CHAPTER -1

1. Semiconductors

Solid materials may be divided, with respect to their electrical properties, into three categories:

1. Conductors

Conductors (e.g., copper, aluminum) have a cloud of free electrons at all temperature above absolute zero. This is formed by the weakly bound "valence" electrons in the outermost orbits of their atoms. If an electric field is applied across such a material, electrons will flow, causing an electric current.

2. Insulators

In insulating materials, the valence electrons are tightly bound to the nuclei of the atoms and very few of them are able to break free to conduct electricity. The application of an electric field does not cause a current to flow as there are no mobile charge carriers.

3. Semiconductors

At very low temperatures, semiconductors have the properties of an insulator. However, at higher temperatures, some electrons are free to move and the materials take on the properties of a conductor (albeit a poor one). Nevertheless, semiconductors have some useful characteristics that make them distinct from both insulators and conductors.

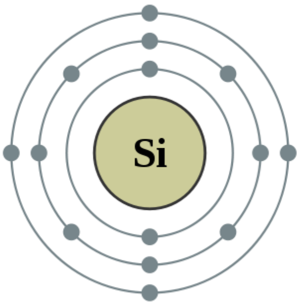
To understand the operation of diodes, transistors, and other electronic devices, we need to understand the basic structure of semiconductors.

A few common semiconductor materials: silicon (Si), germanium (Ge), gallium arsenide (GaAs), indium phosphide (InP), silicon carbide (SiC), silicon-germanium (SiGe).

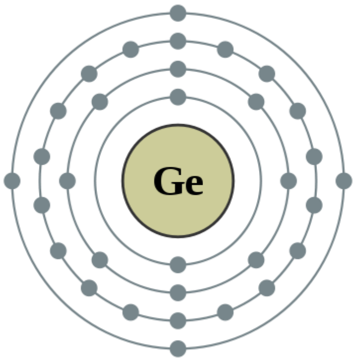
The first transistors were made from germanium (Ge). Silicon (Si) types currently predominate but certain advanced microwave and high performance versions employ the compound semiconductor material gallium arsenide (GaAs) and the semiconductor alloy silicon germanium (SiGe).

Silicon and germanium fall in column IVa of the Periodic Table. This is the carbon family of elements. The characteristic of these elements is that each atom has four electrons to share with adjacent atoms.

14: Silicon **2,8,4**

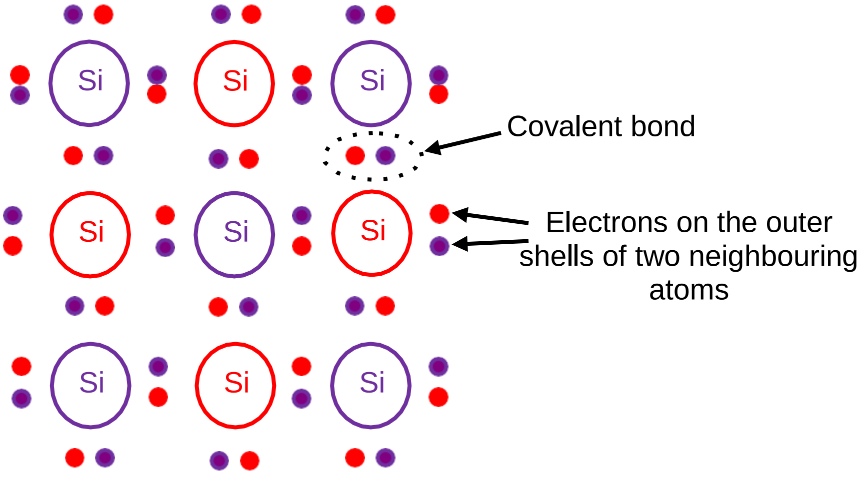


32: Germanium **2,8,18,4**



Z	Element	No. of electrons/shell
6	carbon	2, 4
14	silicon	2, 8, 4
32	germanium	2, 8, 18, 4
50	tin	2, 8, 18, 18, 4
82	lead	2, 8, 18, 32, 18, 4

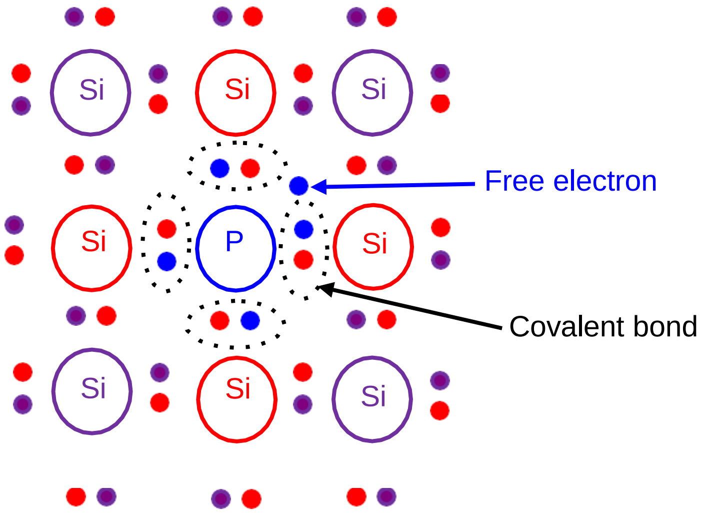
Let us have a closer look at silicon. The crystal structure of silicon is represented below.



The nature of a bond between two silicon atoms is such that each atom provides one electron to share with the other. The two electrons thus shared between atoms form a “covalent bond”. Such a bond is very stable and holds the two atoms together very tightly. It requires a lot of energy to break this bond.

All of the outer electrons of all silicon atoms are used to make covalent bonds with other atoms. There are no electrons available to move from place to place as an electrical current. Thus, a pure silicon crystal is quite a good insulator. Increasing the temperature results in some electrons breaking free from their covalent bonds and this improves the conductivity of the silicon crystal.

To allow a silicon crystal to conduct electricity without having to increase the temperature, we must find a way to allow some electrons to move from one place to the other within the crystal despite the covalent bonds between atoms. One way to accomplish this is to introduce an impurity such as arsenic or phosphorus into the crystal structure. Such process is called doping. These elements are from column Va of the Periodic Table, and have five outer valence electrons to share with other atoms.

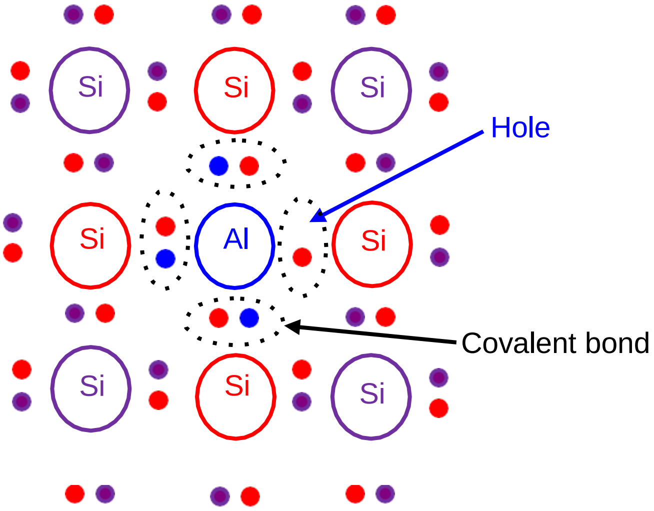


Four of these five electrons bond with adjacent silicon atoms as before, but the fifth electron cannot form a bond and is thus left “alone”. This electron can easily be moved with only a small applied electrical voltage. Because the resulting crystal has an excess of current-carrying electrons, each with a negative charge, it is known as "N-type" silicon.

Such construction does not conduct electricity as easily as, say, copper or silver since it does exhibit some resistance to the flow of electricity. It cannot properly be called a conductor, but at the same time it is no longer an insulator. Therefore, it is known as a semiconductor.

We obtained a semiconductor material by introducing a 5-electron impurity into a matrix of 4-electron atoms. We can also do the opposite and introduce a 3-electron impurity into such a crystal. Suppose we introduce some aluminium (from column IIIa in the Periodic Table) into the crystal. We could also use gallium which is also in column IIIa.

These elements only have three valence electrons available to share with other atoms. Those three electrons do indeed form covalent bonds with adjacent silicon atoms, but the expected fourth bond cannot be formed. A complete connection is impossible here, leaving a "hole" in the structure of the crystal.

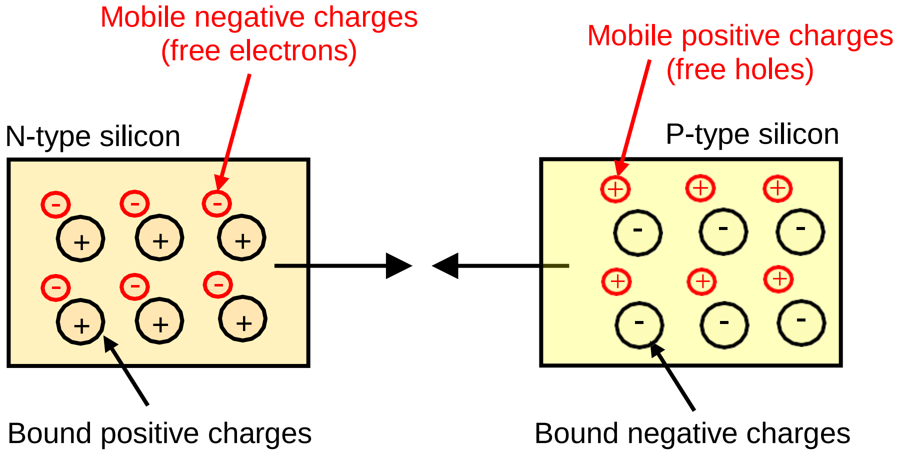


There is an empty place where an electron should logically go, and often an electron will try to move into that space to fill it. However, the electron filling the hole has to leave a covalent bond behind to fill this empty space, and therefore leaves another hole behind as it moves. Yet another electron may move into that hole, leaving another hole behind, and so on. In this manner, holes appear to move as positive charges through the crystal. Therefore, this type of semiconductor material is designated "P-type" silicon.

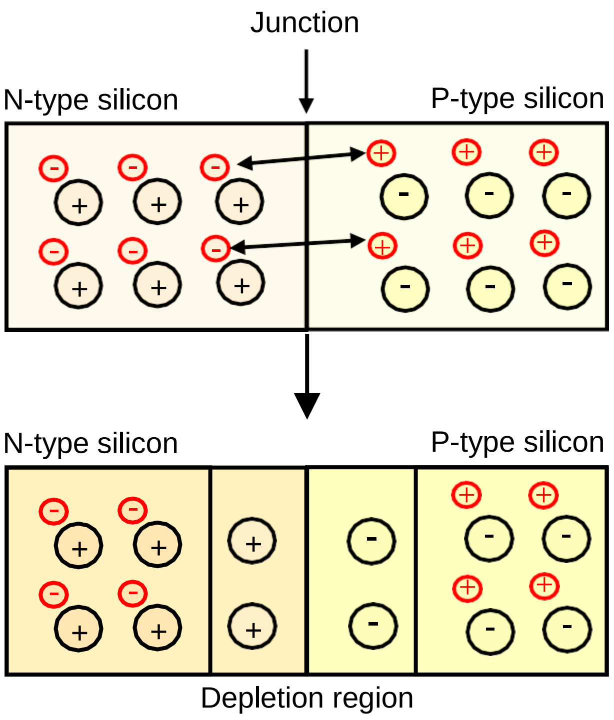
In an N-type semiconductor, the electrons are often referred to as the majority charge carriers, whereas the holes are called the minority charge carriers since they are actually also present but at much lower concentration. In a similar way, in a P-type semiconductor, the holes are referred to as the majority charge carriers, whereas the electrons, which are present at much lower concentration, are the minority charge carriers.

The role played by the minority charge carriers can sometimes be ignored for simplicity purposes.

The PN Junction (Diode)



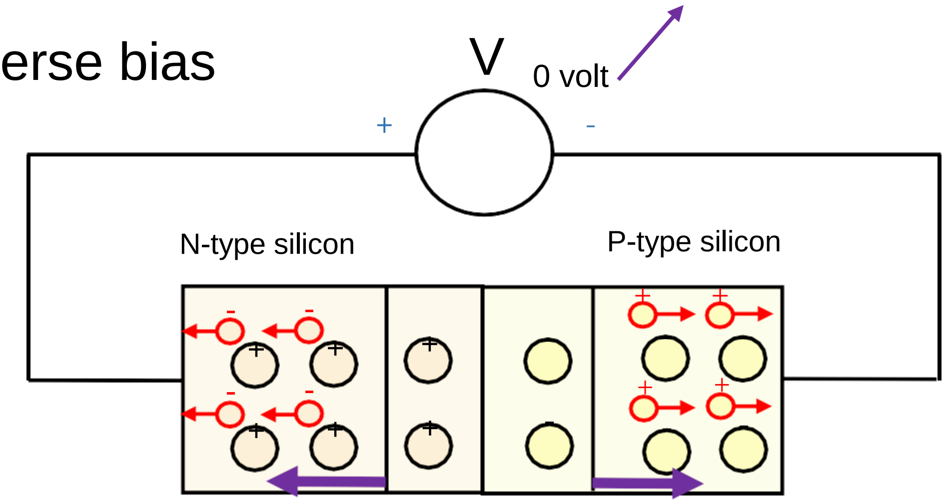
When we join the N- and P-type crystals together, an interesting interaction occurs around the junction. The extra electrons in the N region will combine with the extra holes in the P region. This leaves an area where there are no mobile charges, known as depletion region, around the junction.



Suppose now that we apply a voltage to the outside ends of our PN crystal.

Assume first that the positive voltage is applied to the N-type material. In such case, the positive voltage applied to the N-type material attracts free electrons towards the end of the crystal and away from the junction, while the negative voltage applied to the P-type end attracts holes away from the junction.

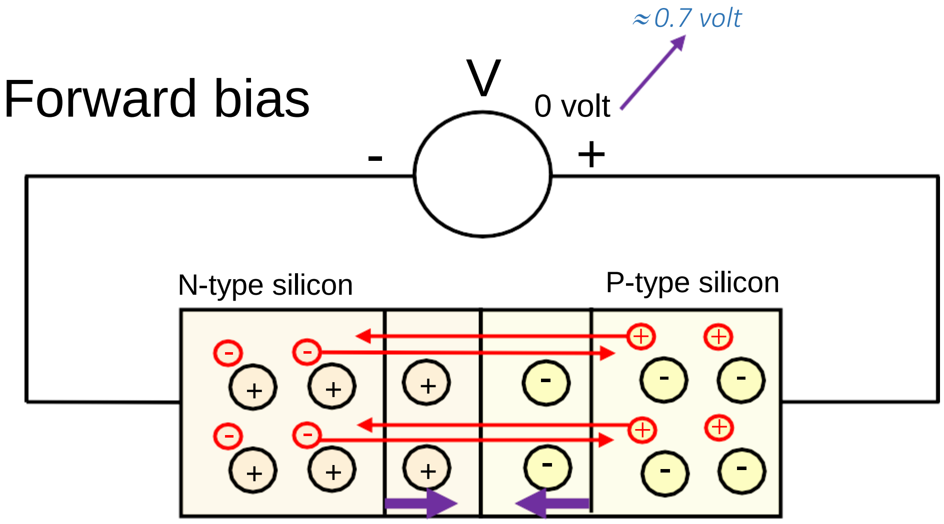
Reverse bias



The depletion region
becomes wider

The result is that all available current carriers are attracted further away from the junction, and the depletion region grows correspondingly larger. Therefore, there is no current flow through the crystal because no current carriers can cross the junction. This is known as reverse bias applied to the semiconductor crystal.

Assume now that the applied voltage polarities are reversed. The negative voltage applied to the N-type end pushes electrons towards the junction, while the positive voltage at the P-type end pushes holes towards the junction. This has the effect of shrinking the depletion region.



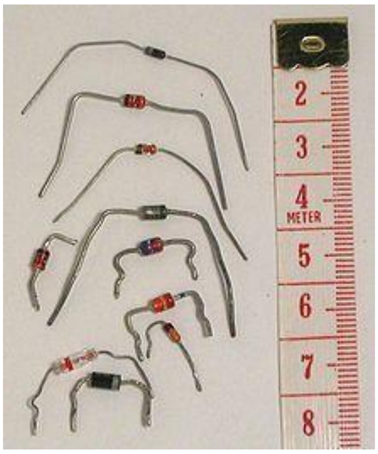
The depletion region becomes narrower as V is increased, until eventually it disappears.

Once the applied voltage V has become large enough to make the depletion region completely disappear, i.e. once the value of V becomes equal to the threshold voltage V_d of the PN junction ($V_d \approx 0.7$ volt for silicon and $V_d \approx 0.3$ volt for germanium), current carriers of both types are finally able to cross the junction into the opposite ends of the crystal. Now, electrons in the P-type end are attracted to the positive applied voltage, while holes in the N-type end are attracted to the negative applied voltage. This is the condition of forward bias.

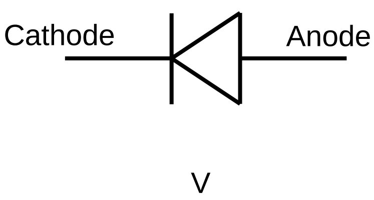
The conclusion is that an electrical current can flow through the junction in the forward direction, but not in the reverse direction. This is the basic property of a semiconductor diode.

It is important to realize that holes exist only within the crystal. A hole reaching the negative terminal of the crystal is filled by an electron from the power source and simply disappears. At the positive terminal, the power supply attracts an electron out of the crystal, leaving a hole behind to move through the crystal toward the junction again.

• Current-Voltage Characteristic of a Diode



Symbol of a diode



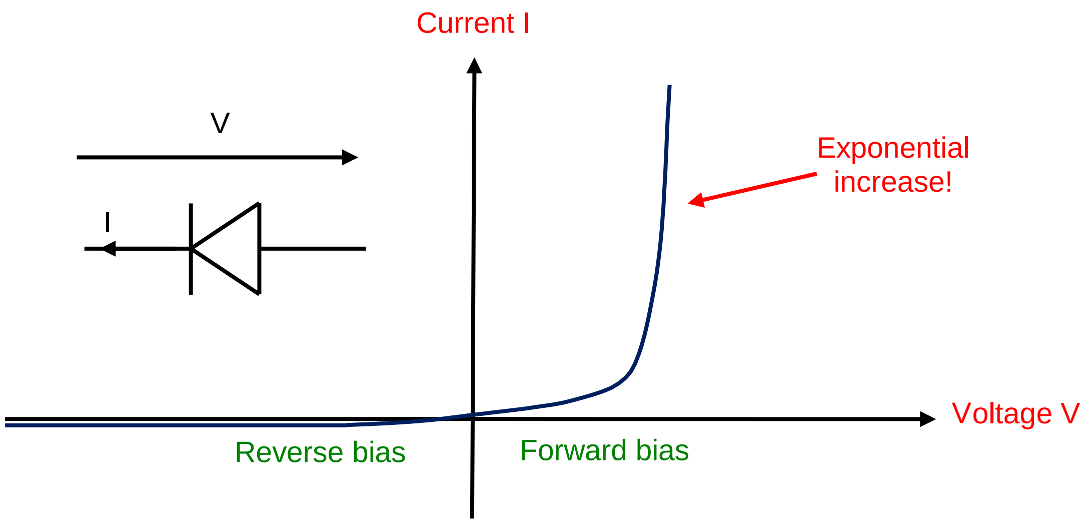
The Shockley diode equation, named after transistor co-inventor William Shockley, gives the current–voltage characteristic of a diode in either forward or reverse bias. The equation is given by

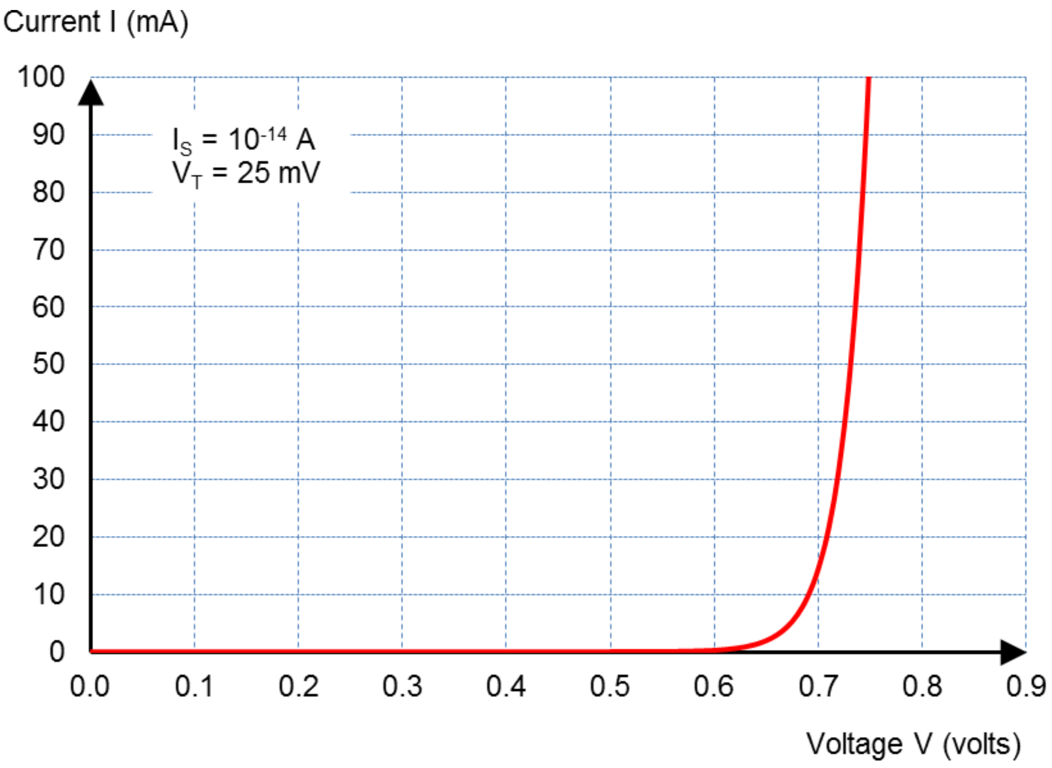
$$I = I_S\left(\exp\left\{\frac{qV}{\eta kT}\right\} - 1\right) = I_S\left(\exp\left\{\frac{V}{\eta V_T}\right\} - 1\right),$$

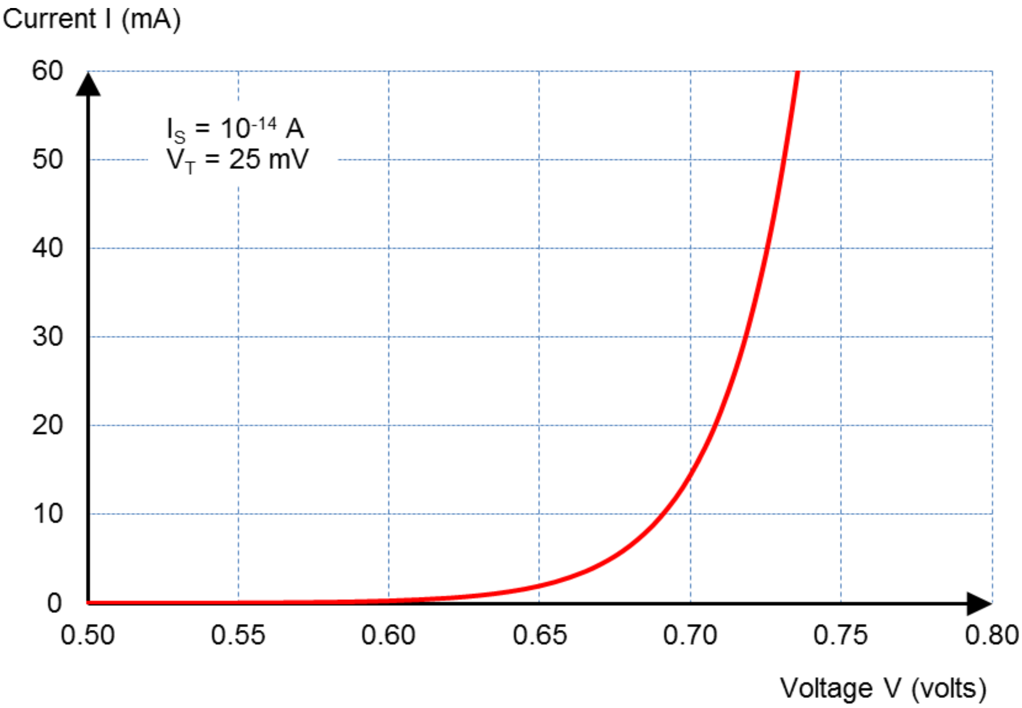
where - I_S: Saturation current of the diode (in the range 10^{-8} to 10^{-16} A, typically);

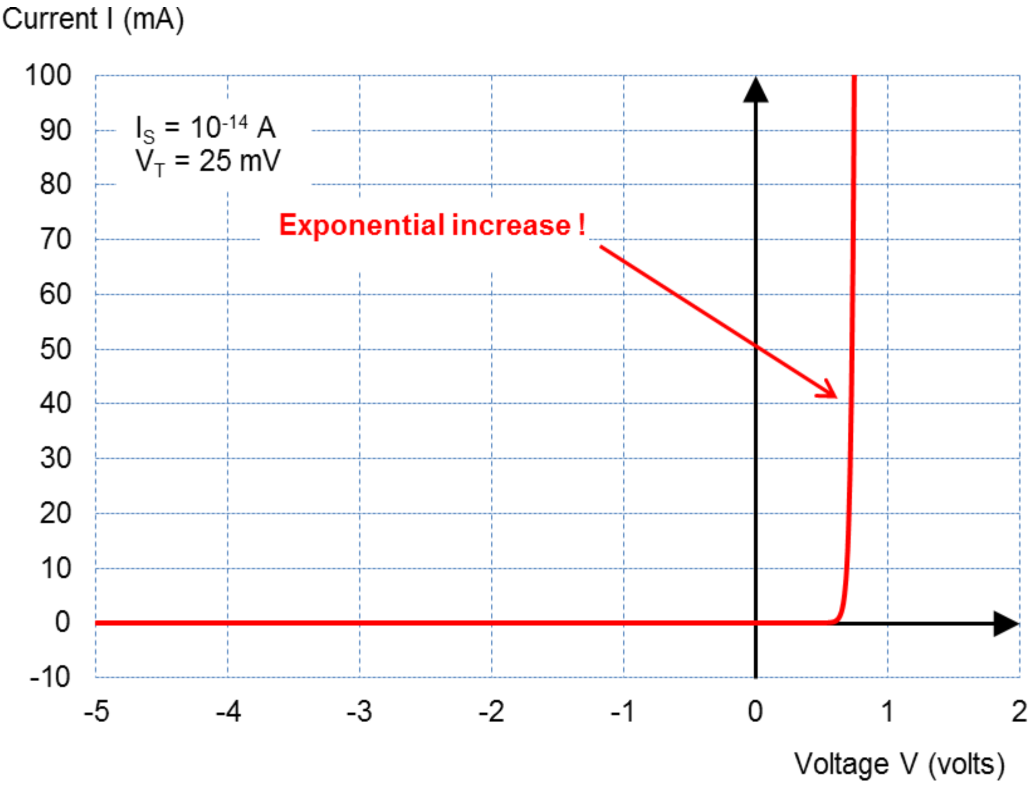
- η: Emission coefficient. This is an empirical constant that varies from 1 to 2 depending on the fabrication process and semiconductor material and in many cases is assumed to be approximately equal to 1 (and thus omitted).
- q: Electron charge (= 1.602×10^{-19} C);
- T: Temperature in degrees Kelvin;
- k: Boltzmann's constant (= 1.38×10^{-23} J/K);
- V_T: Thermal voltage ($\approx$ 25 mV at room temperature).

This expression means that the current flowing through a diode varies exponentially with the applied voltage.

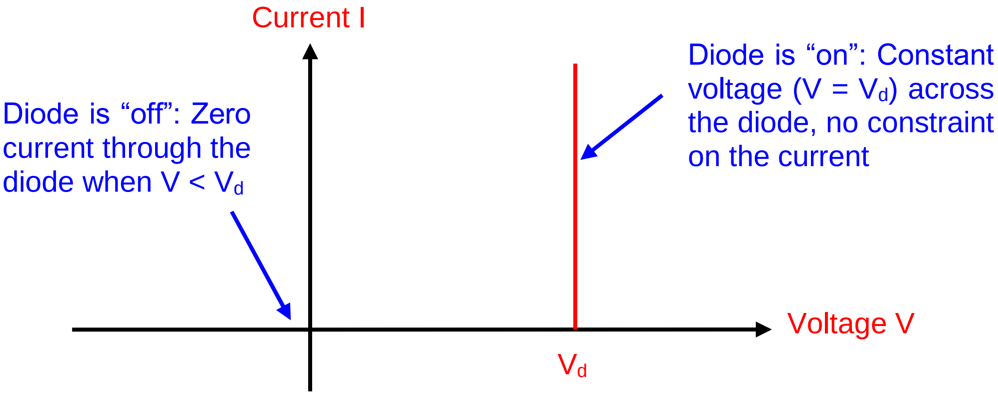





Current I (mA)
60
50
40
30
20
10
0
$I_S = 10^{-14}$ A
V_T = 25 mV
0.50
0.55
0.60
0.65
0.70
0.75
0.80
Voltage V (volts)


Current I (mA)
100
90
80
70
60
50
40
30
20
10
0
-10
$I_S = 10^{-14}$ A
V_T = 25 mV
Exponential increase !
-5
-4
-3
-2
-1
0
1
2
Voltage V (volts)

This rather complicated equation is a bit difficult to use for manual circuit analysis. Electronic engineers deal with this problem by simplifying things and using the much simpler model of the diode given below.



Note that V_d is called *threshold voltage* or *forward voltage drop* of the diode. We have $V_d \approx 0.7$ V for a silicon diode, $V_d \approx 0.3$ V for a germanium diode, and $V_d \approx 0.25$ V for a Schottky diode.

In this model, the current is zero for any voltage below the threshold voltage V_d. In effect, the diode is viewed as a switch which is open when we apply low or negative voltages across it but which closes when we apply a voltage equal to V_d across it. It is important to understand that, with this model, it is strictly impossible to get a voltage larger than V_d across the diode.

IMPORTANT TERMS: -

(i) **BREAKDOWN VOLTAGE**: - It is the minimum reverse voltage at which pn junction breaks down with sudden rise in reverse current.

(ii) **KNEE VOLTAGE**: - It is the forward voltage at which the current through the junction starts to increase rapidly.

(iii) **PEAK INVERSE VOLTAGE (PIV)**:- It is the maximum reverse voltage that can be applied to the pn junction without damage to the junction. If the reverse voltage across the junction exceeds its PIV, the junction may be destroyed due to excessive heat. The peak inverse voltage is of particular importance in rectifier service.

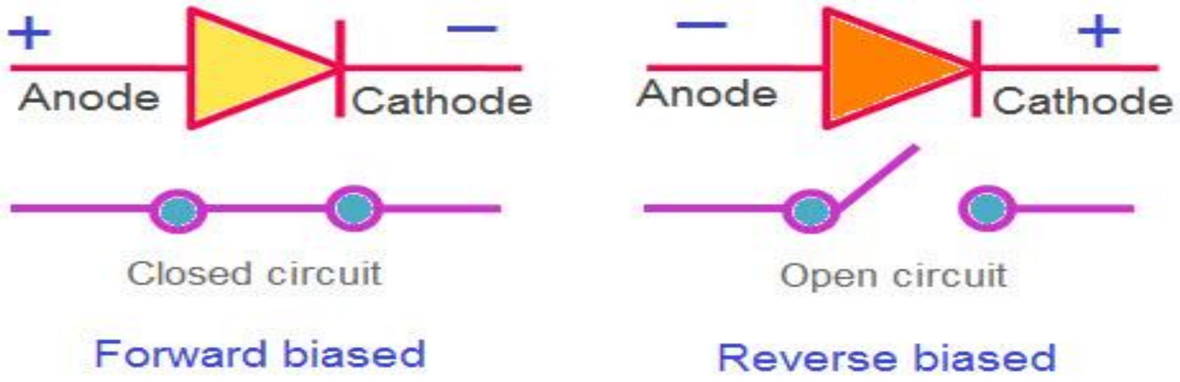
(iv) **MAXIMUM FORWARD CURRENT**:- It is the highest instantaneous forward current that a pn junction can conduct without damage to the junction. Manufacturer's data sheet usually specifies this rating. If the forward current in a pn junction is more than this rating, the junction will be destroyed due to overheating.

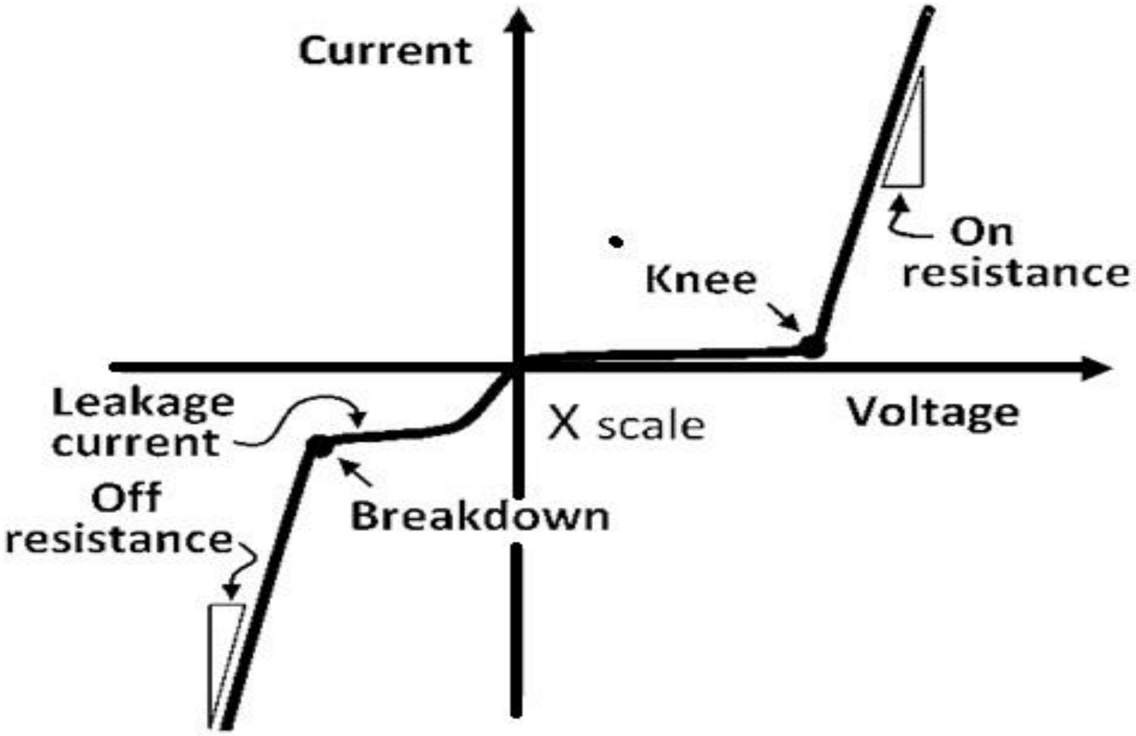
(v) **MAXIMUM POWER RATING**: - It is the maximum power that can be dissipated at the junction without damaging it. The power dissipated at the junction is equal to the product of junction current and the voltage across the junction. This is a very important consideration and is invariably specified by the manufacturer in the data sheet.

Ideal Diode

An ideal diode consists of two terminals like a normal diode. The connections of component's end and terminals are polarized. It is important to know that not to combine the connections on a diode up. The two terminals of an ideal diode are called the anode and cathode where anode is positive and cathode is negative.

The circuit symbol of an ideal diode is a triangle shape against a line. There are different kinds of diodes are available in the market, but generally the symbol of the diode will look like the following diagram. The fatal entering the smooth edge of the triangle signifies the anode. The flow of current in the triangle direction is pointing, but it cannot go the other way.





PN Junction Breakdown

Electrical break down of any material (say metal, conductor, semiconductor or even insulator) can occur due to two different phenomena. Those two phenomena are **1) Zener breakdown** and **2) Avalanche breakdown**
These two phenomena are quite like a natural occurrence. It even applies to our daily life while lightning. We all know air is an insulator under normal conditions. But when lightning occurs (an extremely high voltage), it charges the air molecules nearby and charges get transferred via air medium. Now that's a kind of electrical break down of an insulator. A similar kind of situation arises in Zener and avalanche breakdown as well. Let see what's it all about!

Zener Breakdown

When we increase the reverse voltage across the pn junction diode, what really happens is that the electric field across the diode junction increases (both internal & external). This results in a force of attraction on the negatively charged electrons at junction. This force frees electrons from its covalent bond and moves those free electrons to conduction band. When the electric field increases (with applied voltage), more and more electrons are freed from its covalent bonds. This results in drifting of electrons across the junction and electron hole recombination occurs. So a net current is developed and it increases rapidly with increase in electric field.

Zener breakdown phenomena occurs in a pn junction diode with heavy doping & thin junction (means depletion layer width is very small). Zener breakdown does not result in damage of diode. Since current is only due to drifting of electrons, there is a limit to the increase in current as well.

Avalanche Breakdown

Avalanche breakdown occurs in a pn junction diode which is moderately doped and has a thick junction (means its depletion layer width is high). Avalanche breakdown usually occurs when we apply a high reverse voltage across the diode (obviously higher than the zener breakdown voltage,say Vz). So as we increase the applied reverse voltage, the electric field across junction will keep increasing.

If applied reverse voltage is Va and the depletion layer width is d;

then the generated electric field can be calculated as Ea =Va/d

This generated electric field exerts a force on the electrons at junction and it frees them from covalent bonds. These free electrons will gain acceleration and it will start moving across the junction with high velocity. This results in collision with other neighboring atoms. These collisions in high velocity will generate further free electrons. These electrons will start drifting and electron-hole pair recombination occurs across the junction. This results in net current that rapidly increases.

We learned that avalanche breakdown occurs at a voltage (Va) which is higher than zener breakdown voltage (Vz). The reason behind this is simple. We know, avalanche phenomena occurs in a diode which is moderately doped and junction width (say d) is high. A zener break down occurs in a diode with heavy doping and thin junction (here d is small). The electric field that occur due to applied reverse voltage (say V) can be calculated as E = V/d.

So in a Zener breakdown, the electric field necessary to break electrons from covalent bond is achieved with lesser voltage than in avalanche breakdown. The reason is thin depletion layer width. In avalanche breakdown, the depletion layer width is higher and hence much more reverse voltage has to be applied to develop the same electric field strength (necessary enough to break electrons free).

CLIPPING CIRCUITS

A clipping circuit or a clipper is a device used to 'clip' the input voltage to prevent it from attaining a value larger than a predefined one. As you can see in the picture below this device cuts off the positive or negative peak value of a cycle.

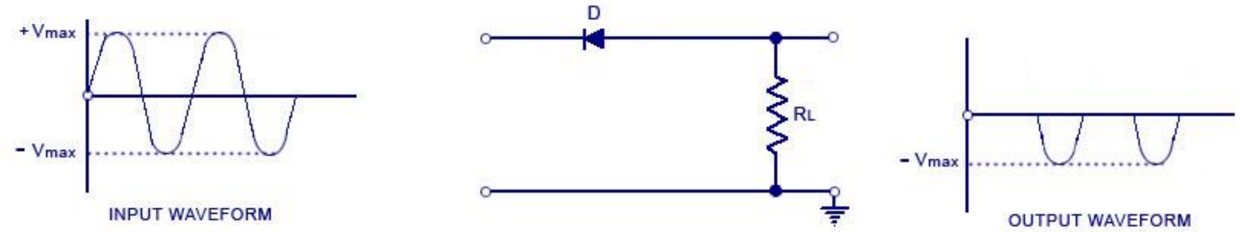
diode clippers are:-

1. Positive clipper and negative clipper
2. Biased positive clipper and biased negative clipper
3. Combination clipper.

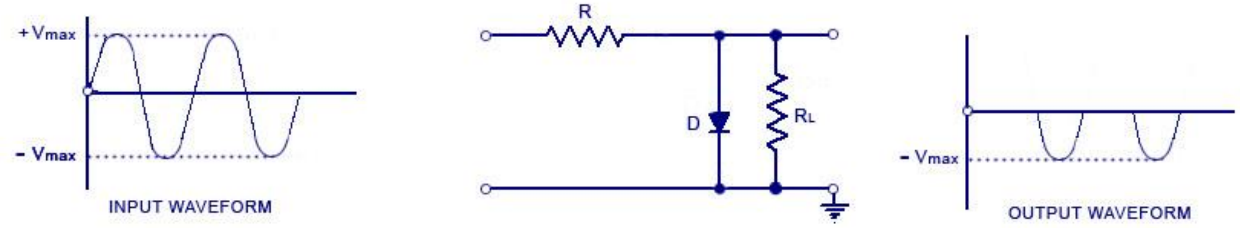
Positive Diode Clipper

In a positive clipper, the positive half cycles of the input voltage will be removed. The circuit arrangements for a positive clipper are illustrated in the figure given below.

Positive Series Clipper and Positive Shunt Clipper



(a) Positive Series Clipper



(b) Positive Shunt Clipper

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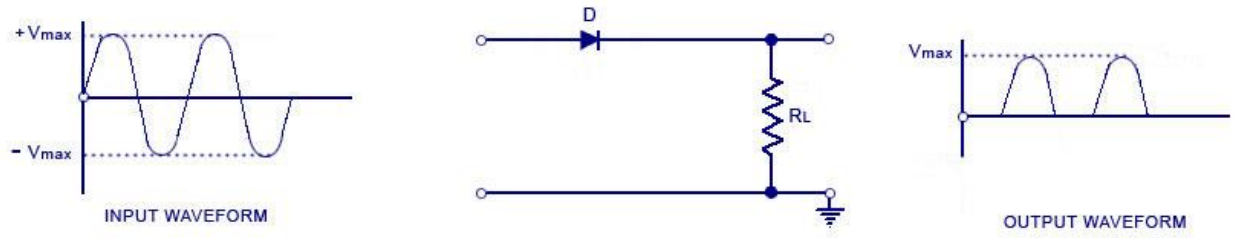
As shown in the figure, the diode is kept in series with the load. During the positive half cycle of the input waveform, the diode 'D' is reverse biased, which maintains the output voltage at 0 Volts. This causes the positive half cycle to be clipped off. During the negative half cycle of the input, the diode is forward biased and so the negative half cycle appears across the output.

In Figure (b), the diode is kept in parallel with the load. This is the diagram of a positive shunt clipper circuit. During the positive half cycle, the diode 'D' is forward biased and the diode acts as a closed switch. This causes the diode to conduct heavily. This causes the voltage drop across the diode or across the load resistance R_L to be zero. Thus output voltage during the positive half cycles is zero, as shown in the output waveform. During the negative half cycles of the input signal voltage, the diode D is reverse biased and behaves as an open switch. Consequently, the entire input voltage appears across the diode or across the load resistance R_L if R is much smaller than R_L
Actually the circuit behaves as a voltage divider with an output voltage of $[R_L / R+ R_L] V_{max} = -V_{max}$ when $R_L >> R$.

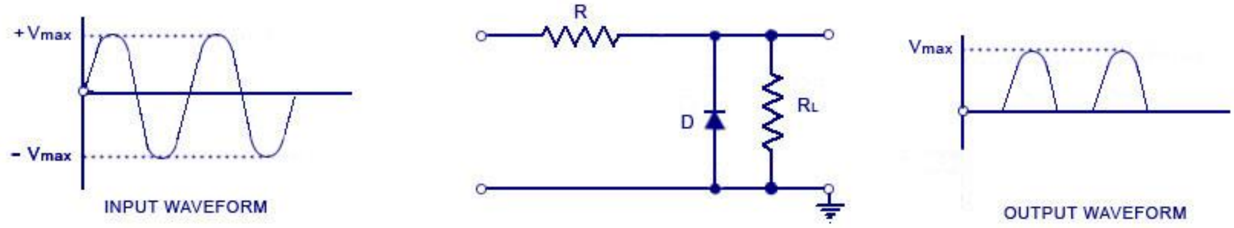
<u>Negative Diode Clipper</u>

The negative clipping circuit is almost the same as the positive clipping circuit, with only one difference. If the diode in figures (a) and (b) is reconnected with reversed polarity, the circuits will become for a negative series clipper and negative shunt clipper respectively. The negative series and negative shunt clippers are shown in figures (a) and (b) as given below.

Negative Series Clipper and Negative Shunt Clipper



(a) Negative Series Clipper



(b) Negative Shunt Clipper

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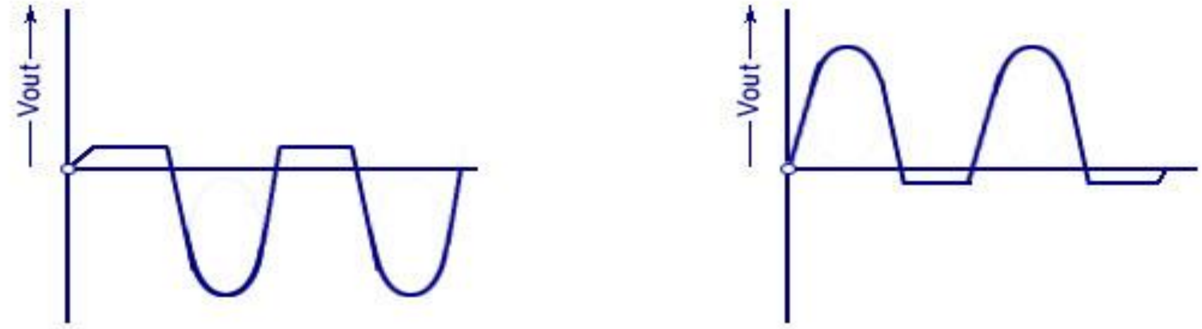
In all the above discussions, the diode is considered to be the ideal one. In a practical diode, the breakdown voltage will exist (0.7 V for silicon and 0.3 V for Germanium). When this is taken into account, the output waveforms for positive and negative clippers will be of the shape shown in the figure below.

Output Waveform - Positive Clipper and Negative Clipper



(a) Output Waveform For Positive Clipper

(b) Output Waveform For Negative Clipper

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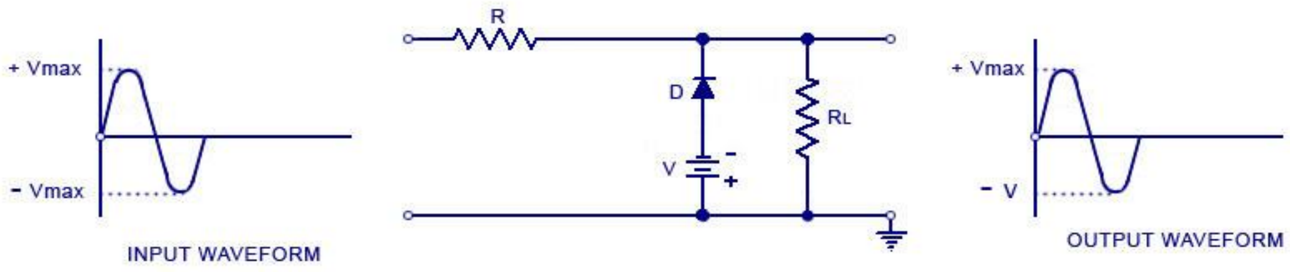
Biased Positive Clipper and Biased Negative Clipper

A biased clipper comes in handy when a small portion of positive or negative half cycles of the signal voltage is to be removed. When a small portion of the negative half cycle is to be removed, it is called a biased negative clipper. The circuit diagram and waveform is shown in the figure below.

BIASED NEGATIVE CLIPPER



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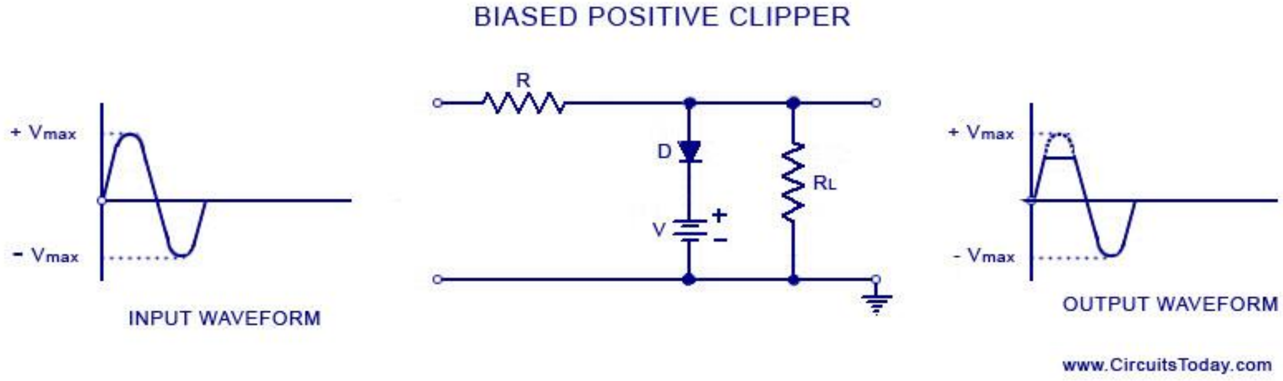
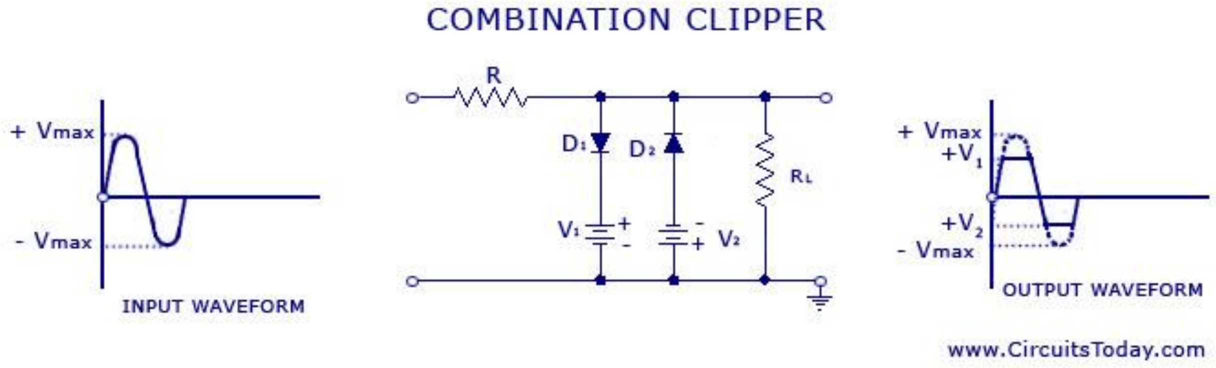
In a biased clipper, when the input signal voltage is positive, the diode ‘D’ is reverse-biased. This causes it to act as an open-switch. Thus the entire positive half cycle appears across the load, as illustrated by output waveform [figure (a)]. When the input signal voltage is negative but does not exceed battery the voltage ‘V’, the diode ‘D’ remains reverse-biased and most of the input voltage appears across the output. When during the negative half cycle of input signal, the signal voltage becomes more than the battery voltage V, the diode D is forward biased and so conducts heavily. The output voltage is equal to ‘- V’ and stays at ‘- V’ as long as the magnitude of the input signal voltage is greater than the magnitude of the battery voltage, ‘V’. Thus a biased negative clipper removes input voltage when the input signal voltage becomes greater than the battery voltage. Clipping can be changed by reversing the battery and diode connections, as illustrated in figure (b).



Combination Clipper

When a portion of both positive and negative of each half cycle of the input voltage is to be clipped (or removed), combination clipper is employed. The circuit for such a clipper is given in the figure below.



The action of the circuit is summarized below. For positive input voltage signal when input voltage exceeds battery voltage ‘+ V_1‘ diode D_1 conducts heavily while diode ‘D_2‘ is reversed biased and so voltage ‘+ V_1‘ appears across the output. This output voltage ‘+ V_1‘ stays as long as. the input signal voltage exceeds ‘+ V_1‘. On the other hand for the negative input voltage signal, the diode ‘D_1‘ remains reverse biased and diode ‘D_2‘ conducts heavily only when input voltage exceeds battery voltage ‘V_2‘ in magnitude. Thus during the negative half cycle the output stays at ‘- V_2‘ so long as the input signal voltage is greater than ‘-V_2‘.

Applications of clipping circuits

- Used in FM transmitters to reduce noise
- To limit the voltage input to a device
- To modify an existing waveform to the desired output.

Clamping Circuit

A clamping circuit is used to place either the positive or negative peak of a signal at a desired level. The dc component is simply added or subtracted to/from the input signal. The clamper is also referred to as an IC restorer and ac signal level shifter.

In some cases, like a TV receiver, when the signal passes through the capacitive coupling network, it loses its dc component. This is when the clamper circuit is used so as to re-establish the dc component into the signal input. Though the dc component that is lost in transmission is not the same as that introduced through a clamping circuit, the necessity to establish the extremity of the positive or negative signal excursion at some reference level is important.

Types of clamping circuits

1. Positive clamper.
2. Negative Clamper.

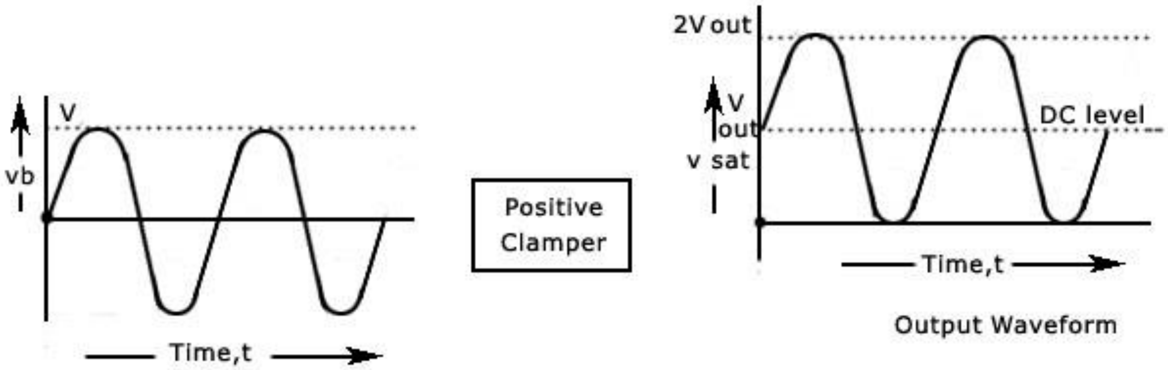
Positive clamper

The circuit will be called a positive clamper, when the signal is pushed upward by the circuit. When the signal moves upward, as shown in figure (a), the negative peak of the signal coincides with the zero level.

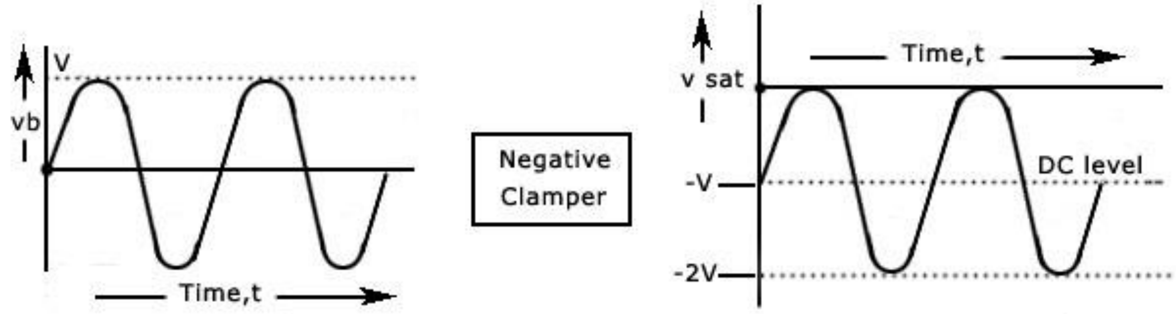
Negative Clamper

The circuit will be called a negative clamper, when the signal is pushed downward by the circuit. When the signal is pushed on the negative side, as shown in figure (b), the positive peak of the input signal coincides with the zero level.

POSITIVE CLAMPING AND NEGATIVE CLAMPING



(a) Positive clamping



(b) Negative clamping

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The important points regarding clamping circuits are:

(i) The shape of the waveform will be the same, but its level is shifted either upward or downward,
(ii) There will be no change in the peak-to-peak or rms value of the waveform due to the clamping circuit. Thus, the input waveform and output waveform will have the same peak-to-peak value that is, $2V_{max}$. This is shown in the figure above. It must also be noted that same reading will be obtained in the ac voltmeter for the input voltage and the clamped output voltage.
(iii) There will be a change in the peak and average values of the waveform. In the figure shown above, the input waveform has a peak value of V_{max} and average value over a complete cycle is zero. The clamped output varies from 2 V_{max} and 0 (or 0 and $-2V_{max}$). Thus ths peak value of the clamped output is $2V_{max}$ and average value is V_{max}.
(iv) The values of the resistor R and capacitor C affect the waveform.

Applications of clamping circuits

- They find some applications in sonar and radar testing
- Used as voltage doublers
- They are used to remove distortions in a circuit
- Used in video processing equipment like TV.

CHAPTER -2

Thermistor:

A **thermistor** is a type of resistor whose resistance is dependent on temperature, more so than in standard resistors.

Uses of Thermistors

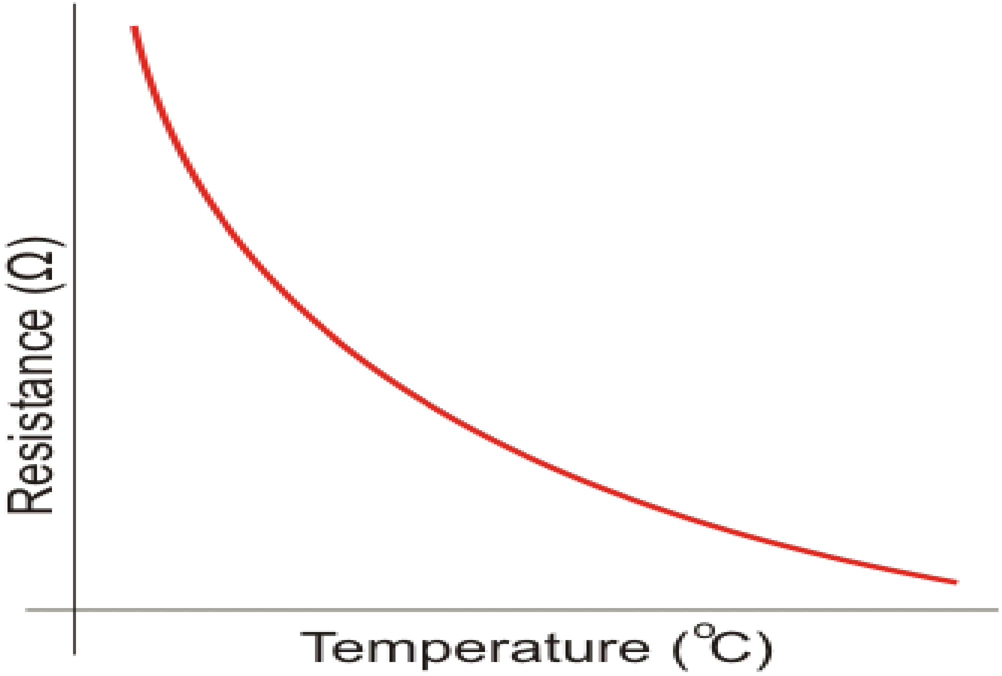
Thermistors have a variety of applications. They are widely used as a way to measure temperature as a thermistor thermometer in many different liquid and ambient air environments. Some of the most common uses of thermistors include:

- Digital thermometers (thermostats)
- Automotive applications (to measure oil and coolant temperatures in cars & trucks)
- Household appliances (like microwaves, fridges, and ovens)
- Circuit protection. (i.e. surge protection)
- Rechargeable batteries (ensure the correct battery temperature is maintained)
- To measure the thermal conductivity of electrical materials.
- Useful in many basic electronic circuits. (e.g. as part of a beginner Arduino starter kit)
- Temperature compensation (i.e. maintain resistance to compensate for effects caused by changes in temperature in another part of the circuit)
- Used in Wheatstone bridge circuits.

How Does a Thermistor Work

The working principle of a thermistor is that its resistance is dependent on its temperature. We can measure the resistance of a thermistor using an ohmmeter. If we know the exact relationship between how changes in the temperature will affect the resistance of the thermistor – then by measuring the thermistor’s resistance we can derive its temperature.

How much the resistance changes depends on the type of material used in the thermistor. The relationship between a thermistor's temperature and resistance is non-linear. A typical thermistor graph is shown below:



Thermistor Construction

To make a thermistor, two or more semiconductor powders made of metallic oxides are mixed with a binder to form a slurry. Small drops of this slurry are formed over the lead wires. For drying purpose, we have to put it into a sintering furnace. During this process, that slurry will shrink onto the lead wires to make an electrical connection. This processed metallic oxide is sealed by putting a glass coating on it. This glass coating gives a waterproof property to the thermistors – helping to improve their stability.

SENSORS:

sensor is a device, module, machine, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics, frequently a computer processor. A sensor is always used with other electronics.

Sensors are used in everyday objects such as touch-sensitive elevator buttons (tactile sensor) and lamps which dim or brighten by touching the base, besides innumerable applications of which most people are never aware. With advances in micromachinery and easy-to-use microcontroller platforms, the uses of sensors have expanded beyond the traditional fields of temperature, pressure or flow measurement,[1] for example into MARG sensors. Moreover, analog sensors such as potentiometers and force-sensing resistors are still widely used. Applications include manufacturing and machinery, airplanes and aerospace, cars, medicine, robotics and many other aspects of our day-to-day life. There are a wide range of other sensors, measuring chemical & physical properties of materials. A few examples include optical sensors for Refractive index measurement, vibrational sensors for fluid viscosity measurement and electro-chemical sensor for monitoring pH of fluids.

BARRETERS:

A battery is a device consisting of one or more electrochemical cells with external connections for powering electrical devices such as flashlights, mobile phones, and electric cars.

Zener diode:

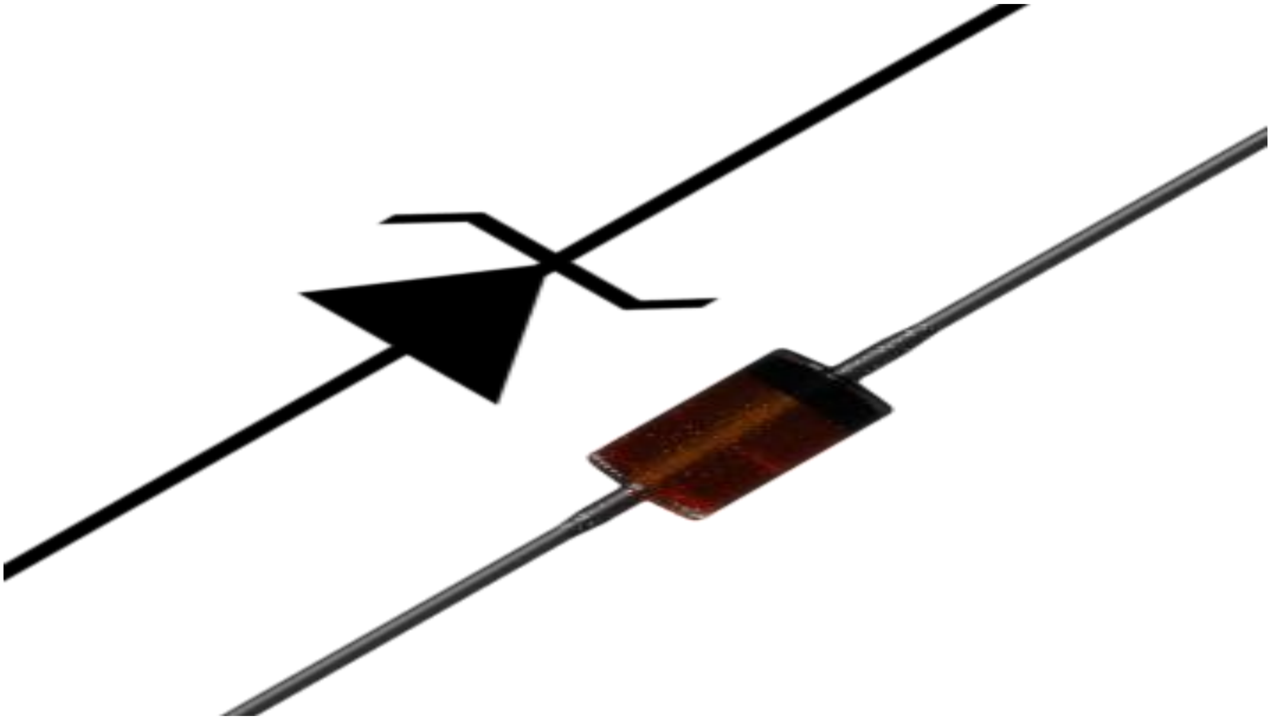
Zener diode is basically like an ordinary PN junction diode but normally operated in reverse biased condition. But ordinary PN junction diode connected in reverse biased condition is not used as Zener diode practically. A Zener diode is a specially designed, highly doped PN junction diode.

Working Principle of Zener Diode

When a PN junction diode is reverse biased, the depletion layer becomes wider. If this reverse biased voltage across the diode is increased continually, the depletion layer becomes more and more wider. At the same time, there will be a constant reverse saturation current due to minority carriers.

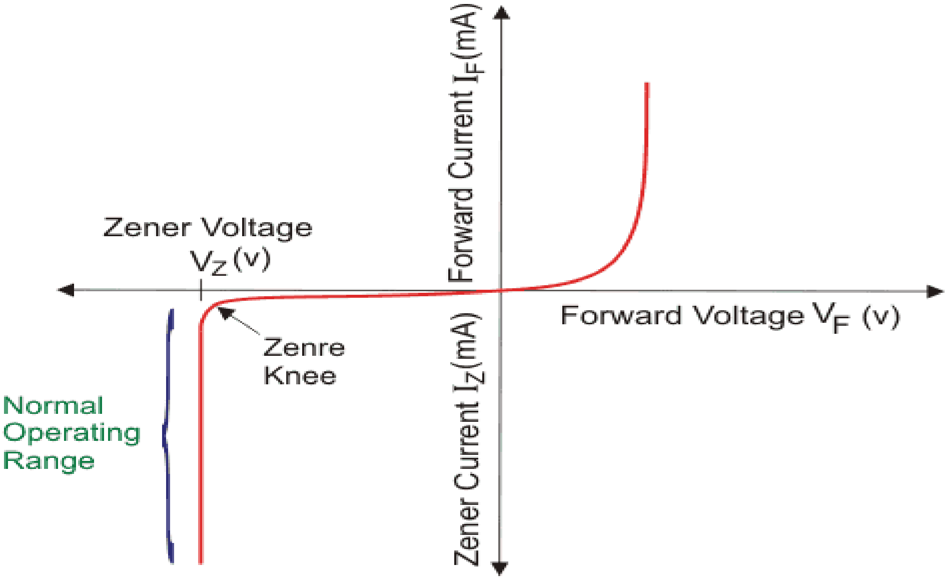
After certain reverse voltage across the junction, the minority carriers get sufficient kinetic energy due to the strong electric field. Free electrons with sufficient kinetic energy collide with stationary ions of the depletion layer and knock out more free electrons. These newly created free electrons also get sufficient kinetic energy due to the same electric field, and they create more free electrons by collision cumulatively. Due to this commutative phenomenon, very soon, huge free electrons get created in the depletion layer, and the entire diode will become conductive. This type of breakdown of the depletion layer is known as avalanche breakdown, but this breakdown is not quite sharp. There is another type of breakdown in depletion layer which is sharper compared to avalanche breakdown, and this is called Zener breakdown. When a PN junction is diode is highly doped, the concentration of impurity atoms will be high in the crystal. This higher concentration of impurity atoms causes the higher concentration of ions in the depletion layer hence for same applied reverse biased voltage, the width of the depletion layer becomes thinner than that in a normally doped diode.

Due to this thinner depletion layer, voltage gradient or electric field strength across the depletion layer is quite high. If the reverse voltage is continued to increase, after a certain applied voltage, the electrons from the covalent bonds within the depletion region come out and make the depletion region conductive. This breakdown is called Zener breakdown. The voltage at which this breakdown occurs is called Zener voltage. If the applied reverse voltage across the diode is more than Zener voltage, the diode provides a conductive path to the current through it hence, there is no chance of further avalanche breakdown in it. Theoretically, Zener breakdown occurs at a lower voltage level then avalanche breakdown in a diode, especially doped for Zener breakdown. The Zener breakdown is much sharper than avalanche breakdown. The Zener voltage of the diode gets adjusted during manufacturing with the help of required and proper doping. When a zener diode is connected across a voltage source, and the source voltage is more than Zener voltage, the voltage across a Zener diode remain fixed irrespective of the source voltage. Although at that condition current through the diode can be of any value depending on the load connected with the diode. That is why we use a Zener diode mainly for controlling voltage in different circuits.



Characteristics of a Zener Diode

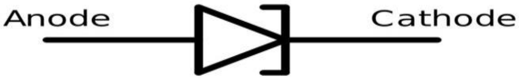
Now, discussing about the diode circuits we should look through the graphical representation of the operation of the **Zener diode**. Normally, it is called the V-I characteristics of a Zener diode.



Tunnel Diode

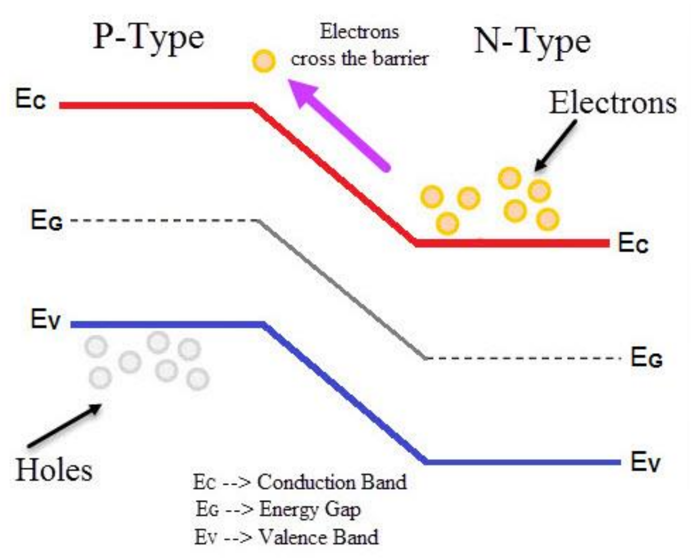
A Tunnel Diode is a heavily doped p-n junction diode. The tunnel diode shows negative resistance. When voltage value increases, current flow decreases. Tunnel diode works based on Tunnel Effect.

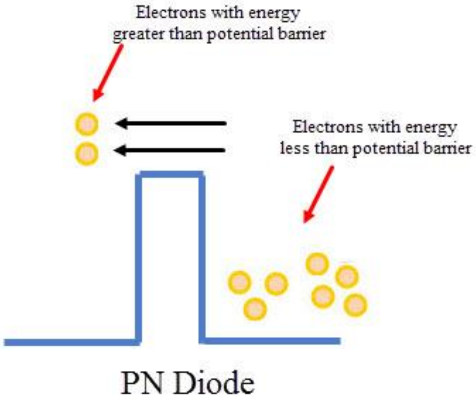
The symbol of a Tunnel Diode.



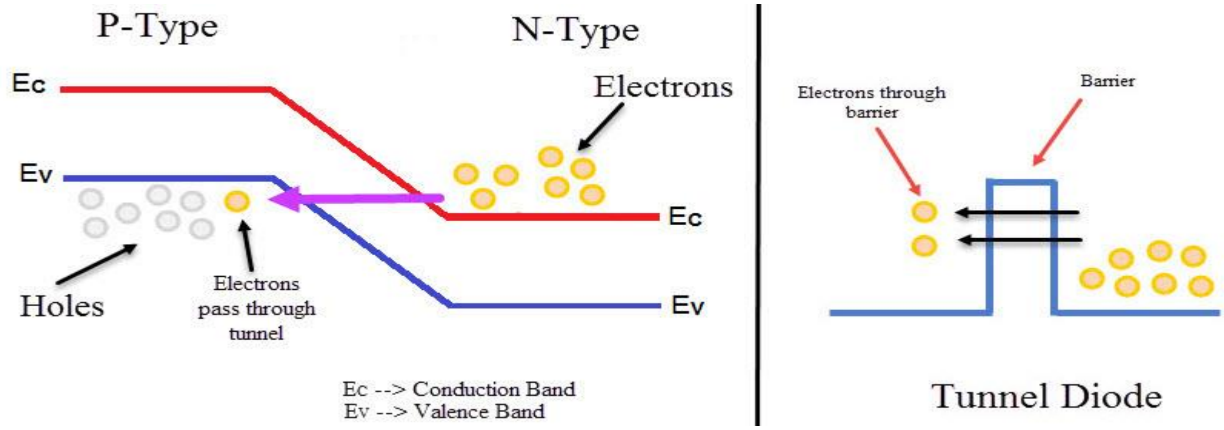
Tunneling Effect

In electronics, Tunneling is known as a direct flow of electrons across the small depletion region from n-side conduction band into the p-side valence band. In a p-n junction diode, both positive and negative ions form the depletion region. Due to these ions, in-built electric potential or electric field is present in the depletion region. This electric field gives an electric force to the opposite direction of externally applied voltage.





As the width of the depletion layer reduces, charge carriers can easily cross the junction. Charge carriers do not need any form of kinetic energy to move across the junction. Instead, carriers punch through junction. This effect is called Tunneling and hence the diode is called Tunnel Diode.



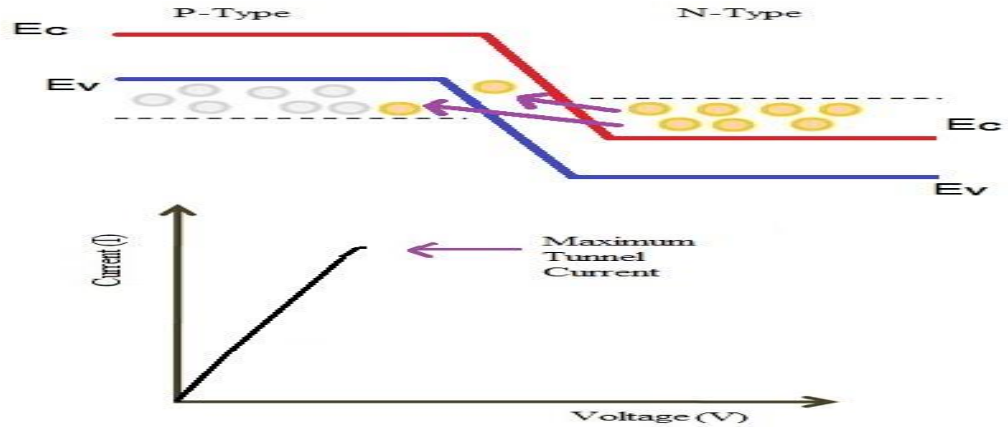
Due to Tunneling, when the value of forward voltage is low value of forward current generated will be high. It can operate in forward biased as well as in reverse biased. Due to high doping, it can operate in reverse biased. Due to the reduction in barrier potential, the value of reverse breakdown voltage also reduces. It reaches a value of zero. Due to this small reverse voltage leads to diode breakdown. Hence, this creates negative resistance region.

Tunnel Diode Working Phenomenon

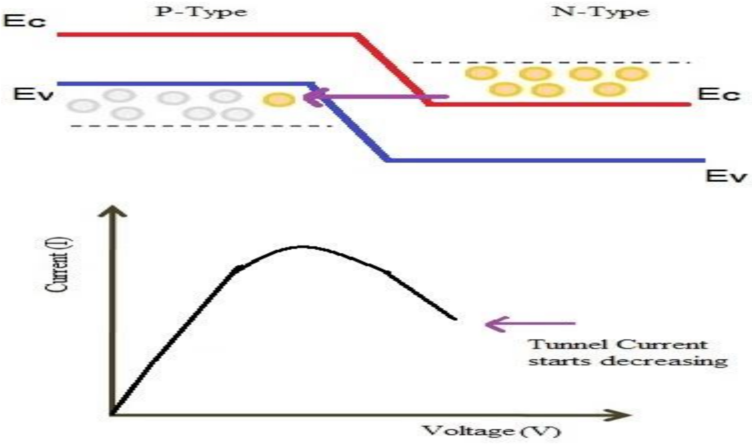
Unbiased Tunnel Diode

In an unbiased tunnel diode, no voltage will be applied to the tunnel diode. Here, due to heavy doping conduction band of n – type semiconductor overlaps with valence band of p – type material. Electrons from n side and holes from p side overlap with each other and they will be at same energy level.

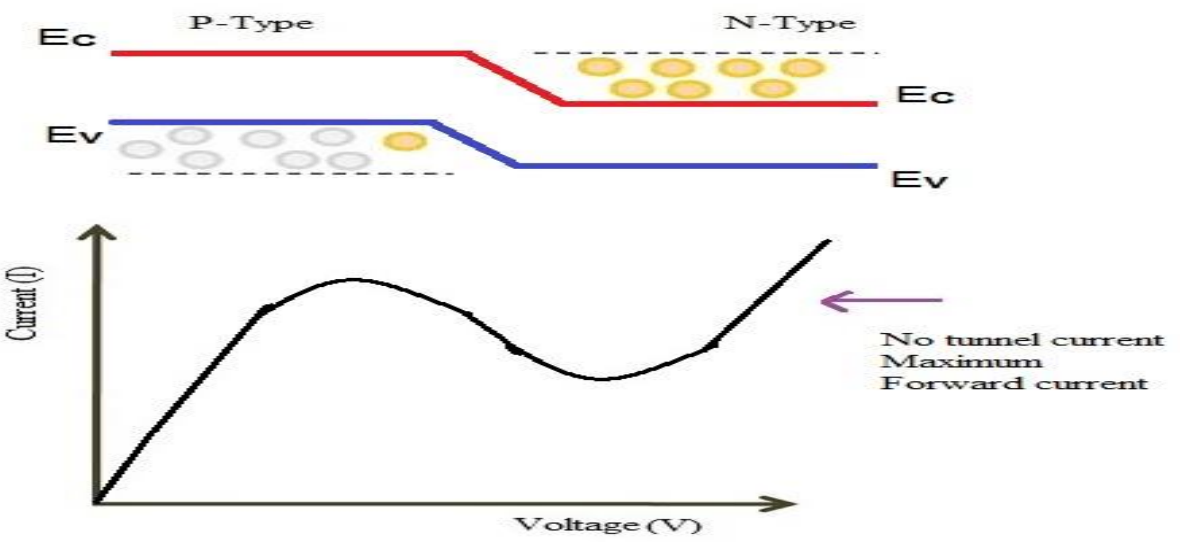
Some electrons tunnel from the conduction band of n-region to the valence band of p-region when temperature increases. Similarly, holes will move from valence band of p-region to the conduction band of n-region. Finally, the net current will be zero since equal numbers of electrons are holes flow in opposite direction.



Small voltage applied



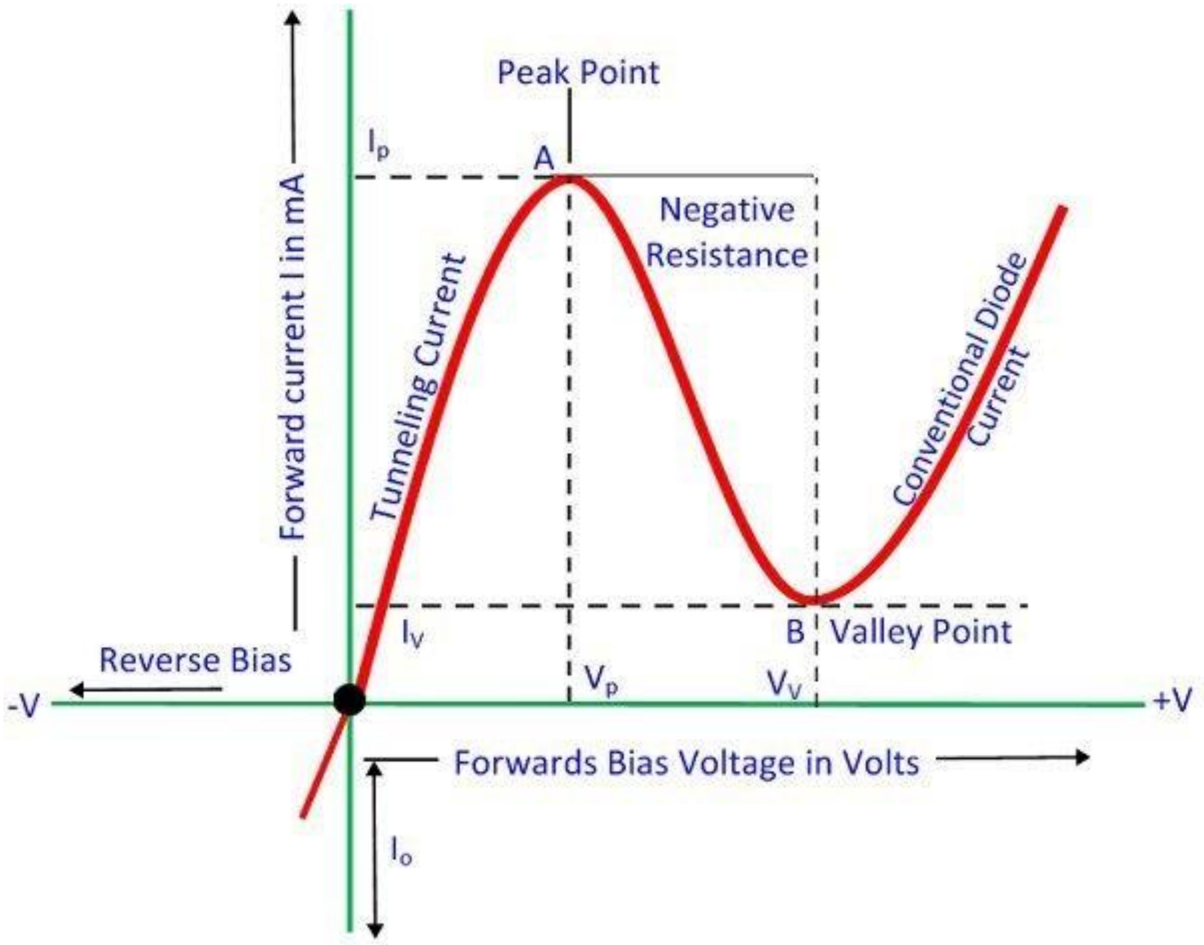
further increase in the applied voltage



Largely Increased Voltage Applied

V-I Characteristics of Tunnel Diode

Due to forward biasing, because of heavy doping conduction happens in the diode. The maximum current that a diode reaches is Ip and voltage applied is Vp. The current value decreases, when more amount of voltage is applied. Current keeps decreasing until it reaches a minimal value.



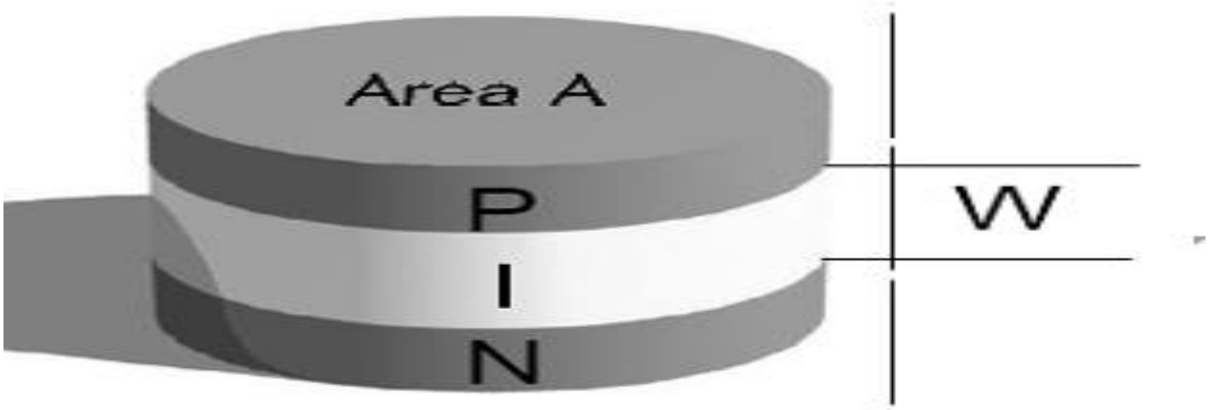
The small minimal value of current is Iv. From the above graph, it is seen that from point A to B current reduces when voltage increases. That is the negative resistance region of diode. In this region, tunnel diode produces power instead of absorbing it.

Applications of Tunnel Diode

- Tunnel diode can be used as a switch, amplifier, and oscillator.
- Since it shows a fast response, it is used as high frequency component.
- Tunnel diode acts as logic memory storage device.
- They are used in oscillator circuits, and in FM receivers. Since it is a low current device, it is not used more.

PIN Diode

The PIN diode is a one type of photo detector, used to convert optical signal into an electrical signal. The PIN diode comprises of three regions, namely P-region, I-region and N-region. Typically, both the P and N regions are heavily doped due to they are utilized for Ohmic contacts.The intrinsic region in the diode is in contrast to a PN junction diode. This region makes the PIN diode an lower rectifier, but it makes it appropriate for fast switches, attenuators, photo detectors and applications of high voltage power electronics.



Structure and Working of PIN Diode

The term PIN diode gets its name from the fact that includes three main layers. Rather than just having a P-type and an N-type layer, it has three layers such as

- P-type layer
- Intrinsic layer
- N-type layer

The working principle of the PIN diode exactly same as a normal diode. The main difference is that the depletion region, because that normally exists between both the P & N regions in a reverse biased or unbiased diode is larger. In any PN junction diode, the P region contains holes as it has been doped to make sure that it has a majority of holes. Likewise the N-region has been doped to hold excess electrons.

The layer between the P & N regions includes no charge carriers as any electrons or holes merge As the depletion region of the diode has no charge carriers it works as an insulator. The depletion region exists within a PIN diode, but if the PIN diode is forward biased, then the carriers come into the depletion region and as the two carrier types get together, the flow of current will starts.

When the PIN diode is connected in forward biased, the charge carriers are very much higher than the level of intrinsic carrier's attention. Due to this reason the electric field and the high level injection level extends deeply into the region. This electric field assists in speeding up of the moving of charge carriers from P to N region, which consequences in quicker operation of the PIN diode, making it an appropriate device for high frequency operations.

Applications of PIN Diode:

- **High Voltage Rectifier** – It is used as a high voltage rectifier. The diode has a large intrinsic region between the N and P-region which can tolerate the high reverse voltage.
- **Photo-detector** – The PIN diode is used for converting the light energy into the electrical energy. The diode has large depletion region which improves their performance by increasing the volume of light conversion.

The PIN diode is most suitable for low voltage applications.