.

(v) When V exceeds V_B – majority charge carriers flow easily across the junction ie forward current increases with increase in applied voltage.

Reverse Biasing: +ve terminal of the battery connected to n-side and -ve side of battery connected to p-side of diode — reverse biased p n junction.

(i) Here the applied voltage (V) favours barrier potential V_B as they are in same direction. Due to this majority charge carriers are pushed away from the junction. effective barrier potential is $V_B + V$.



(ii) width of the depletion layer increases. But a very small reverse current of the order of μA flows across the junction. This is due to the thermal agitation some of the covalent bonds break releasing a few holes in n-region & few e's in the p-region where they are minority charge carriers. This is known as reverse leakage current. A small applied voltage is sufficient to sweep the minority carriers through the junction — so reverse current is almost independent of applied voltage.

(iii) The resistance of the p-n junction is very large

(iv) no current flows across the junction due to majority carriers.

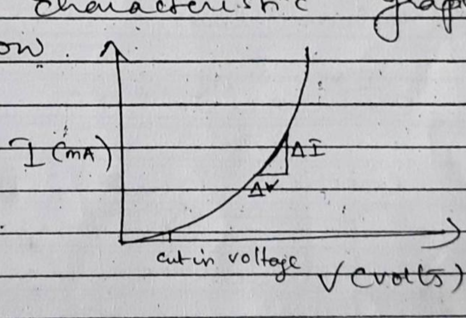
V-I Characteristic

– A graph showing the variation of current flowing thru' a p-n junction with the voltage applied across it – V-I characteristic.

(i) Forward bias characteristic –

Experimental arrangement to study forward characteristic is as shown in the fig

The arrangement is such that the voltage across the p-n junction can be varied. For different values of voltages, the values of current is noted. The forward characteristic graph is as shown below.



(i) Initially, the current increases slowly, till the voltage across the diode reaches a certain value – known as threshold voltage or cut in voltage. (It is 0.2 V for Ge diode & 0.7V for Si diode).
Before this, the depletion layer plays a dominant role in controlling the motion

of charge carriers.

(ii) After the threshold voltage, diode current increases exponentially, even for a small increase in the bias voltage. Resistance across the junction is negligible.

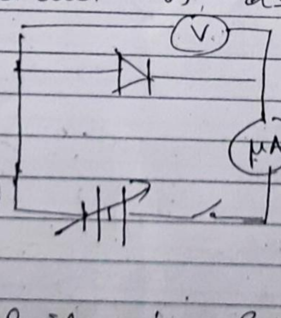
(iii) Current - voltage relation is non - linear. The resistance of the junction varies with applied voltage. The ratio of small change in applied voltage to the corresponding change in current is called dynamic or ac resistance.

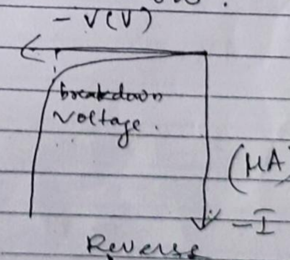
$$r_d = \frac{\Delta V}{\Delta I}$$

Above threshold voltage, r_d is almost independent of V and ohm's law is roughly obeyed.

Reverse characteristic

The circuit is as shown below.





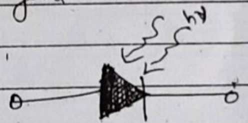
Reverse characteristic graph.

(i). When the diode is reverse biased, the applied voltage produces a small current due to leakage of minority carriers across the junction — known as reverse saturation current. It is almost independent of applied voltage.

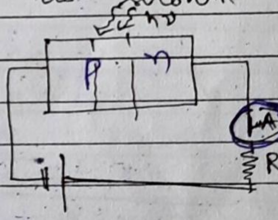
(ii) when the reverse voltage reaches sufficiently high value, the reverse current suddenly increases to a large value. This value of applied voltage at which breakdown of the junction happens is called Zener breakdown voltage or peak inverse voltage. This breakdown is also known as Avalanche Breakdown. This is due to the fact, the covalent bonds near the junction break down releasing free $\bar{e}$s and holes. These $\bar{e}$s and holes gain sufficient energy & break other bonds resulting in a large current increasing rapidly to high value.

Special purpose junction diodes

(i) Photodiode: A photodiode is fabricated using photosensitive semiconducting material & with a transparent window to allow light to fall on the junction.



The circuit arrangement is as shown below.



A series resistance R is connected with a rev. biased photodiode.
The voltage is kept slightly less than the breakdown voltage. When no light is incident on the junction, a small rev. current flows which are due to thermally agitated $\bar{e}$-hole pairs hence known as dark current. When light of frequency ν is incident on the junction such that the energy of photons ($h\nu$)

is sufficiently greater than the Bandgap E_g of the semiconductor, ∴ additional $\bar{e}$-hole pairs are created. These photo generated charge carriers increase the conductivity. Larger the intensity of incident light, larger would be the increase in the conductivity of the semiconductor. The graph showing V-I characteristic of a photo diode illuminated with light of different intensities is shown below.

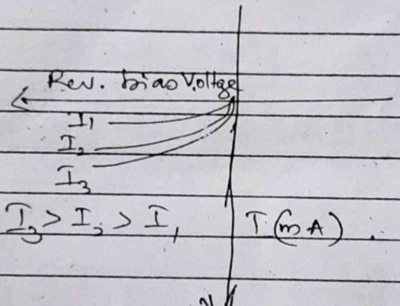


photo diode is always operated in reverse bias - this is due to the fact - that it is easier to observe the change in current with change in intensity of light when it is reverse biased.

Consider the case of n-type semiconductor, where $n >> p$.
On illumination, the no. of both type of carriers would equally increase,

$$n' = n + \Delta n \quad \text{and} \quad p' = p + \Delta p.$$

But $\Delta n = \Delta p$

Hence fractional change in majority carrier

$$\frac{\Delta n}{n} << \frac{\Delta p}{p}$$ ~~(fractional change in minority carrier)~~

Fractional change due to photoeffects on minority carriers dominated reverse current is more easily measurable than majority carrier dominated forward current. Hence photodiodes are always operated in Rev. bias.

* Used in detection of optical signals.
* demodulation of optical signal.
* light operated switches / photodetectors.

LED (light Emitting diode)

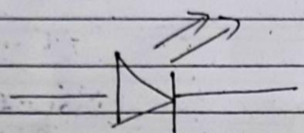
heavily doped It is a forward biased p-n junction which spontaneously converts the biasing energy into optical energy like infrared, visible etc.

~~Materials~~ Translucent semi conductor materials like GaAs or Indium phosphide are usually used for fabrication of LEDs.

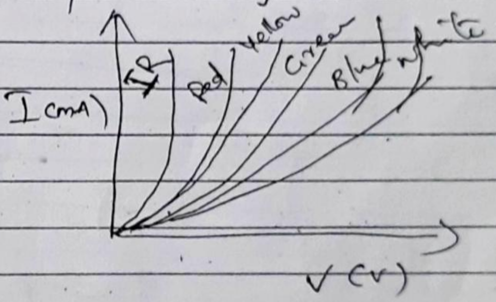
when it is forward biased thru' a series resistance R, light photons are emitted. when a diode is forward biased, e's from n-side ~~move to p-side~~ and holes from p-side moves to n-side where they recombine with holes and e's respectively. On recombination, energy is released in the form of photons. photons with energy slightly less than the band gap are emitted. As the forward current increases, the light intensity also increases and reaches a max. Further increase in the current would actually lower the intensity of light & hence LEDs are appropriately biased to emit max. intensity.

* V-I characteristics of LEDs is similar to a p-n junction diode but the threshold voltages are higher & slightly diff. for diff. colours.
* Reverse break down voltage for LED is v. low, so care should be taken that high reverse voltage do not appear across them.
* LEDs can emit red, yellow, orange, green & blue light.
* Band gap is ~ 1.8eV.

Advantages
(i) Low operational voltage.
(ii) Fast action & no warm up time.
(iii) It is light emitted nearly monochromatic.
(iv) Long life and ruggedness.
(v) fast on-off switching capability.



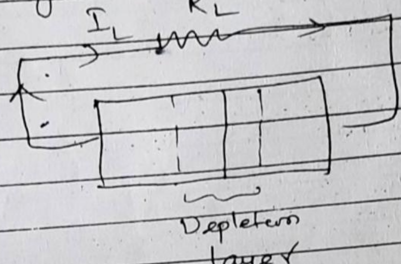
Symbol.

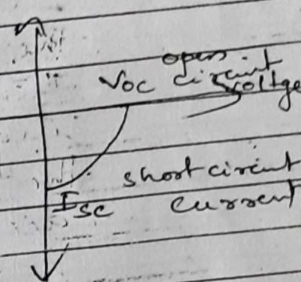


SOLAR Cell : It is a junction diode which converts light energy into electrical energy based on photo voltaic effect. The surface layer of p-region is made very thin so that incident photons may easily penetrate to reach the junction which is the active region. The material for fabrication of solar cells (GaAs), (CdS) and (CdSe). The top of p-region is provided with few finger electrodes

The bottom of the n-layer is provided with a current collecting electrode. (Refer Text for fig.)

Working: When light photons of energy greater than Band gap ($h\nu > E_g$) reach the junction, they excite ēs from valence band to conduction band. These ē-hole pairs created in the depletion layer move in opposite directions due to barrier field i.e. ēs move towards n-side and holes towards p-side where they are collected. The collection of these charges makes p-side +ve and n-side negative which sets up a photo voltage. When a load resistance R_L is connected in the external circuit, a photo current I_L flows. This current is proportional to intensity of illumination.





V-I characteristic of a solar cell.

V_{oc} — depends on illumination or intensity of light

* Semiconductors of band gap ~ 1.5 eV is ideal for making solar cells.

Criteria for choosing the materials

* Band gap (~ 1.0 eV to 1.8 eV)
* high optical absorption
* elec. conductivity
* Availability of raw material and cost.

(i) Used to power electronic devices in satellites & space vehicles

(ii) Power supply to calculators, digital appliances, house domestic & commercial purposes.

* V-I characteristics drawn in fourth quandrant because a solar cell does not draw current ~~from~~ but delivers to the load.

Zener diode : Th

Diode as a Rectifier (AC to DC)

The process of converting alternating current into direct current is called Rectification and the device used for this purpose is called Rectifier.

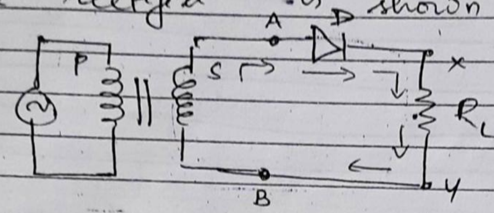
Principle of a Rectifier

* A p-n junction diode conducts when it is forward biased and does not conduct or offer high resistance when it is revers

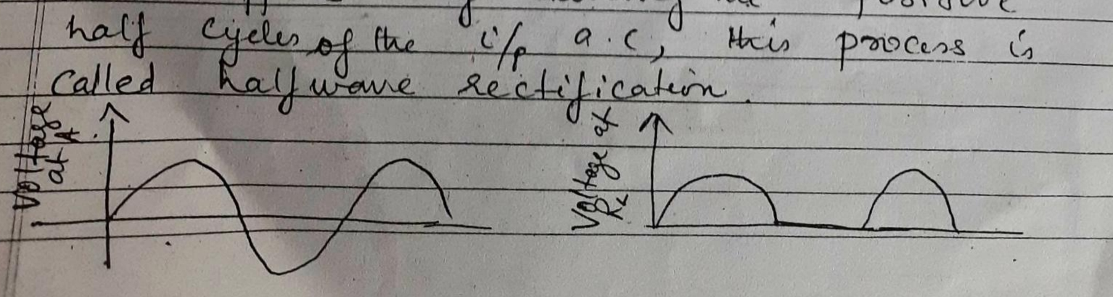
biased.

* This unidirectional property is utilised as the principle of rectifier using diodes.
* A p-n junction can be used as
(i) half wave rectifier
(ii) Full wave rectifier.

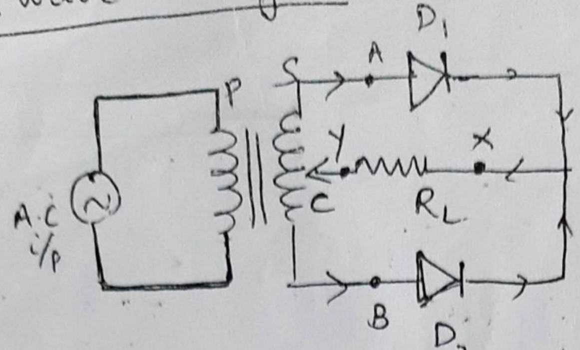
Halfwave Rectifier: The circuit diagram for a halfwave rectifier is shown below.



Working: when a.c. is supplied to the primary, the secondary of the transformer supplies desired alternating voltage across A and B. During +ve half cycle of the a.c, the end A is +ve & end B is −ve ∴ The diode D is forward biased and current I flows in the circuit thru' R_L as shown in the fig. As the i/p ~~current~~ voltage increases or decreases the current also increases or decreases & so does the o/p voltage ($= IR_L$) across the Load. While during −ve half cycle, the end A is −ve & B is +ve & hence the diode does not conduct during −ve half cycles of the a.c as it is reverse biased. The i/p and o/p wave forms are shown below. Since the voltage across the load appears only during the positive half cycles of the i/p a.c, this process is called halfwave rectification.



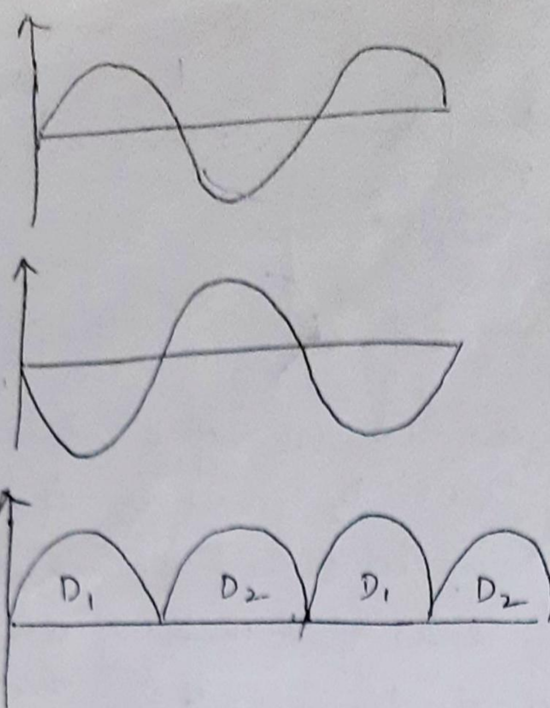
Full wave Rectifier



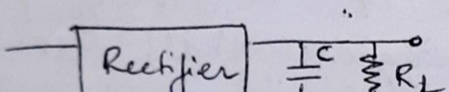
A full wave rectifier consists of a transformer, 2 junction diodes D_1 and D_2 and a load resistance R_L. The i/p signal is fed to the primary 'P' of the transformer, the 2 ends of secondary are connected to the p-ends of diodes D_1 and D_2. The secondary is tapped at its central point 'C' which is connected to the n-ends of the diodes through load resistance R_L as shown in fig.

working: At any instant, the voltages at end A and end B of the secondary with respect to the centre tap C will be out of phase with each other. During +ve half cycle of a.c, end A is +ve & end B is −ve w.r.t centre tap C. So D_1 is forward biased and D_2 is reverse biased and hence D_1 conducts and D_2 does not conduct. During −ve half cycle, reverse happens, ie D_1 does not conduct and D_2 conducts. In both cases, current flows in the same direction along R_L from X to Y. As a result, we get a pulsating d.c. The i/p and o/p wave forms are shown below.

The o/p obtained from a diode rectifier is unidirectional but pulsating. Such a signal can be considered as the sum of a d.c. signal superimposed with many a.c. signal of different harmonic frequencies. The a.c. components can be filtered out by simple filter circuits



Shunt Capacitor filter: fig shows the circuit of a full wave rectifier with a capacitor of capacitance C connected in parallel with its load resistance R_L.



The capacitor has a reactance of $X_C = \frac{1}{2\pi f C}$

A high capacitance C offers a low impedance path to high frequency a.c. component but high impedance to low frequency d.c. component. Hence a.c. component is bypassed thru' C or filtered. A smooth d.c voltage appears at the load resistance

[The fluctuating o/p can be smoothened by filtering thru' a filter circuit where a capacitor of high capacitance is connected across the o/p of rectifier. When voltage across 'C' rises, it gets charged. As there is a load resistor, it gets discharged thru' the load & the voltage begins to fall. During the next — half cycle of the rectified o/p it again gets charged to the peak value. Therefore, the rate of voltage across the capacitor depends on the inverse product of capacitance and effective resistance R_L used in the circuit known as time constant. To keep 't' large, C should be large.]