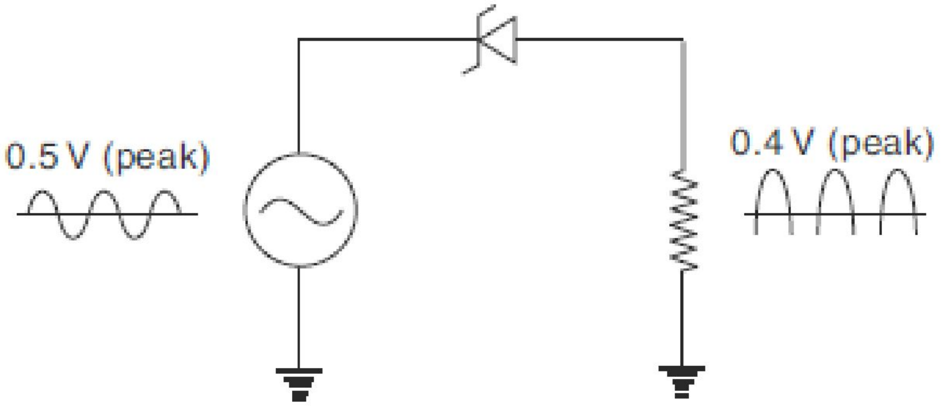
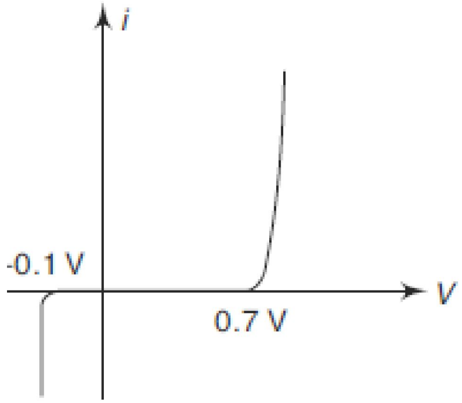
UNIT III
Special Diodes

Backward Diode

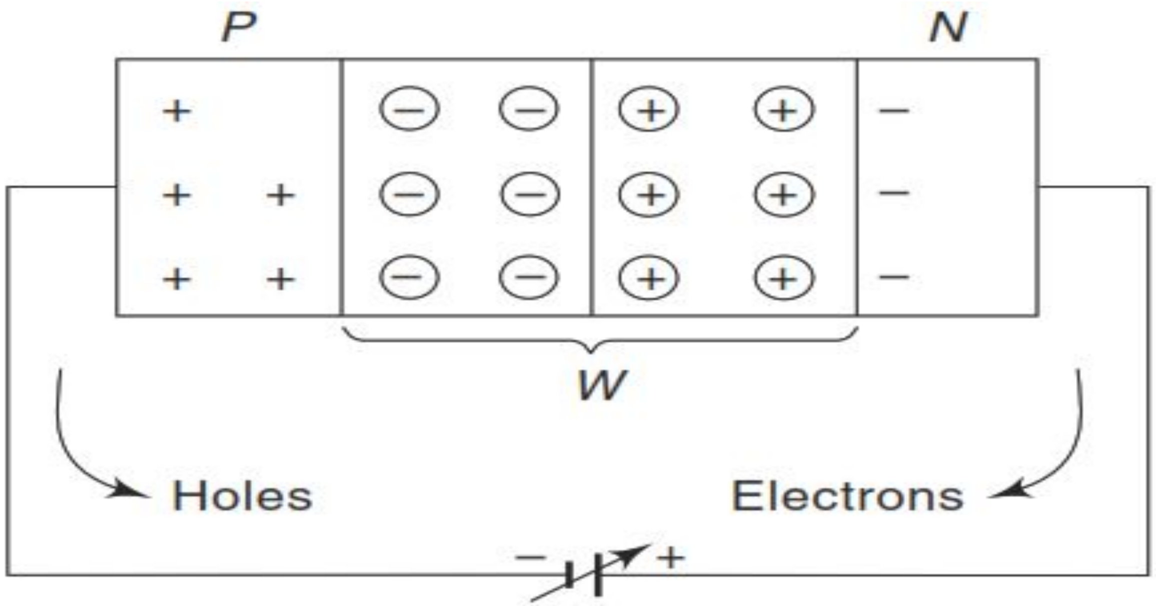
- Zener diode- Breakdown occurs at > -2V
- Zener effect under the reverse bias condition can also be obtained near zero (0.1V)
- Backward diode- Conducts better in reverse than in forward direction
- In fig below, sine wave with peak of 0.5V is given as input
- It is not enough for forward bias but enough for breakdown.
- Output- Rectified half wave signal at 0.4V
- It rectifies signals with peak amplitudes between 0.1 to 0.7V





Varactor Diode

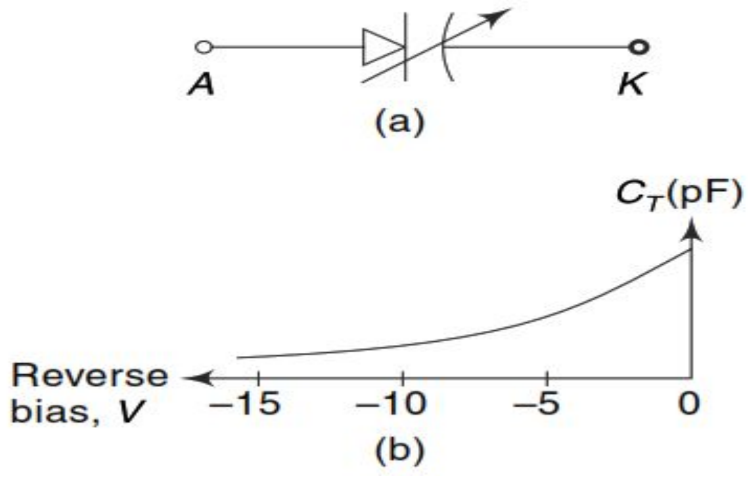
- The varactor, also called a varicap, tuning or voltage variable capacitor diode
- The useful PN property that its junction or transition capacitance is easily varied electronically



- The larger the reverse bias applied across the diode, the width of the depletion layer “W ” becomes wider.

- This depletion region is devoid of majority carriers Holes Electrons and acts like an insulator preventing conduction between N and P regions of the diode, just like a dielectric, which separates the two plates of a capacitor.
- As the capacitance is inversely proportional to the distance between the plates , the transition capacitance C_T varies inversely with the reverse voltage.

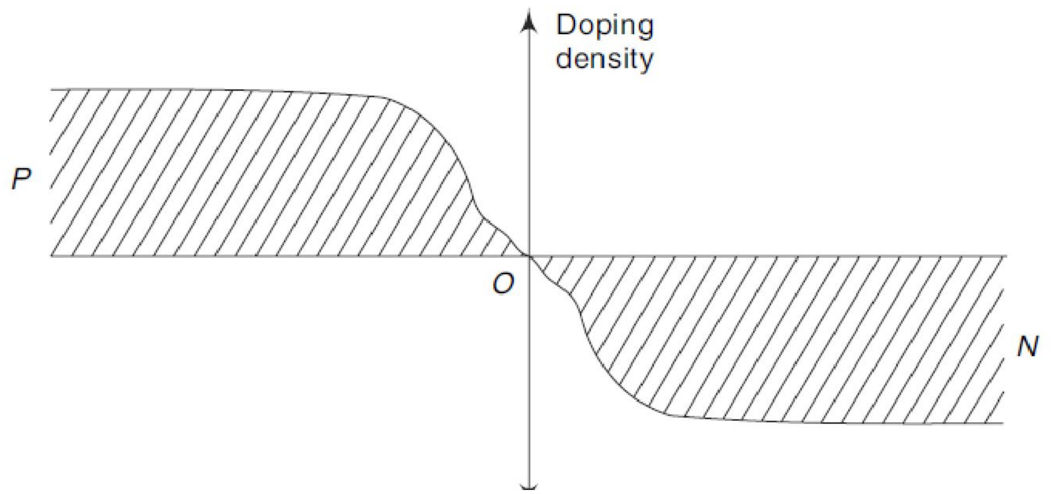
$$(C_T \propto 1/W).$$



- At zero volt, the varactor depletion region W is small and the capacitance is large at approximately

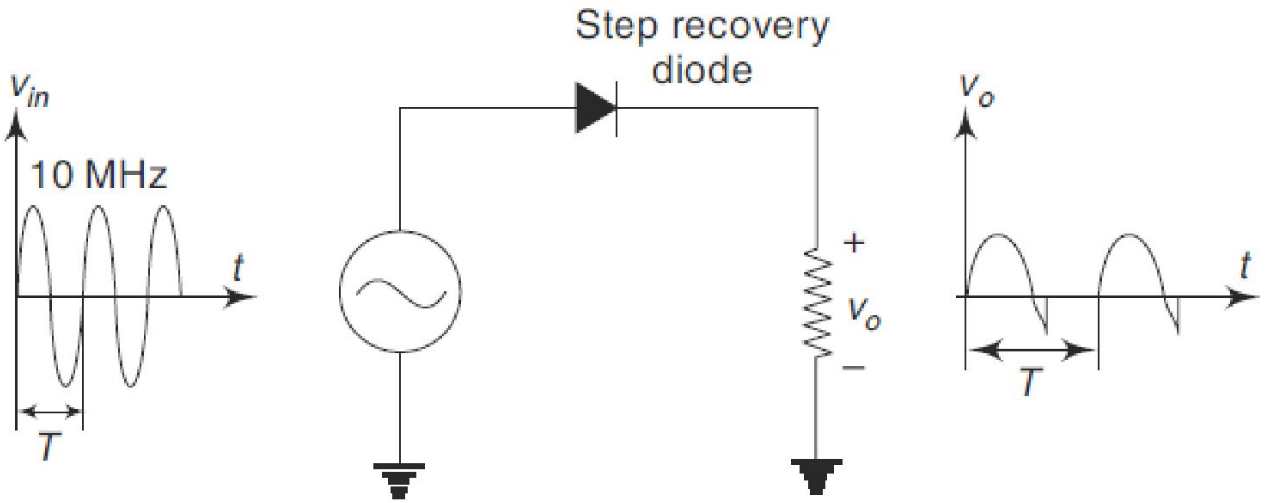
Step recovery Diode

- Also known as snap-off varactor
- Construction similar to varactor diode
- Has graded doping profile – density decreases near the junction
- Store charge in forward bias
- Low frequency- works as normal diode- recovers immediately from ON to OFF state.
- High frequency signal- does not recover immediately



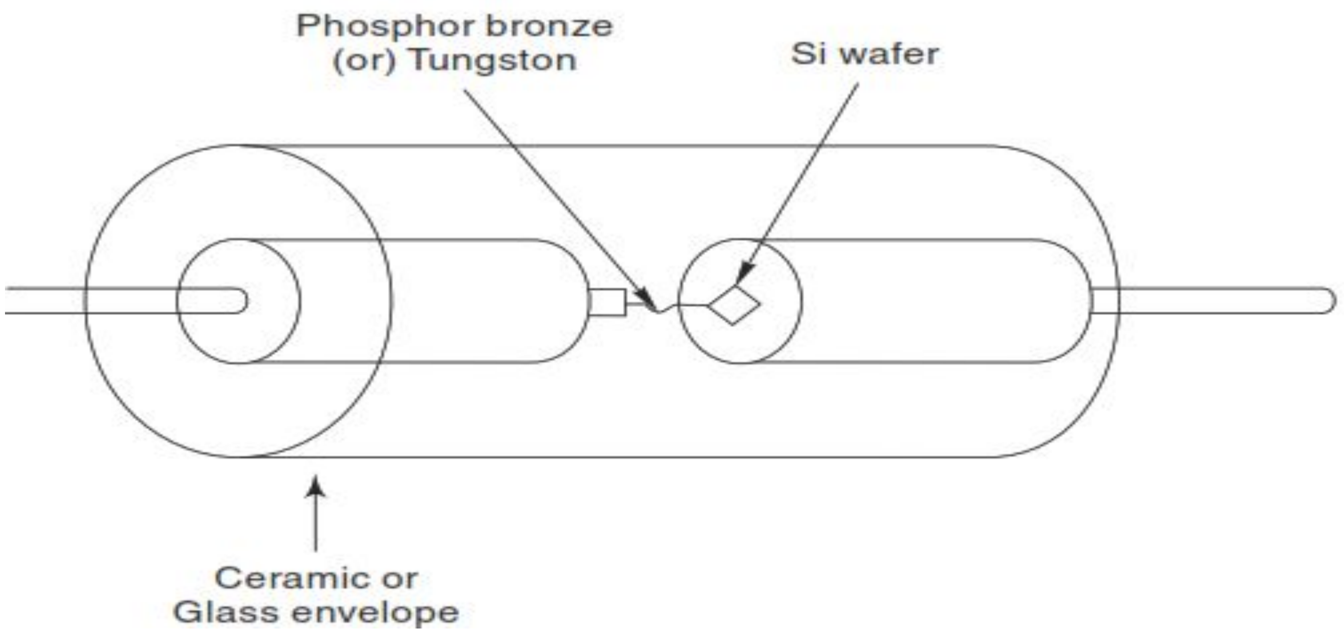
Step recovery Diode

- During negative half cycle it keeps conducting for a while, after which the reverse current ceases abruptly in one step.
- It is due to the charges stored in the depletion region during forward bias takes time to drain away from the junction
- Hence diode very briefly discharges this stored energy in the form of sharp pulse under reverse bias condition
- Sudden recovery from ON to OFF state gives diode its name.

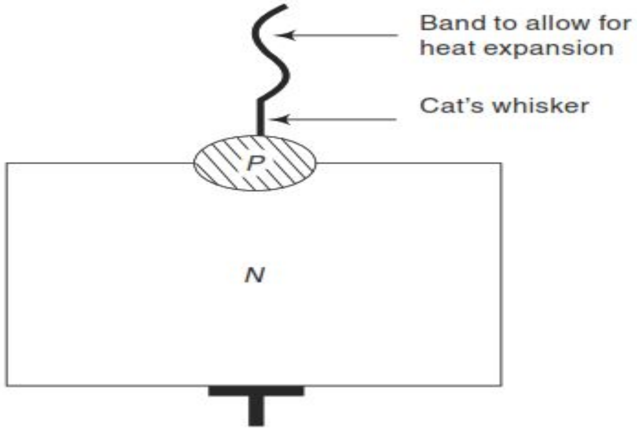


Point Contact Diode

- It consists of N-type germanium or silicon wafer about 1.25 mm square by 0.5 mm thick, one face of which is soldered to a metallic base, by radio frequency heating, so that an external ohmic contact can be made.
- The point contact is made simply by pressing a tungsten or phosphor bronze wire of a few micro meter diameter, called Cat's whisker, against the exposed surface of the crystal.



- The S shaped bend in the whisker gives it mechanical stability and also spring like property for maintaining good electrical contact.
- To form the rectifying junction at the contact point, electrical forming process is used which consists of passing Ceramic or a large current pulse of 100–200 mA Glass envelope amplitude and of 1–100ms duration

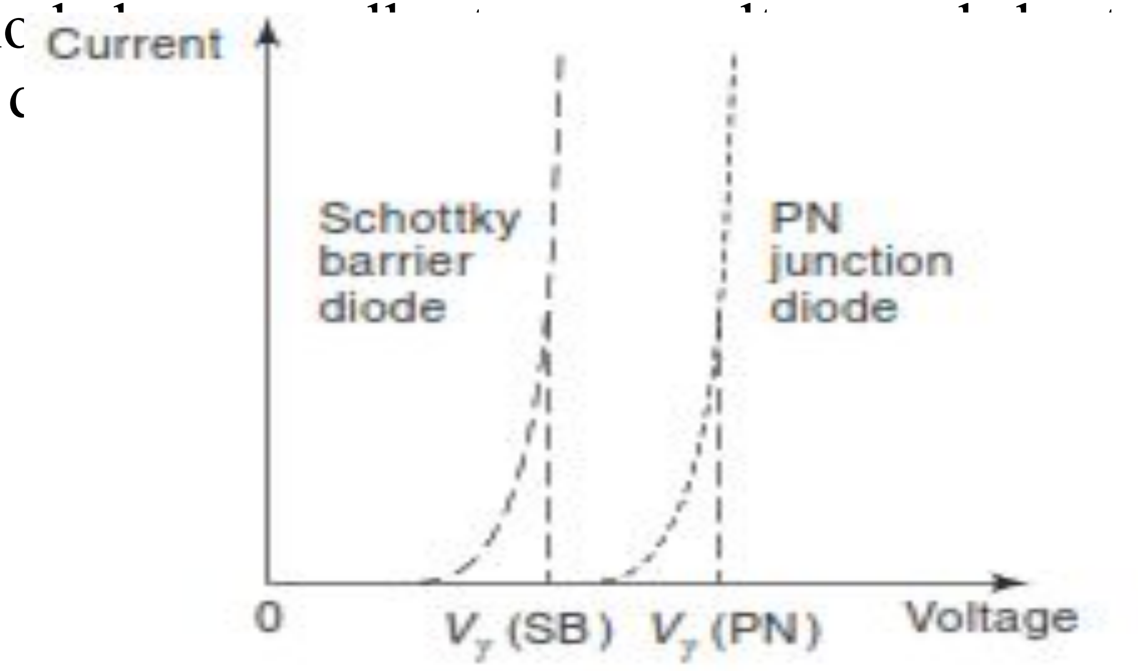


- The heat so produced drives away some of the electrons from the atoms in the small region around the point of contact thereby leaving holes behind
- The small area of the PN junction results in very low junction capacitance (0.1 to 1pF) that makes it suitable for operation at frequencies as high as 10 GHz or more and for applications in pulse circuits

SCHOTTKY DIODE

- Schottky barrier diode is an extension of the oldest semiconductor Device that is the point contact diode.
- The metal–semiconductor interface is a surface, the Schottky barrier rather than a point contact.
- The Schottky diode is formed when a metal, such as Aluminum, is brought into contact with a moderately doped N-type semiconductor.
- It is a unipolar device
- It has electrons as majority carriers on both sides of the junction.
- There is no depletion layer
- The delay present in the junction diodes due to hole–electron recombination time is absent here
- The l n the point contact diode.

- When it is forward biased, conduction of electrons on the N side gains sufficient energy to cross the junction and enter the metal.
- They are commonly called as hot carriers.
- The current in the Schottky diode results from the flow of majority carriers over the potential barrier at the metal-semiconductor junction.
- The reverse saturation current for a Schottky diode is larger than that of a PN junction diode.
- The Schottky dic … switching time than the PN junction



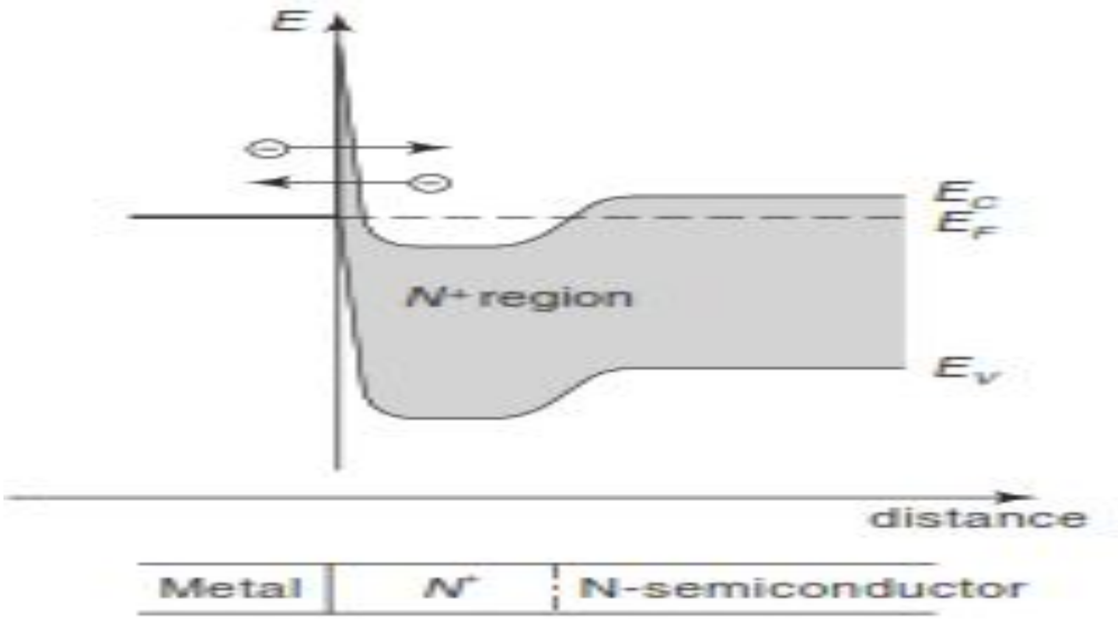
Applications

- Schottky diode can be used for rectification of signals of frequencies even exceeding 300 MHz.
- commonly used in switching power supplies at frequencies of 20 GHz.
- also used in clipping and clamping circuits and in computer gating.

TUNNEL DIODE

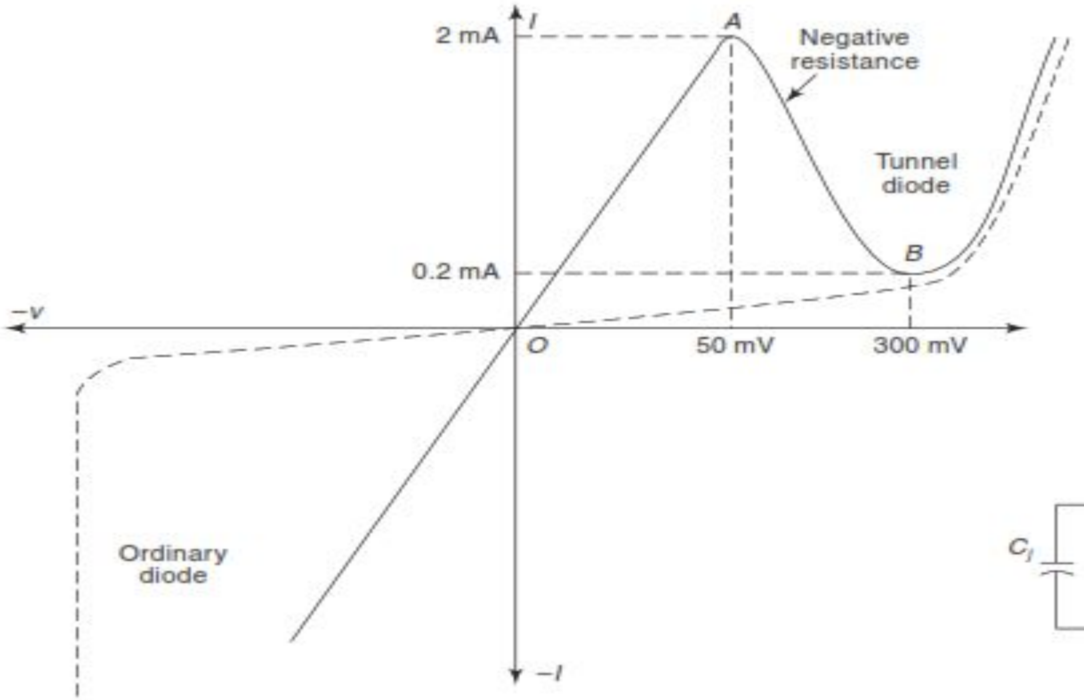
- The Tunnel or Esaki diode is a thin-junction diode which exhibits negative resistance under low forward bias conditions.
- An ordinary PN junction diode has an impurity concentration of about 1 part in 10^8.
- With this amount of doping, the width of the depletion layer is of the order of 5 microns.
- This potential barrier restrains the flow of carriers from the majority carrier EC side to the minority carrier side.

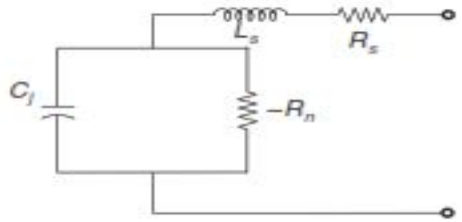
- If the concentration of impurity atoms is greatly increased to the level of 1 part in 10^3, the device characteristics are completely changed.
- This thickness is only about 1/50th of the wavelength of visible light.



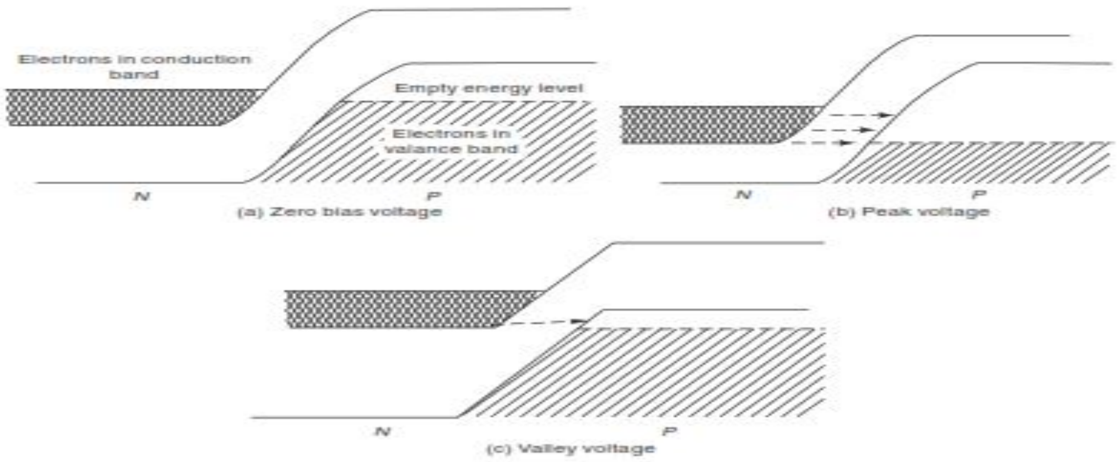
- For such thin potential energy barriers, the electrons will penetrate through the junction rather than surmounting them.

- This quantum mechanical behavior is referred to as tunneling.
- These high-impurity-density PN junction devices are called tunnel diodes.





- The V–I characteristic for a typical germanium tunnel diode is shown.
- It is seen that at first forward current rises sharply as applied voltage is increased, where it would have risen slowly for an ordinary PN junction diode (which is shown as dashed line for comparison).
- Also, reverse current is much larger for comparable back bias than in other diodes due to the thinness of the junction.
- The interesting portion of the characteristic starts at the point A on the curve, i.e. the peak voltage.
- As the forward bias is increased beyond this point, the forward current drops and continues to drop until point B is reached.
- This is the valley voltage. At B, the current starts to increase once again and does so very rapidly as bias is increased further.



- Apart from the peak voltage and valley voltage, the other two parameters normally used to specify the diode behaviour are the Peak current and the peak-to-valley current ratio, which are 2mA and 10mA
- The shaded areas show the energy states occupied by electrons in the valence band, whereas the cross hatched regions represent energy states in the conduction band occupied by the electrons.
- The levels to which the energy states are occupied by electrons on either side of the junctions are shown by dotted lines.
- When the bias is zero, these lines are at the same height. Unless energy is imparted to the electrons from some external source, the energy possessed by the electrons on the N–side of the junction is insufficient to permit to climb over the junction barrier to reach the P-side
- When a small forward bias is applied to the junction, the energy level of the P-side is lower as compared with the N-side.

- electrons in the conduction band of the N-side see empty energy level on the P-side. Hence, tunneling from N-side to P-side takes place.
- Tunneling in other directions is not possible because the valence band electrons on the P-side are now opposite to the forbidden energy gap on the N-side.
- When the forward bias is raised beyond this point, tunneling will decreases
- As the bias is raised, forward current drops. This corresponds to the negative resistance region of the diode characteristic.
- As forward bias is raised still further, tunneling stops altogether and it behaves as a normal PN junction diode.

Applications

1. Tunnel diode is used as an ultra-high speed switch with switching speed of the order of ns or ps
2. As logic memory storage device
3. As microwave oscillator
4. In relaxation oscillator circuit
5. As an amplifier

Advantages

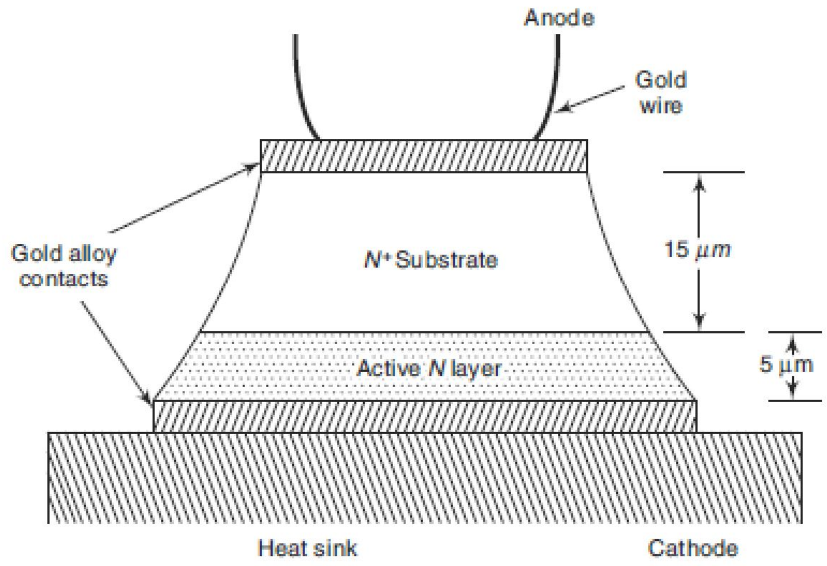
1. Low noise
2. Ease of operation
3. High speed
4. Low power

Disadvantages

1. Voltage range over which it can be operated is 1 V less
2. Being a two terminal device, there is no isolation between the input and output circuit.

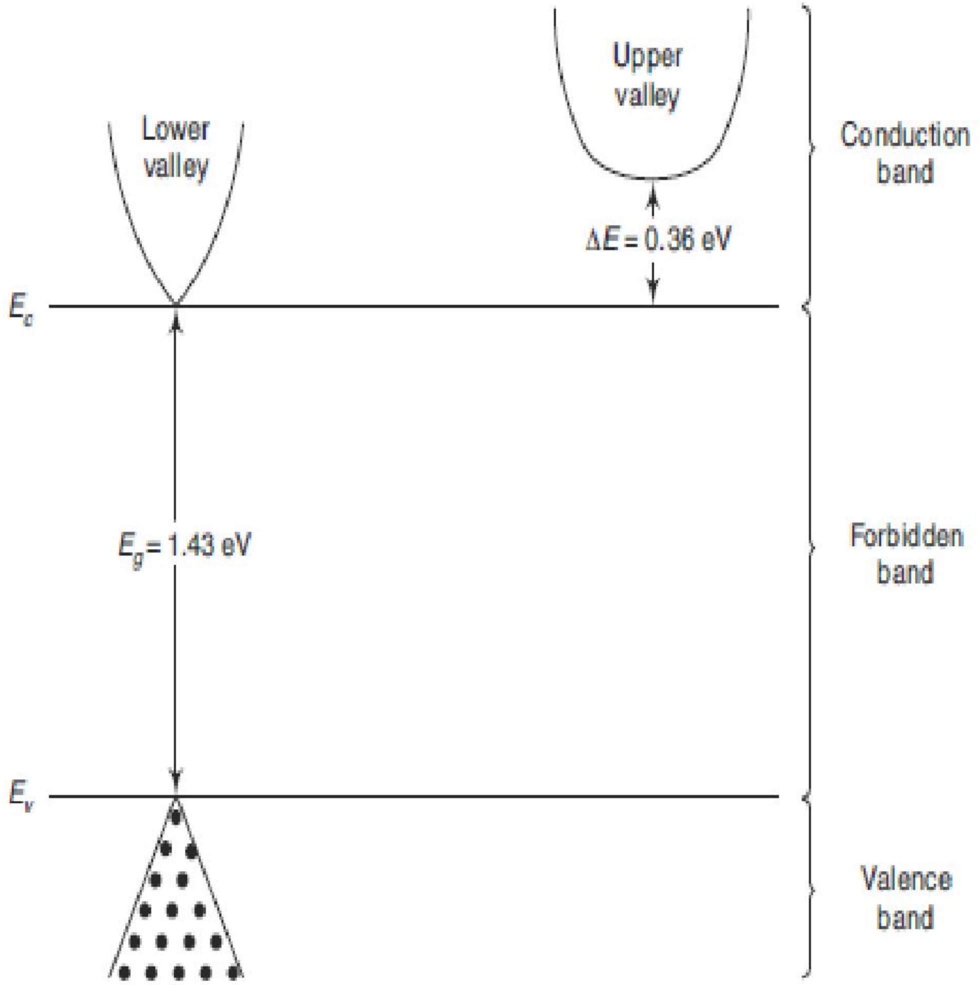
GUNN Diode

- Works on the principle of transferred electron effect (Gunn effect)
- This effect is effectively utilised for generation of microwave oscillations
- Materials: Gallium Arsenide, Indium Phosphide, Cadmium Telluride and Indium Arsenide
- Gunn Effect: When a voltage gradient of more than 3300V/cm, negative resistance will manifest itself



GUNN Diode

- Gunn effect is a bulky property of semiconductor and does not depend on other semiconductor properties like junction or contact properties
- Conduction band has two valleys, lower and upper valley
- Mobility of electrons will be high in lower valley than upper valley
- Energy level difference between upper valley and lower valley is smaller than forbidden band
- For the applied voltage, current increases linearly with voltage

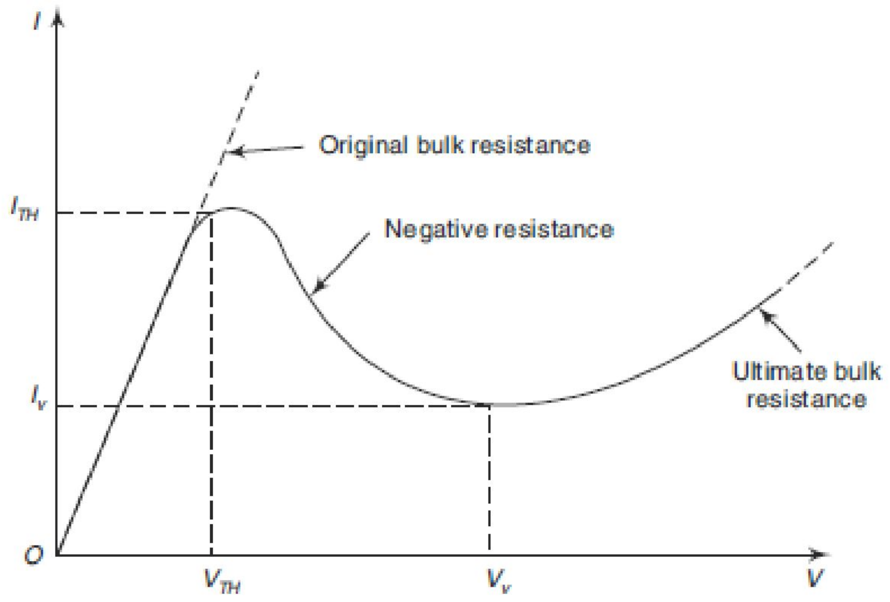


GUNN Diode

- When the electric field applied is greater than threshold electric field, electrons are transferred from high mobility lower valley to low mobility upper valley
- Thus current decreases with increase in voltage exhibiting negative resistance
- Extent of doping will not be uniform throughout the sample, thus few areas will have lesser conductivity, resulting in greater potential across it
- When applied voltage increases, this region will be the first to have voltage across it large enough to induce transfer of electrons to higher valley- called as negative resistance domain
- The domain is unstable and moves towards the positive end
- This domain corresponds to negative pulse of voltage and when it arrives at the positive end, triggers oscillation in tank circuit

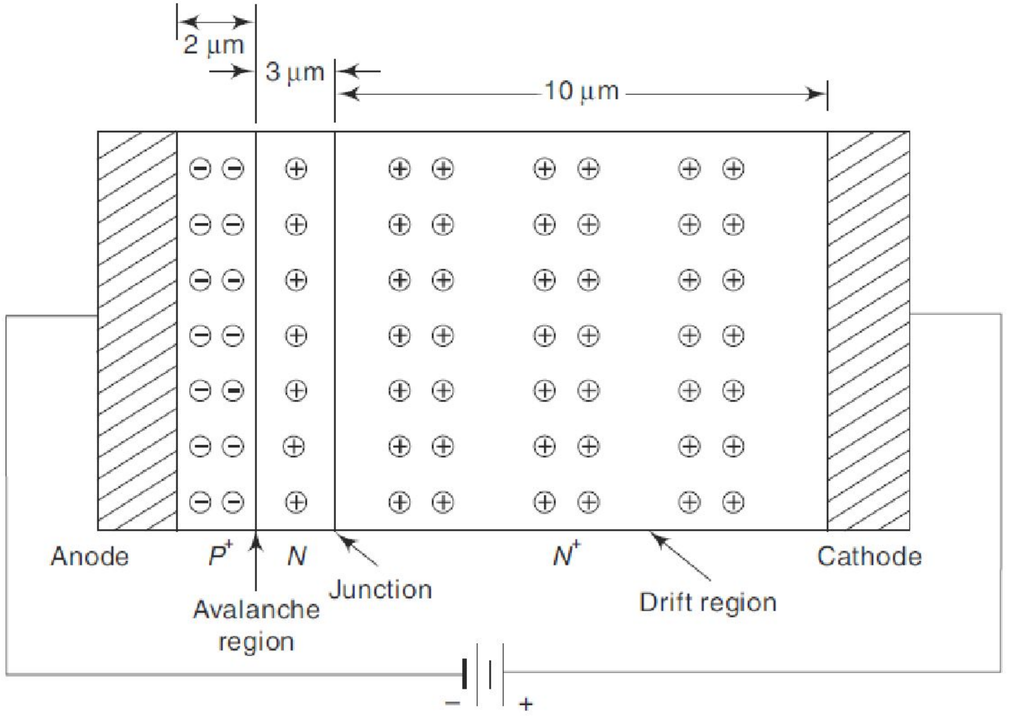
GUNN Diode

- Thickness of the slice and the applied voltage are such that one domain or pulse is formed per cycle of RF oscillations
- Energy is received by the tank circuit in correct phase to permit the oscillations to continue
- Application: Microwave generation and amplification



IMPATT Diode

- IMPact Avalanche and Transit Time diode
- Device that exhibits dynamic negative resistance for direct current will also exhibit it for alternate current
- Current will rise when alternating voltage falls
- Current is 180 degree out of phase with voltage



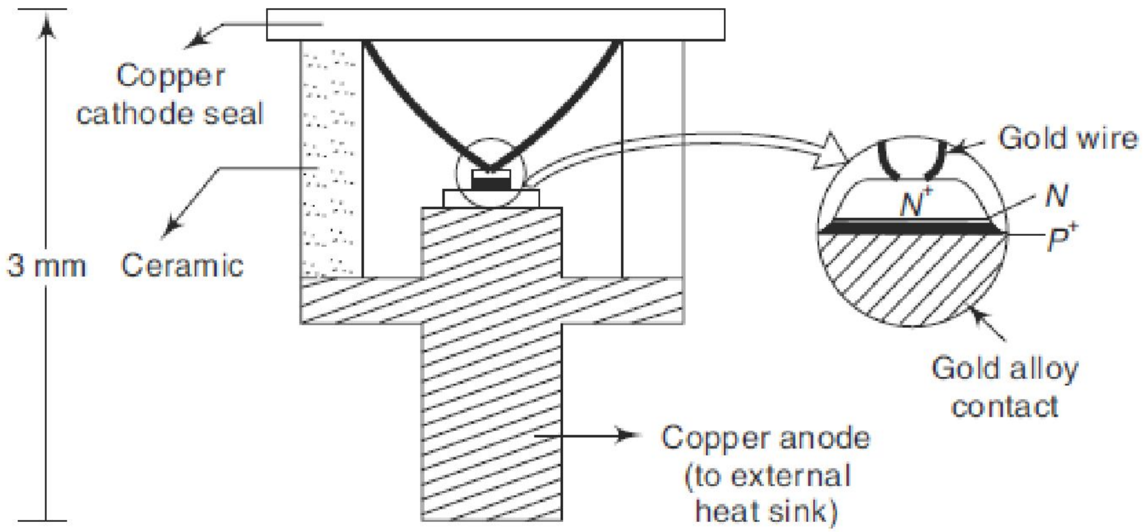
IMPATT Diode

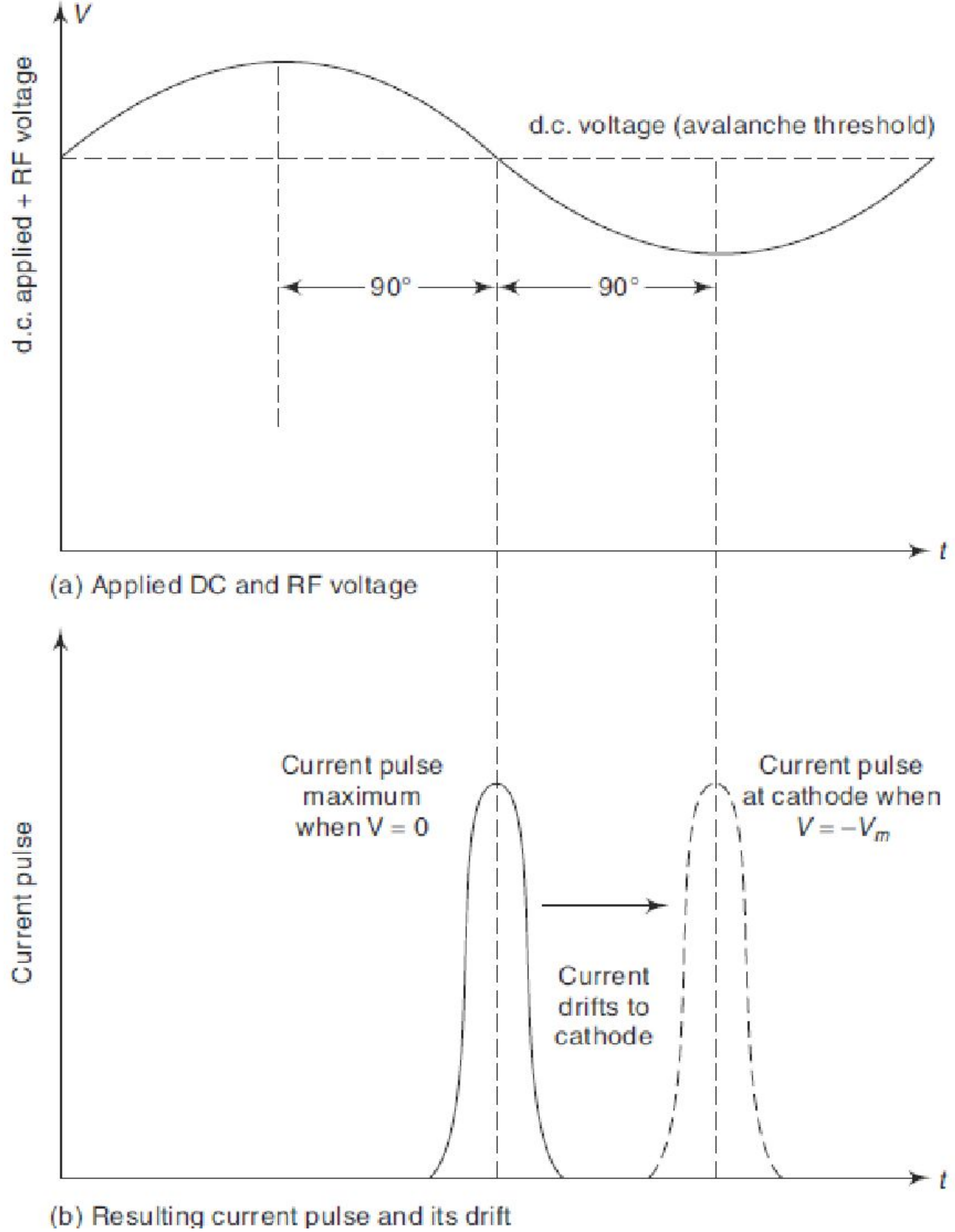
- The junction being between the P+ and N layers
- Voltage gradient of the order to the 400KV/cm is applied to IMPATT diode
- Such high voltage applied in reverse direction results in flow of minority carriers across the junction
- Positive swing of RF voltage superimposed on dc voltage increases charge velocity , which creates additional holes and electrons by impact ionization creating avalanche effect
- If dc field was just at the threshold of producing this avalanche, then during the whole of positive RF cycle, avalanche multiplication takes place
- 90 degree phase difference between the voltage and current is established

IMPATT Diode

- Because of reverse bias that is applied, the current pulse flows to the cathode at a drift velocity dependent on the magnitude of high dc field
- Time taken by the pulse to reach the cathode depends on this velocity and thickness of the highly doped N+ layer.
- Thickness of the drift region is selected so that time taken for the current pulse to arrive at the cathode corresponds to further 90 degree phase difference
- Thus voltage and current in IMPATT diode is 180 degree out of phase
- Application of negative resistance- Oscillators of amplifiers
- Short transit time- can be operated in microwave frequency region

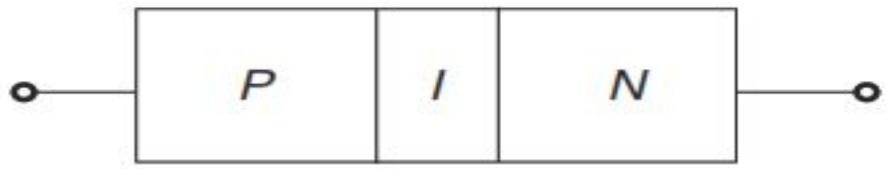
IMPATT Diode





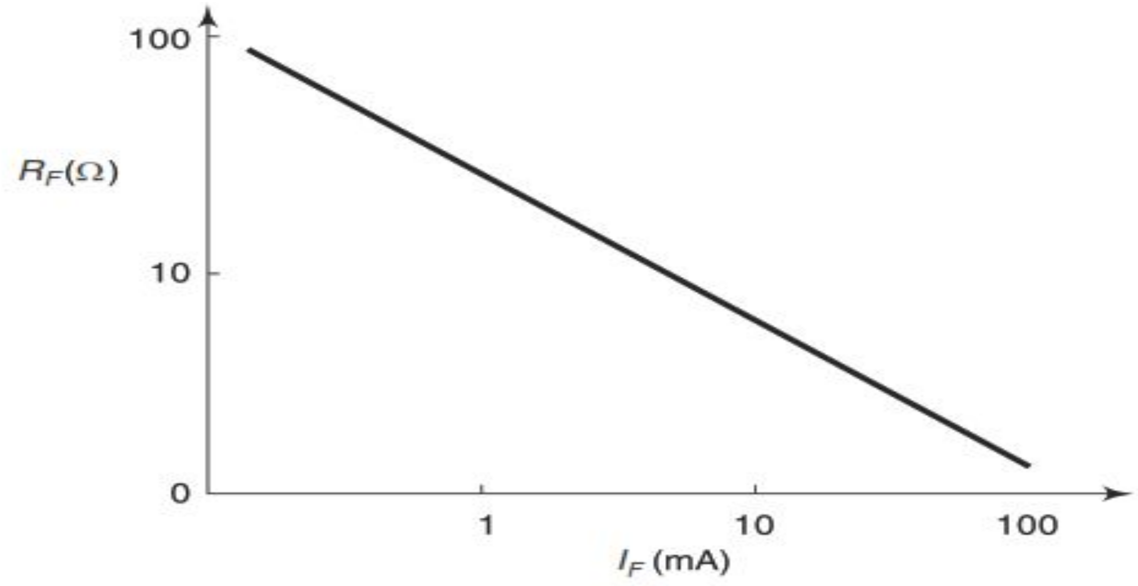
PIN DIODE

- It is composed of three regions. In addition to the usual N and P regions, an intrinsic layer (I region) is sandwiched between them, to form the PIN structure



- Being intrinsic, the intermediate layer offers relatively high resistance which gives it two advantages compared to an ordinary PN diode.
- (1) decrease in capacitance between P and N regions as it is inversely proportional to the separation between these regions.
- (2) possibility of greater electric PIN field between the P and N junctions, so that the charge carriers drift towards their majority carrier side.

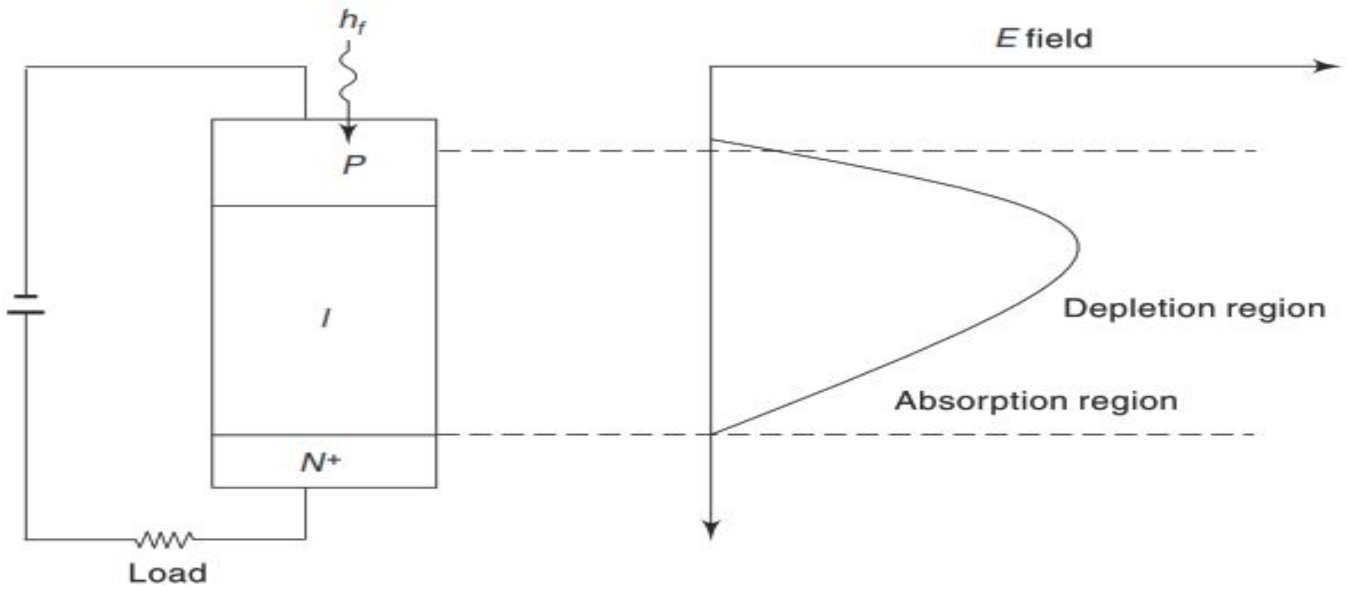
- It offers a variable resistance under forward bias condition



- Hence, for large d.c. currents, the diode will look like a short. In reverse biased condition it looks like an open, i.e. it offers an infinite resistance.
- It is used as a switching diode for signal frequencies up to GHz range and as an AM modulator of very high frequency signals.
- PIN diodes are used at high frequencies (more than 300 MHz)

PIN PHOTODIODE

- It is a three-region reverse biased junction diode.
- A layer of intrinsic silicon is sand-witched between heavily doped P and N type semiconductor materials.



- The depletion region extends almost to the entire intrinsic layer where most of the absorption of light photons take place.
- The width of the intrinsic layer is large compared to the width of the other two layers.

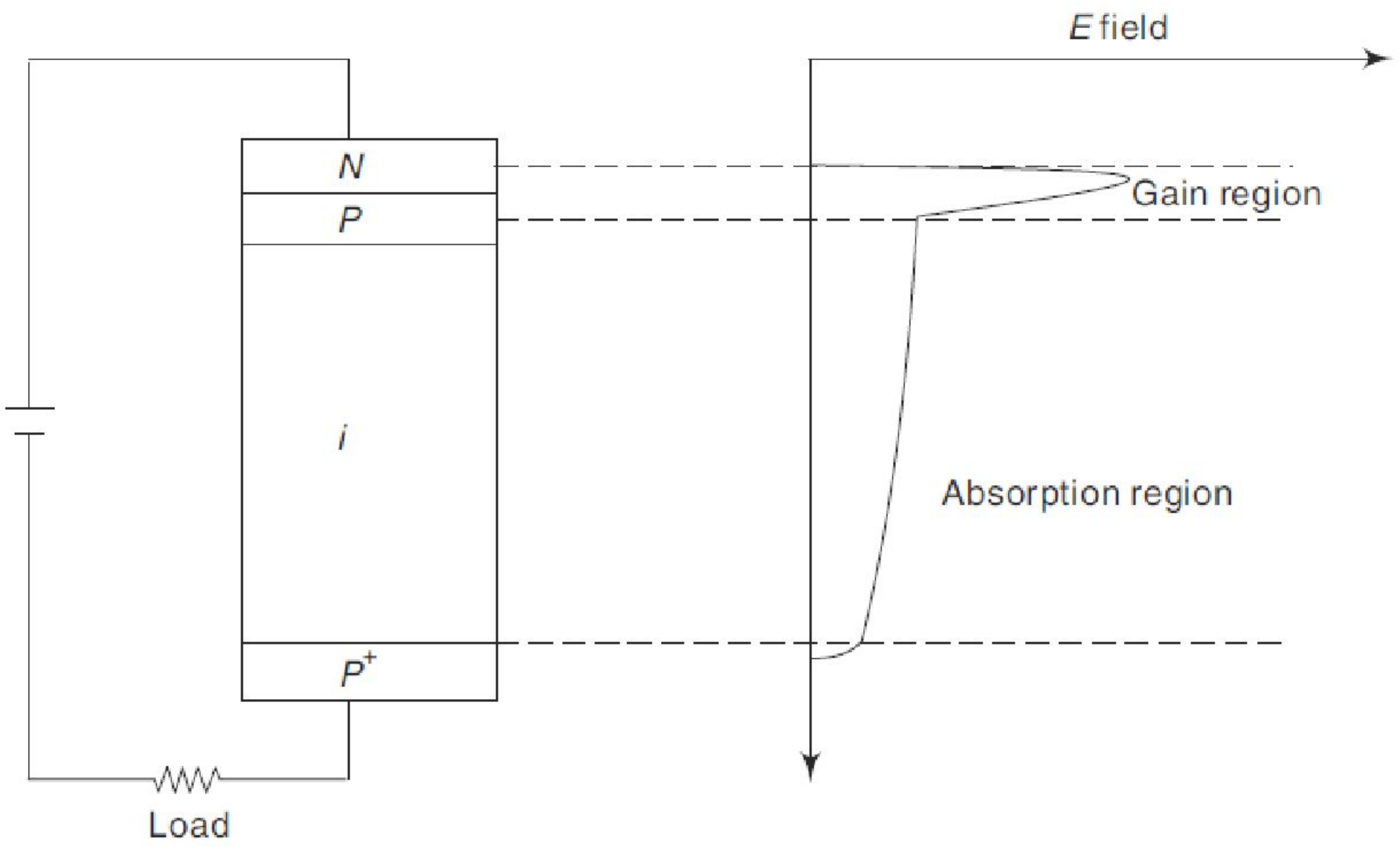
- Light photons incident on the PIN photodiode are absorbed in the absorption region which leads to the generation of electron–hole pairs.
- Due to the applied reverse bias, these charge carriers present in the depletion region drift under the influence of the existing electric field.
- The transit time of the charge carriers is small.
- The response time is considerably reduced.
- The large width of the depletion region results in achieving high quantum efficiency.

Avalanche Photo Diode

- Used for detection of light at the receive end
- Converts input light signal in to electrical signal
- Consists of reverse biased PN junction
- Depletion region is formed by immobile positively charged donor atoms in N type semiconductor material and immobile negatively acceptor atoms in P type material
- Electric field in this depletion region is very high where most of the photons are absorbed and primary charge carriers are generated
- These charge carriers excite new electron hole pair by a process called Impact Ionisation
- Reverse bias voltage is in the order 0f 100 – 400V
- Carrier multiplication factors as great as 10^4 may be obtained using defect free materials

Avalanche Photo Diode

- Due to internal gain mechanism large electrical response is obtained for a weak light signal
- Quantum efficiency closer to 100%



Laser Diode

- Convert electrical signal to light
- In direct band gap material, optical gain can be achieved by creating population inversion of carriers through high level current injection and by forming a resonant cavity which is produced by high Fresnel reflectivity obtained from cleaving the material along faces perpendicular to the junction plane
- Opposite end of laser diode are polished to get mirror like surfaces
- Emitted photon from recombination reflect back and froth between the mirror surfaces
- Region between the mirrored ends acts like a cavity that filters the light and purifies it colour
- Avalanche effect causes newly created photons to be emitted with the same phase

Laser Diode

- One mirror is semi transparent from which a fine thread like beam of photons emerge out which have same frequency and phase (Coherent)
- It has current threshold below which the device exhibits low levels of spontaneous emission
- At limiting current density , stimulated emission occurs and the emitted radiation increases linearly with drive current