Electronics for 4th semester BSc Physics, Pondicherry University

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1 Introduction

Certain substances like germanium, silicon, carbon etc. are neither good conductors like copper nor insulators like glass. The resistivity of these materials lies in between conductors and insulators. Such substances are classified as semiconductors. A semiconductor is a substance which has resistivity (10^4 to 0.5 Ωm) in between conductors and insulators e.g. germanium, silicon, selenium, carbon etc. However, it will be wrong to consider the semiconductor as a resistance material. For example, nichrome, which is one of the highest resistance material, has resistivity much lower than germanium. This shows that electrically germanium cannot be regarded as a conductor or insulator or a resistance material. This gave such substances like germanium the name of semiconductors. Semiconductors have a number of peculiar properties which distinguish them from conductors, insulators and resistance materials.

Semiconductors can be pure elements, such as silicon or germanium, or compounds such as gallium arsenide or cadmium selenide. Most common semiconducting materials are crystalline solids, but amorphous and liquid semiconductors are also known. These include hydrogenated amorphous silicon and mixtures of arsenic, selenium and tellurium in a variety of proportions.

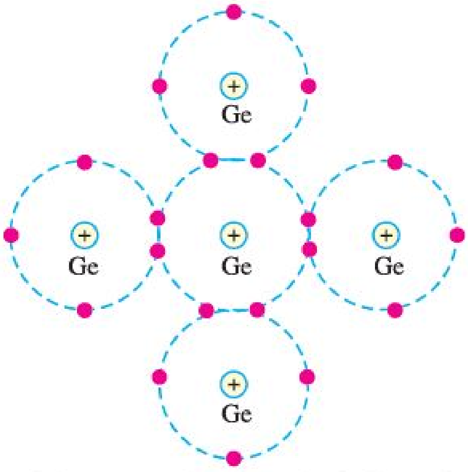
1.1 Properties of Semiconductors

1. The resistivity of a semiconductor is less than an insulator but more than a conductor.
2. Semiconductors have negative temperature co-efficient of resistance i.e. the resistance of a semiconductor decreases with the increase in temperature and vice-versa. For example, germanium is actually an insulator at low temperatures but it becomes a good conductor at high temperatures.
3. When a suitable metallic impurity (e.g. arsenic, gallium etc.) is added to a semiconductor, its current conducting properties change appreciably.

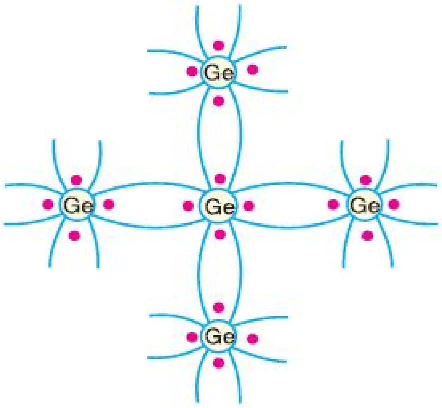
1.1.1 Bond Structure of Elemental Semiconductors - Si & Ge

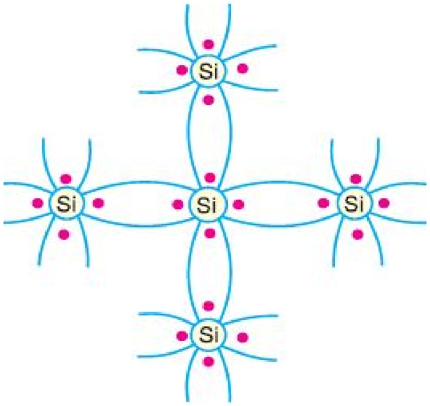
In Si and Ge semiconductors, bonds are formed by sharing of valence electrons. Such bonds are called co-valent bonds. In the formation of a co-valent bond, each atom contributes equal number of valence electrons and the contributed electrons are shared by the atoms engaged in the formation of the bond. A germanium atom has 32 electrons. First orbit has 2 electrons, second 8 electrons, third 18 electrons and the fourth orbit has 4 electrons. A silicon atom has 14 electrons - 2,8,4.

A germanium atom has 4 valence electrons. It is the tendency of each germanium atom to have 8 electrons in the last orbit. To do so, each germanium atom positions itself between four other germanium atoms as shown in Fig. Each neighbouring atom shares one valence electron with the central atom. In this business of sharing, the central atom completes its last orbit by having 8 electrons revolving around the nucleus. In this way, the central atom sets up co-valent bonds.



COVALENT BONDS AMONG Ge ATOMS





The two most frequently used materials are germanium (Ge) and silicon (Si). It is because the energy required to break their co-valent bonds (i.e. energy required to release an electron from their valence bands) is very small; being about 0.7 eV for germanium and about 1.1 eV for silicon. Like germanium, silicon atoms are also arranged in an orderly manner. Therefore, silicon has **crystalline structure**.

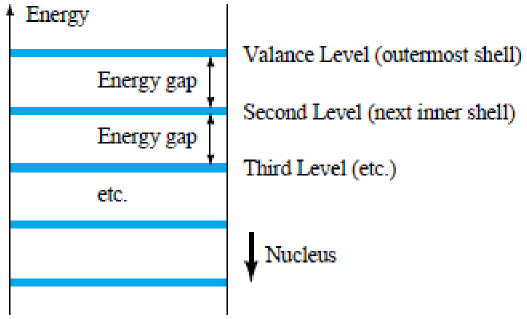
Although the covalent bond will result in a stronger bond between the valence electrons and their parent atom, it is still possible for the valence electrons to absorb sufficient kinetic energy from natural causes to break the covalent bond and assume the "free" state. The term free reveals that their motion is quite sensitive to applied electric fields such as established by voltage sources or any difference in potential. These natural causes include effects such as light energy in the form of photons and thermal energy from the surrounding medium. At room temperature there are approximately 1.5×10^{10} free carriers in a cubic centimeter of intrinsic silicon material. At the same temperature, intrinsic germanium material will have approximately 2.5×10^{13} free carriers per cubic centimeter. The ratio of the number of carriers in germanium to that of silicon is greater than 103 and would indicate that germanium is a better conductor at room temperature. This may be true, but both are still considered poor conductors in the intrinsic state.

Intrinsic materials are those semiconductors that have been carefully refined to reduce the impurities to a very low level - essentially as pure as can be made available through modern technology.

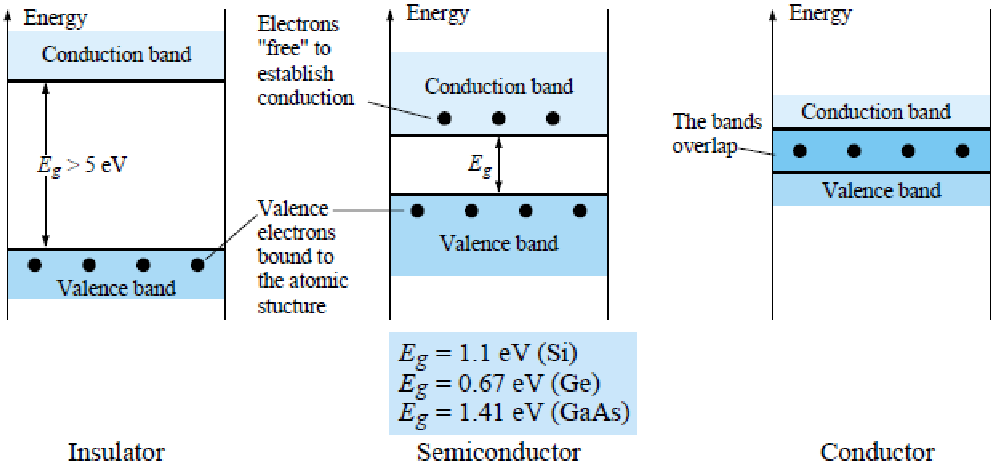
An increase in temperature of a semiconductor can result in a substantial increase in the number of free electrons in the material. As the temperature rises from absolute zero (0 K), an increasing number of valence electrons absorb sufficient thermal energy to break the covalent bond and contribute to the number of free carriers as described above. This increased number of carriers will increase the conductivity index and result in a lower resistance level. Semiconductor materials such as Ge and Si that show a reduction in resistance with increase in temperature are said to have a negative temperature coefficient.

2 Energy Band Structure of Semiconductors

A semiconductor can be defined much more comprehensively on the basis of **energy bands** than on the basis of resistivity. In the isolated atomic structure there are discrete (individual) energy levels associated with each orbiting electron, as shown in Fig.



Each material will, in fact, have its own set of permissible energy levels for the electrons in its atomic structure. The more distant the electron from the nucleus, the higher the energy state, and any electron that has left its parent atom has a higher energy state than any electron in the atomic structure.



Between the discrete energy levels are gaps in which no electrons in the isolated atomic structure can appear. As the atoms of a material are brought closer together to form the crystal lattice structure, there is an interaction between atoms that will result in the electrons in a particular orbit of one atom having slightly different energy levels from electrons in the same orbit of an adjoining atom. The net result is an expansion of the discrete levels of possible energy states for the valence electrons to that of bands as shown in Fig. Note that there are boundary levels and maximum energy states in which any electron in the atomic lattice can find itself, and there remains a forbidden region between the valence band and the ionization level. Ionization is the mechanism whereby an electron can absorb sufficient energy to break away from the atomic structure and enter the conduction band.

2.1 Effect of temperature

At 0 K or absolute zero (-273.15^0C), all the valence electrons of semiconductor materials find themselves locked in their outermost shell of the atom with energy levels associated with the valence band of Fig. 1.8b. However, at room temperature (300 K, 25C) a large number of valence electrons have acquired sufficient energy to leave the valence band, cross the energy gap defined by Eg in Fig. and enter the conduction band. For silicon Eg is 1.1 eV, for germanium 0.67 eV, and for gallium arsenide 1.41 eV. The obviously lower Eg for germanium accounts for the increased number of carriers in that material as compared to silicon at room temperature. Note for the insulator that the energy gap is typically 5 eV or more, which severely limits the number of electrons that can enter the conduction band at room temperature. The conductor has electrons in the conduction band even at 0 K. Quite obviously, therefore, at room temperature there are more than enough free carriers to sustain a heavy flow of charge, or current.

If certain impurities are added to the intrinsic semiconductor materials, energy states in the forbidden bands will occur which will cause a net reduction in Eg for both semiconductor materials - consequently, increased carrier density in the conduction band at room temperature

3 Intrinsic & Extrinsic Semiconductors

3.1 Intrinsic Semiconductors

A semiconductor in an extremely pure form is known as an intrinsic semiconductor. In an intrinsic semiconductor, even at room temperature, hole-electron pairs are created. The total number of free electrons in the conduction band will be equal to the total number of holes in the valance bandand the net charge is zero.

When electric field is applied across an intrinsic semiconductor, the current conduction takes place by two processes, namely ; by free electrons and holes. The free electrons are produced due to the breaking up of some covalent bonds by thermal energy. At the same time, holes are created in the covalent bonds. Under the influence of electric field, conduction through the semiconductor is by both free electrons and holes. Therefore, the total current inside the semiconductor is the sum of currents due to free electrons and holes.

3.2 Extrinsic Semiconductor

The intrinsic semiconductor has little current conduction capability at room temperature. To be useful in electronic devices, the pure semiconductor must be altered so as to significantly increase its conducting properties. This is achieved by adding a small amount of suitable impurity to a semiconductor. It is then called impurity or extrinsic semiconductor. The process of adding impurities to a semiconductor is known as doping. The amount and type of such impurities have to be closely controlled during the preparation of extrinsic semiconductor. Generally, for 108 atoms of semiconductor, one impurity atom is added.

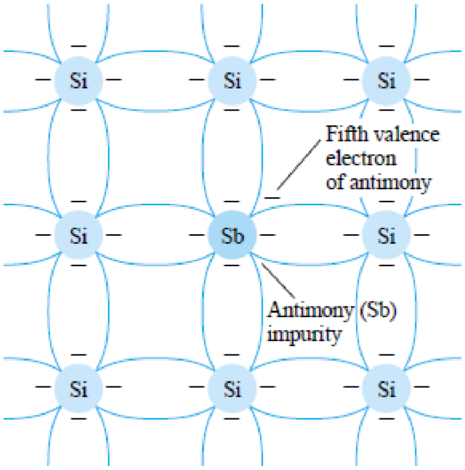
The characteristics of semiconductor materials can be altered significantly by the addition of certain impurity atoms into the relatively pure semiconductor material. These impurities, although only added to perhaps 1 part in 10 million, can alter the band structure sufficiently to totally change the electrical properties of the material. A semiconductor material that has been subjected to the doping process is called an extrinsic material.

The purpose of adding impurity is to increase either the number of free electrons or holes in the semiconductor crystal. As we shall see, if a pentavalent impurity (having 5 valence electrons) is added to the semiconductor, a large number of free electrons are produced in the semiconductor. On the other hand, addition of trivalent impurity (having 3 valence electrons) creates a large number of holes in the semiconductor crystal. Depending upon the type of impurity added, extrinsic semiconductors are classified into: **n-type and p-type**

3.2.1 n-Type Material

Both the n- and p-type materials are formed by adding a predetermined number of impurity atoms into a germanium or silicon base. The n-type is created by introducing those impurity elements that have five valence electrons (**pentavalent**), such as antimony, arsenic, and phosphorus. The effect of such impurity elements is indicated in Fig. (using antimony as the impurity in a silicon base). Note that the four covalent bonds are still present. There is, however, an additional fifth electron due to the impurity atom, which is unassociated with any particular covalent bond. This remaining electron, loosely bound to its parent (antimony) atom, is relatively free to move within the newly formed n-type material. Since the inserted impurity atom has donated a relatively free electron to the structure.

Diffused impurities with five valence electrons are called **donor atoms**.



It is important to realize that even though a large number of “free” carriers have been established in the n-type material, it is still electrically neutral since ideally the number of positively charged protons in the nuclei is still equal to the number of “free” and orbiting negatively charged electrons in the structure. The effect of this doping process on the relative conductivity can best be described through the use of the energy-band diagram of Fig. Note that a discrete energy level (called the donor level) appears in the forbidden band with an Eg significantly less than that of the intrinsic material. Those free electrons due to the added impurity sit at this energy level and have less difficulty absorbing a sufficient measure of thermal energy to move into the conduction band at room temperature. The result is that at room temperature, there are a large number of carriers (electrons) in the conduction level and the conductivity of the material increases significantly. At room temperature in an intrinsic Si material there is about one free electron for every 10^{12} atoms (1 to 10^9 for Ge). If our dosage level were 1 in 10 million (10^7), the ratio (10^5) would indicate that the carrier concentration has increased by a ratio of 100,000:1.

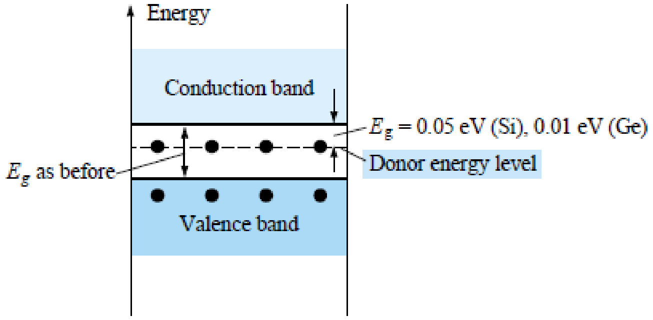
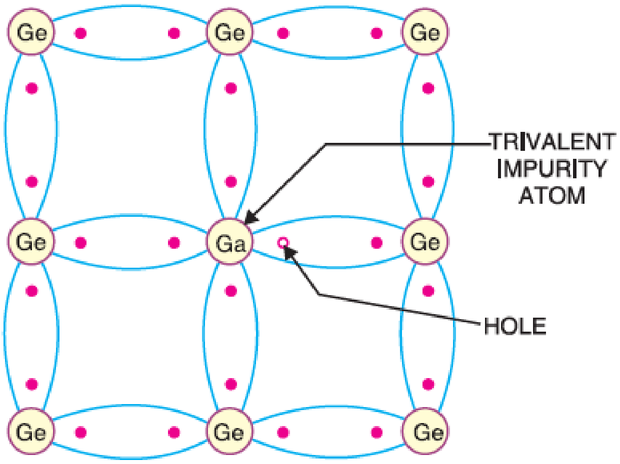


Figure 1.10 Effect of donor impurities on the energy band structure.

3.2.2 p-Type Material

The p-type material is formed by doping a pure germanium or silicon crystal with impurity atoms having three valence electrons. The elements most frequently used for this purpose are boron, gallium, and indium



Note that there is now an insufficient number of electrons to complete the covalent bonds of the newly formed lattice. The resulting vacancy is called a hole and is represented by a small circle or positive sign due to the absence of a negative charge. Since the resulting vacancy will readily accept a “fre” electron: The diffused impurities with three valence electrons are called acceptor atoms. The resulting p-type material is electrically neutral, for the same reasons described for the n-type material.

The addition of trivalent impurity has produced a large number of holes. However, there are a few conduction band electrons due to thermal energy associated with room temperature. But the holes far outnumber the conduction band electrons. It is due to the predominance of holes over free electrons that it is called p-type semiconductor (p stands for positive).

n-type as well as p-type semiconductor is electrically neutral

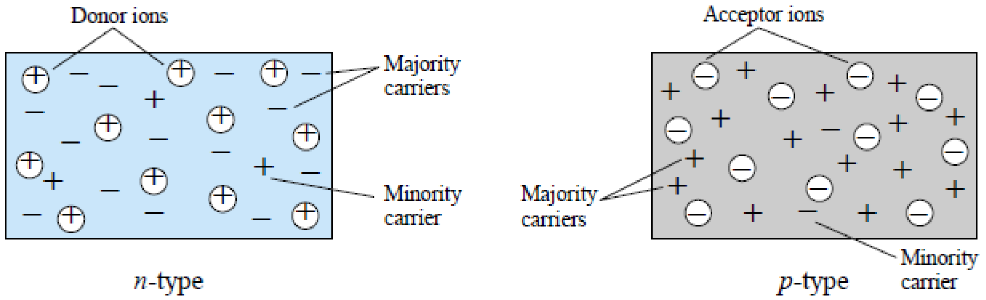
3.3 Majority and Minority Carriers

In the intrinsic state, the number of free electrons in Ge or Si is due only to those few electrons in the valence band that have acquired sufficient energy from thermal or light sources to break the covalent bond or to the few impurities that could not be removed. The vacancies left behind in the covalent bonding structure represent our very limited supply of holes. In an n-type material, the number of holes has not changed significantly from this intrinsic level. The net result, therefore, is that the number of electrons far outweighs the number of holes. For this reason:

In an n-type material the electron is called the majority carrier and the hole the minority carrier.

For the p-type material the number of holes far outweighs the number of electrons, as shown in Fig. Therefore:

In a p-type material the hole is the majority carrier and the electron is the minority carrier.



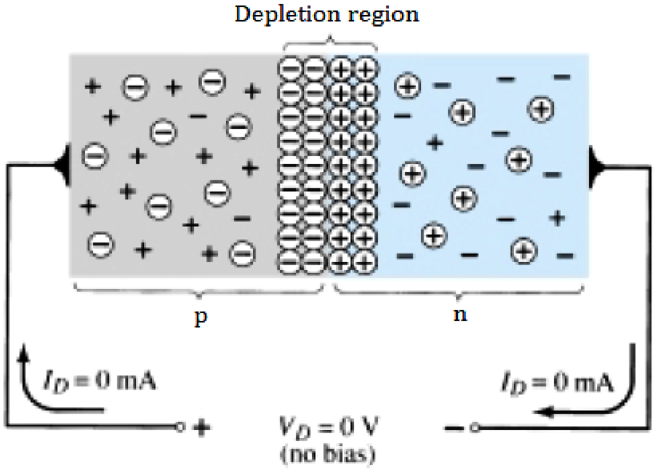
When the fifth electron of a donor atom leaves the parent atom, the atom remaining acquires a net positive charge: hence the positive sign in the donor-ion representation. For similar reasons, the negative sign appears in the acceptor ion. The n- and p-type materials represent the basic building blocks of semiconductor devices. We will find in the next section that the “joining” of a single n-type material with a p-type material will result in a semiconductor element of considerable importance in electronic systems.

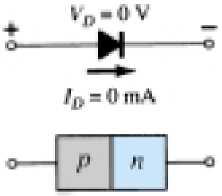
4 pn junction diode

When a p-type semiconductor is suitably joined to n-type semiconductor, the contact surface is called pn junction

The semiconductor diode is formed by simply bringing these materials together (constructed from the same base — Ge or Si), as shown in Fig., using techniques to be described in Chapter 20. At the instant the two materials are “joined” the electrons and holes in the region of the junction will combine, resulting in a lack of carriers in the region near the junction. This region of uncovered positive and negative ions is called the **depletion region** due to the depletion of carriers in this region.

Once pn junction is formed and depletion layer created, the diffusion of free electrons stops. In other words, the depletion region acts as a **barrier** to the further movement of free electrons across the junction. The positive and negative charges set up an electric field. The electric field is a barrier to the free electrons in the n-region. There exists a potential difference across the depletion layer and is called **barrier potential** (V_B).The barrier potential of a pn junction depends upon several factors including the type of semiconductor material, the amount of doping and temperature. The typical barrier potential is approximately: For silicon, 0.7 V ; For germanium, 0.3 V





No-bias conditions
for a semiconductor diode

Since the diode is a two-terminal device, the application of a voltage across its terminals leaves three possibilities: no bias ($V_D = 0V$), forward bias ($V_D > 0V$), and reverse bias ($V_D < 0V$). Each is a condition that will result in a response that the user must clearly understand if the device is to be applied effectively.

Under no-bias (no applied voltage) conditions, any minority carriers (holes) in the n-type material that find themselves within the depletion region will pass directly into the p-type material. The closer the minority carrier is to the junction, the greater the attraction for the layer of negative ions and the less the opposition of the positive ions in the depletion region of the n-type material. For the purposes of future discussions we shall assume that all the minority carriers of the n-type material that find themselves in the depletion region due to their random motion will pass directly into the p-type material. Similar discussion can be applied to the minority carriers (electrons) of the p-type material. This carrier flow has been indicated in Fig. for the minority carriers of each material.

The majority carriers (electrons) of the n-type material must overcome the attractive forces of the layer of positive ions in the n-type material and the shield of negative ions in the p-type material to migrate into the area beyond the depletion region of the p-type material. However, the number of majority carriers is so large in the n-type material that there will invariably be a small number of majority carriers with sufficient kinetic energy to pass through the depletion region into the p-type material. Again, the same type of discussion can be applied to the majority carriers (holes) of the p-type material. The resulting flow due to the majority carriers is also shown in Fig.

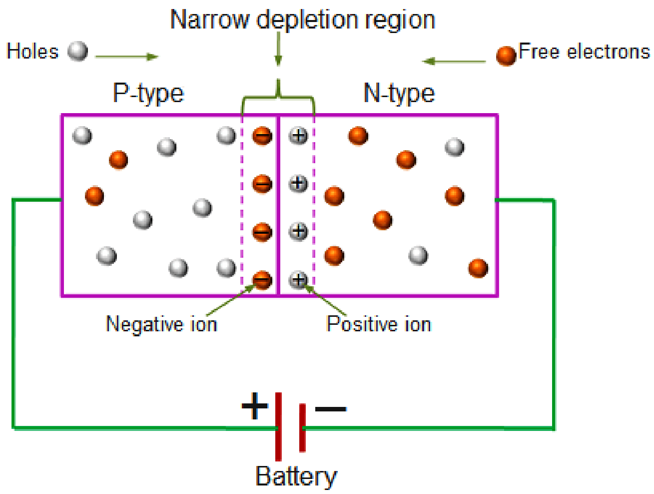
In the absence of an applied bias voltage, the net flow of charge in any one direction for a semiconductor diode is zero.

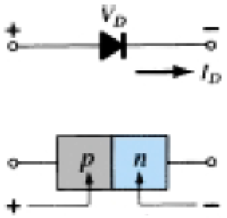
4.1 Applying D.C. Voltage Across pn Junction or Biasing a pn Junction

In electronics, the term bias refers to the use of d.c. voltage to establish certain operating conditions for an electronic device. In relation to a pn junction, there are following two bias conditions : 1. Forward biasing and 2. Reverse biasing

4.1.1 Forward biasing $V_D > 0V$

When external d.c. voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called forward biasing. To apply forward bias, connect positive terminal of the battery to p-type and negative terminal to n-type as shown in Fig. . The applied forward potential establishes an electric field which acts against the field due to potential barrier. Therefore, the resultant field is weakened and the barrier height is reduced at the junction as shown in Fig. 5.21. As potential barrier voltage is very small (0.1 to 0.3 V), therefore, a small forward voltage is sufficient to completely eliminate the barrier. Once the potential barrier is eliminated by the forward voltage, junction resistance becomes almost zero and a low resistance path is established for the entire circuit. Therefore, current flows in the circuit. This is called forward current.





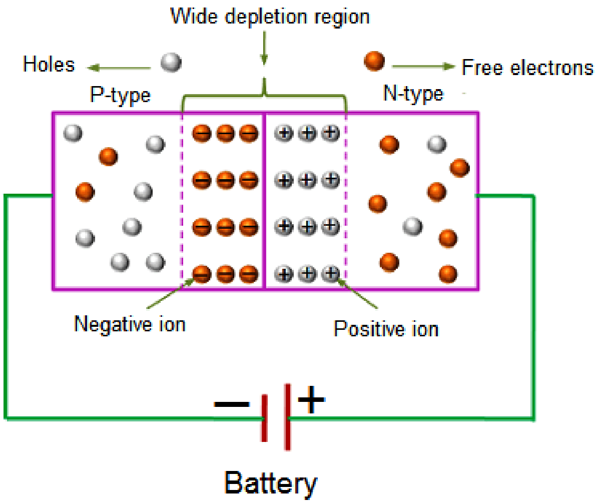
Forward-bias conditions for a semiconductor diode.

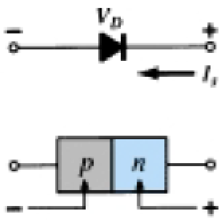
The potential barrier is reduced and at some forward voltage (0.1 to 0.3 V), it is eliminated altogether. The junction offers low resistance (called forward resistance) to current flow. Current flows in the circuit due to the establishment of low resistance path. The magnitude of current depends upon the applied forward voltage.

4.1.2 Reverse biasing $V_D < 0V$

When the external d.c. voltage applied to the junction is in such a direction that potential barrier is increased, it is called reverse biasing. To apply reverse bias, connect negative terminal of the battery to p-type and positive terminal to n-type as shown in Fig. It is clear that applied reverse voltage establishes an electric field which acts in the same direction as the field due to potential barrier. Therefore, the resultant field at the junction is strengthened and the barrier height is increased as shown in Fig. 5.22. The increased potential barrier prevents the flow of charge carriers across the junction. Thus, a high resistance path is established for the entire circuit and hence the current does not flow. The potential barrier is increased. The junction offers very high resistance (called reverse resistance) to current flow. No current flows in the circuit due to the establishment of high resistance path.

Thus with reverse bias to the junction, a high resistance path is established and hence no current flow occurs. On the other hand, with forward bias to the junction, a low resistance path is set up and hence current flows in the circuit.

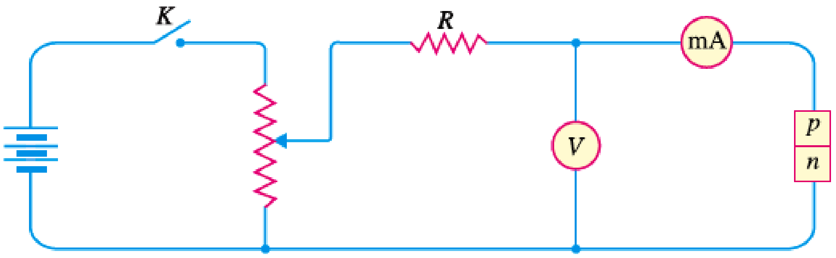




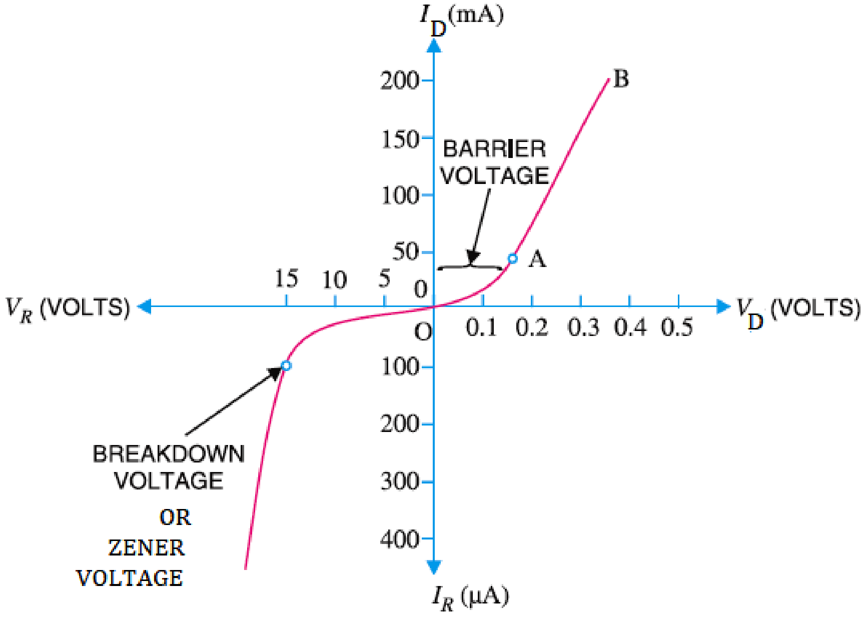
Reverse-bias conditions for a semiconductor diode.

4.2 Volt - Ampere Characteristics of pn Junction

Volt-ampere or V-I characteristic of a pn junction (also called a crystal or semiconductor diode) is the curve between voltage across the junction and the circuit current. Usually, voltage is taken along X-axis and current along Y-axis. Fig. shows the circuit arrangement for determining the V-I characteristics of a pn junction. The characteristics can be studied under three heads, namely; zero external voltage, forward bias and reverse bias.



(i) Zero external voltage. When the external voltage is zero, i.e. circuit is open at K, the potential barrier at the junction does not permit current flow. Therefore, the circuit current is zero as indicated by point O (ii) Forward bias. With forward bias to the pn junction i.e. p-type connected to positive terminal and n-type connected to negative terminal, the potential barrier is reduced. At some forward voltage (0.7 V for Si and 0.3 V for Ge), the potential barrier is altogether eliminated and current starts flowing in the circuit. From now onwards, the current increases with the increase in forward voltage. Thus, a rising curve OB is obtained with forward bias as shown in Fig. From the forward characteristic, it is seen that at first (region OA),the current increases very slowly and the curve is non-linear. It is because the external applied voltage is used up in overcoming the potential barrier. However, once the external voltage exceeds the potential barrier voltage, the pn junction behaves like an ordinary conductor. Therefore, the current rises very sharply with increase in external voltage (region AB on the curve). The curve is almost linear.



(iii) Reverse bias. With reverse bias to the pn junction i.e. p-type connected to negative terminal and n-type connected to positive terminal, potential barrier at the junction is increased. Therefore, the junction resistance becomes very high and practically no current flows through the circuit. However, in practice, a very small current (of the order of μA) flows in the circuit with reverse bias as shown in the reverse characteristic. This is called reverse saturation current (Is) and is due to the minority carriers. It may be recalled that there are a few free electrons in p-type material and a few holes in n-type material. These undesirable free electrons in p-type and holes in n-type are called minority carriers. As shown in Fig., to these minority carriers, the applied reverse bias appears as forward bias. Therefore, a small current flows in the reverse direction. If reverse voltage is increased continuously, the kinetic energy of electrons (minority carriers) may become high enough to knock out electrons from the semiconductor atoms. At this stage breakdown of the junction occurs, characterized by a sudden rise of reverse current and a sudden fall of the resistance of barrier region. This may destroy the junction permanently.

The forward current through a pn junction is due to the majority carriers produced by the impurity. However, reverse current is due to the minority carriers produced due to breaking of some co-valent bonds at room temperature.

Breakdown voltage or Zener voltage - It is the minimum reverse voltage at which pn junction breaks down with sudden rise in reverse current.

Under normal reverse voltage, a very little reverse current flows through a pn junction. However, if the reverse voltage attains a high value, the junction may break down with sudden rise in reverse current. Even at room temperature, some hole-electron pairs (minority carriers) are produced in the depletion layer. With reverse bias, the electrons move towards the positive terminal of supply. At large reverse voltage, these electrons acquire high enough velocities to dislodge valence electrons from semiconductor atoms as shown in Fig. The newly liberated electrons in turn free other valence electrons. In this way, we get an avalanche of free electrons. Therefore, the pn junction conducts a very large reverse current. Once the breakdown voltage is reached, the high reverse current may damage the junction.

Knee voltage - It is the forward voltage at which the current through the junction starts to increase rapidly. When a diode is forward biased, it conducts current very slowly until we overcome the potential barrier. For silicon pn junction, potential barrier is 0.7 V whereas it is 0.3 V for germanium junction. Knee voltage for silicon diode is 0.7 V and 0.3 V for germanium diode. Once the applied forward voltage exceeds the knee voltage, the current starts increasing rapidly. It may be added here that in order to get useful current through a pn junction, the applied voltage must be more than the knee voltage.

4.3 Limitations in the Operating Conditions of pn Junction

Every pn junction has limiting values of maximum forward current, peak inverse voltage and maximum power rating. The pn junction will give satisfactory performance if it is operated within these limiting values. However, if these values are exceeded, the pn junction may be destroyed due to excessive heat.

(i) **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.

(ii) **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. A pn junction i.e. a crystal diode is used as a rectifier to change alternating current into direct current. In such applications, care should be taken that reverse voltage across the diode during negative half-cycle of a.c. does not exceed the PIV of diode.

(iii) **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.

4.4 Diode Equation

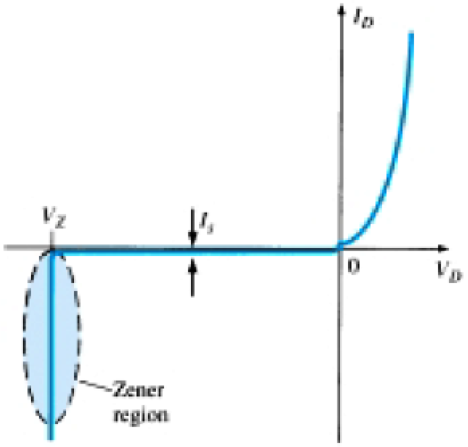
It can be demonstrated through the use of solid-state physics that the general characteristics of a semiconductor diode can be defined by the following equation for the forward- and reverse-bias regions:

$$\boxed{I_D = I_S[e^{(kV_D/T_K)} - 1]}$$

where I_S is the reverse saturation current, $k = 11,600/\eta$ with $\eta = 1$ for Ge and 2 for Si for relatively low levels of diode current (at or below the knee of the curve) and 1 for Ge and Si for higher levels of diode current (in the rapidly increasing section of the curve) and T_K is the temperature in Kelvin scale.

4.5 Breakdown Mechanisms

There is a point where the application of too negative a voltage will result in a sharp change in the characteristics, as shown in Fig. The current increases at a very rapid rate in a direction opposite to that of the positive voltage region. The reverse-bias potential that results in this dramatic change in characteristics is called the **Zener potential or breakdown voltage** and is given the symbol V_Z.



4.5.1 Avalanche Breakdown

As the voltage across the diode increases in the reverse-bias region, the velocity of the minority carriers responsible for the reverse saturation current Is will also increase. Eventually, their velocity and associated kinetic energy will be sufficient to release additional carriers through collisions with otherwise stable atomic structures. That is, an ionization process will result whereby valence electrons absorb sufficient energy to leave the parent atom. These additional carriers can then aid the ionization process to the point where a high avalanche current is established and the avalanche breakdown region determined.

The avalanche region (V_Z) can be brought closer to the vertical axis by increasing the doping levels in the p- and n-type materials.

4.5.2 Zener Breakdown

As V_Z decreases to very low levels, such as -5 V, another mechanism, called **Zener breakdown**, will contribute to the sharp change in the characteristic. It occurs because there is a strong electric field in the region of the junction that can disrupt the bonding forces within the atom and “generate” carriers. Although the Zener breakdown mechanism is a significant contributor only at lower levels of V_Z, this sharp change in the characteristic at any level is called the Zener region and diodes employing this unique portion of the characteristic of a p-n junction are called Zener diodes. They are described in detail in Section 1.14. The Zener region of the semiconductor diode described must be avoided if the response of a system is not to be completely altered by the sharp change in characteristics in this reverse-voltage region.

The maximum reverse-bias potential that can be applied before entering the Zener region is called the peak inverse voltage (referred to simply as the PIV rating) or the peak reverse voltage (denoted by PRV rating). If an application requires a PIV rating greater than that of a single unit, a number of diodes of the same characteristics can be connected in series. Diodes are also connected in parallel to increase the current-carrying capacity.

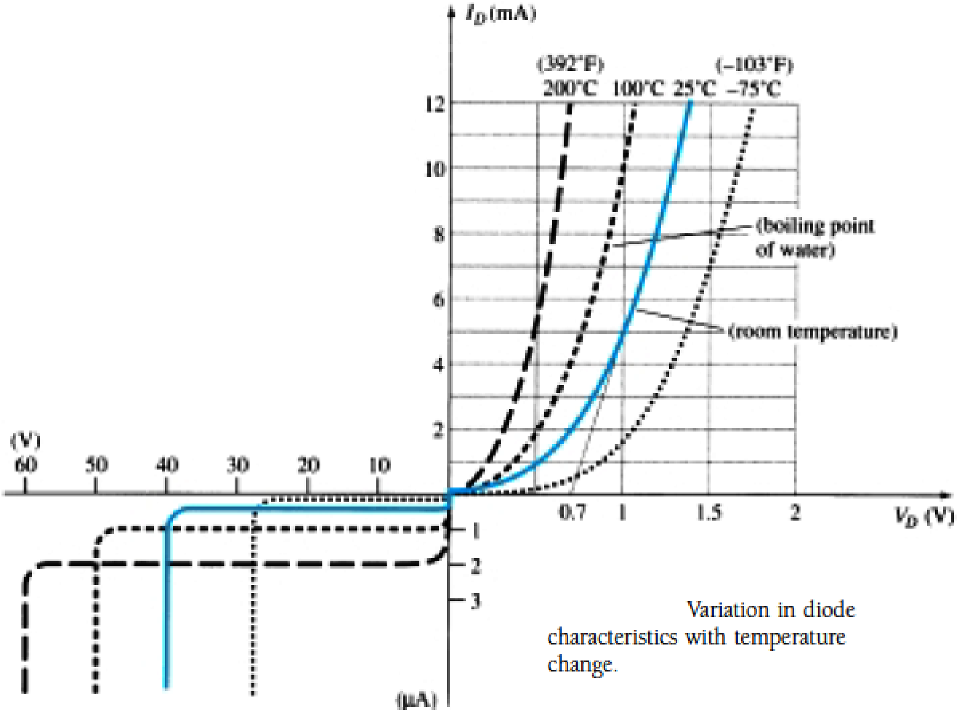
4.6 Silicon vs Germanium

Silicon diodes have, in general, higher PIV and current rating and wider temperature ranges than germanium diodes. PIV ratings for silicon can be in the neighborhood of 1000 V, whereas the maximum value for germanium is closer to 400 V. Silicon can be used for applications in which the temperature may rise to about 200 ^0C whereas germanium has a much lower maximum rating (100 ^0C). The disadvantage of silicon, however, as compared to germanium is the higher forward-bias voltage required to reach the region of upward swing. It is typically of the order of magnitude of 0.7 V for commercially available silicon diodes and 0.3 V for germanium diodes when rounded off to the nearest tenths

4.7 Effect of temperature on pn junction diode

Temperature can have a marked effect on the characteristics of a silicon semiconductor diode. It has been found experimentally that:

The reverse saturation current Is will just about double in magnitude for every 10 ^0C increase in temperature



Variation in diode characteristics with temperature change.

It is not uncommon for a germanium diode with an I_S in the order of 1 or 2 μA at 25 ^0C to have a leakage current of 100 $\mu A = 0.1$ mA at a temperature of 100 ^0C. Current levels of this magnitude in the reverse-bias region would certainly question our desired open-circuit condition in the reverse-bias region. Typical values of Is for silicon are much lower than that of germanium for similar power and current levels. The result is that even at high temperatures the levels of I_S for silicon diodes do not reach the same high levels obtained for germanium - a very important reason that silicon devices enjoy a significantly higher level of development and utilization in design. Fundamentally, the open-circuit equivalent in the reverse bias region is better realized at any temperature with silicon than with germanium.

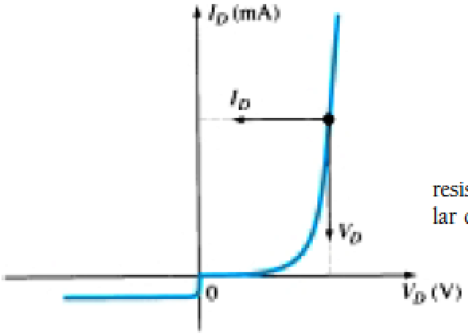
The increasing levels of I_S with temperature account for the lower levels of threshold voltage. Of course, the level of T_K also will be increasing in the same equation, but the increasing level of I_S will overpower the smaller percent change in T_K. As the temperature increases the forward characteristics are actually becoming more "ideal," but we will find when we review the specifications sheets that temperatures beyond the normal operating range can have a very detrimental effect on the diode's maximum power and current levels. In the reverse-bias region the breakdown voltage is increasing with temperature, but note the undesirable increase in reverse saturation current.

4.8 Diode Resistance

4.8.1 DC or Static Resistance

The application of a dc voltage to a circuit containing a semiconductor diode will result in an operating point on the characteristic curve that will not change with time. The resistance of the diode at the operating point can be found simply by finding the corresponding levels of V_D and I_D and applying the following equation:

boxed[R$_D = \frac{V_D}{I_D}$
The dc resistance levels at the knee and below will be greater than the resistance levels obtained for the vertical rise section of the characteristics. The resistance levels in the reverse-bias region will naturally be quite high. Since ohmmeters typically employ a relatively constant-current source, the resistance determined will be at a preset current level (typically, a few milliamperes).



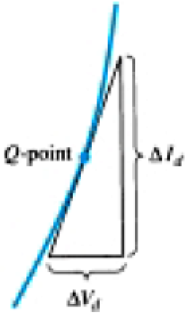
Determining the dc resistance of a diode at a particular operating point.

4.8.2 AC or Dynamic Resistance

The dc resistance of a diode is independent of the shape of the characteristic in the region surrounding the point of interest. If a sinusoidal rather than dc input is applied, the situation will change completely. The varying input will move the instantaneous operating point up and down a region of the characteristics and thus defines a specific change in current and voltage. With no applied varying signal, the point of operation would be the Q-point appearing on Fig. determined by the applied dc levels. The designation Q-point is derived from the word quiescent, which means "**still or unvarying**."

A straight line drawn tangent to the curve through the Q-point as shown in Fig. will define a particular change in voltage and current that can be used to determine the ac or dynamic resistance for this region of the diode characteristics. An effort should be made to keep the change in voltage and current as small as possible and equidistant to either side of the Q-point. In equation form,

$$\boxed{r_D = \frac{\Delta V_d}{\Delta I_d}}$$



Determining the ac resistance at a Q-point.

For Ge and Si, at room temperature,

$$\boxed{r_D = \frac{26\ mV}{I_d}}$$

5 Rectifiers

In a large number of electronic circuits, we require DC voltage for operation. We can easily convert the AC voltage or AC current into DC voltage or DC current by using a device called P-N junction diode.

A rectifier is an electrical device that converts an Alternating Current (AC) into a Direct Current (DC) by using one or more P-N junction diodes.

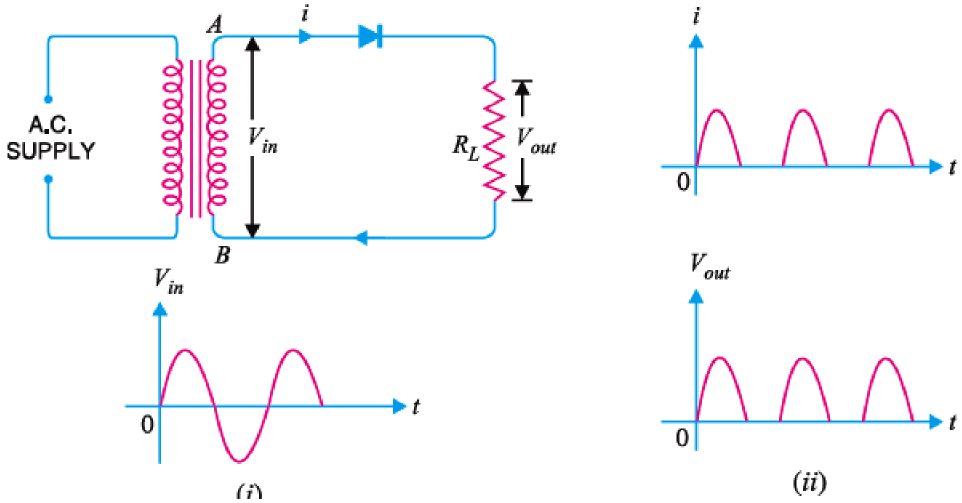
One of the most important applications of a P-N junction diode is the rectification of Alternating Current (AC) into Direct Current (DC). A P-N junction diode allows electric current in only forward bias condition and blocks electric current in reverse bias condition. In simple words, a diode allows electric current in one direction. This unique property of the diode allows it to acts like a rectifier.

The rectifiers are mainly classified into two types: Half wave rectifier and Full wave rectifier

5.1 Half wave rectifier

As the name suggests, the half wave rectifier is a type of rectifier which converts half of the AC input signal (positive half cycle) into pulsating DC output signal and the remaining half signal (negative half cycle) is blocked or lost. In half wave rectifier circuit, we use only a single diode.

In half-wave rectification, the rectifier conducts current only during the positive half-cycles of input a.c. supply. The negative half-cycles of a.c. supply are suppressed i.e. during negative half-cycles, no current is conducted and hence no voltage appears across the load. Therefore, current always flows in one direction (i.e. d.c.) through the load though after every half-cycle



The a.c. voltage across the secondary winding AB changes polarities after every half-cycle. During the positive half-cycle of input a.c. voltage, end A becomes positive w.r.t. end B. This makes the diode forward biased and hence it conducts current. During the negative half-cycle, end A is negative w.r.t. end B. Under this condition, the diode is reverse biased and it conducts no current. Therefore, current flows through the diode during positive half-cycles of input a.c. voltage only ; it is blocked during the negative half-cycles. In this way, current flows through load RL always in the same direction. Hence d.c. output is obtained across RL.

It may be noted that output across the load is **pulsating d.c**. These pulsations in the output are further smoothened with the help of **filter circuits** . The pulsating DC current always flows in one direction like the pure DC current. However, the value of pulsating DC current or pulsating DC voltage slightly changes over a given period. The electric current produced by batteries, power supplies, and solar panels is a pure DC current.

By using the combination of components such as capacitors, inductors, and resistors in the circuit, we can achieve the smoothening of pulsating DC to pure DC.

The output frequency of a half-wave rectifier is equal to the input frequency (50 Hz).

5.1.1 Efficiency of a Half-Wave Rectifier

The ratio of d.c. power output to the applied input a.c. power is known as rectifier efficiency i.e.

Rectifier efficiency, = d.c. power output/Input a.c. power

Let $v = V_m \sin\theta$ be the alternating voltage that appears across the secondary winding. Let r_f and R_L be the diode resistance and load resistance respectively. The diode conducts during positive half-cycles of a.c. supply while no current conduction takes place during negative half-cycles.

d.c. power - The output current is pulsating direct current. Therefore, in order to find d.c. power, average current has to be found out.

$$P_{dc} = I_{dc}^2 R_L$$

$$P_{dc} = \frac{{I_m}^2}{\pi} R_L$$

a.c. power input : The a.c. power input is given by

$$P_{ac} = I_{rms}^2 (r_f + R_L)$$

$$P_{ac} = \frac{I_m}{2}^2 (r_f + R_L)$$

$$\begin{aligned} Efficiency &= \frac{P_{dc}}{P_{ac}} \\ &= \frac{\frac{I_m}{\pi}^2 R_L}{\frac{I_m}{2}^2 (r_f + R_L)} \\ &= \frac{0.406}{1 + r_F/R_L} \end{aligned}$$

The efficiency will be maximum if r_f is negligible as compared to R_L. Max. rectifier efficiency = 40.6 %. This shows that in half-wave rectification, a maximum of 40.6 % of a.c. power is converted into d.c. power.

5.2 Full wave rectifier

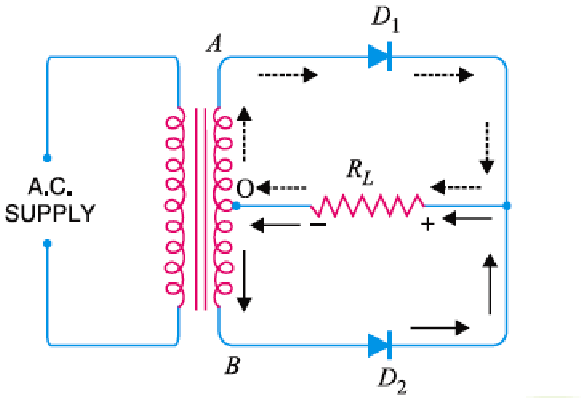
The full wave rectifier is a type of rectifier which converts the full AC input signal (positive half cycle and negative half cycle) to pulsating DC output signal. Unlike the half wave rectifier, the input signal is not wasted in full wave rectifier. The efficiency of full wave rectifier is high as compared to the half wave rectifier.

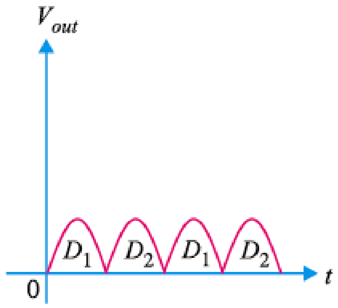
In full-wave rectification, current flows through the load in the same direction for both half-cycles of input a.c. voltage. This can be achieved with two diodes working alternately. For the positive halfcycle of input voltage, one diode supplies current to the load and for the negative half-cycle, the other diode does so ; current being always in the same direction through the load. Therefore, a full-wave rectifier utilises both half-cycles of input a.c. voltage to produce the d.c. output. The following two circuits are commonly used for full-wave rectification - (i) Centre-tap full-wave rectifier (ii) Full-wave bridge rectifier

5.2.1 Centre-tap full-wave rectifier

The circuit employs two diodes D1 and D2 as shown in Fig. A centre tapped secondary winding AB is used with two diodes connected so that each uses one half-cycle of input a.c. voltage. In other words, diode D1 utilises the a.c. voltage appearing across the upper half (OA) of secondary winding for rectification while diode D2 uses the lower half winding OB.

During the positive half-cycle of secondary voltage, the end A of the secondary winding becomes positive and end B negative. This makes the diode D1 forward biased and diode D2 reverse biased. Therefore, diode D1 conducts while diode D2 does not. The conventional current flow is through diode D1, load resistor RL and the upper half of secondary winding as shown by the dotted arrows. During the negative half-cycle, end A of the secondary winding becomes negative and end B positive. Therefore, diode D2 conducts while diode D1 does not. The conventional current flow is through diode D2, load RL and lower half winding as shown by solid arrows. It may be seen that current in the load RL is in the same direction for both half-cycles of input a.c. voltage. Therefore, d.c. is obtained across the load R_L. Also, the polarities of the d.c. output across the load should be noted.

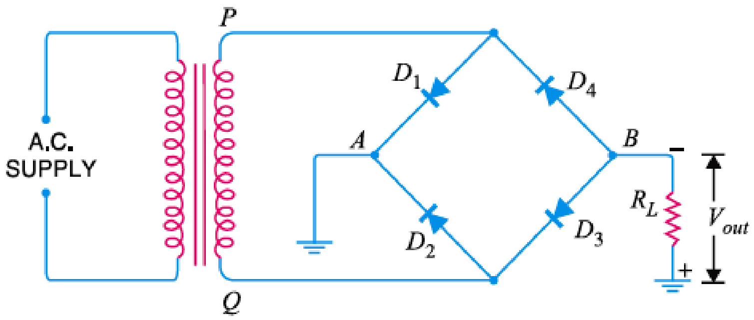


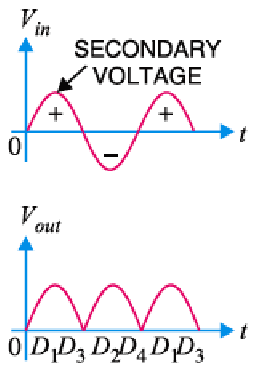


Peak inverse voltage - Suppose V_m is the maximum voltage across the half secondary winding. Fig. 6.25 shows the circuit at the instant secondary voltage reaches its maximum value in the positive direction. At this instant, diode D1 is conducting while diode D2 is non-conducting. Therefore, whole of the secondary voltage appears across the non-conducting diode. Consequently, the peak inverse voltage is twice the maximum voltage across the half-secondary winding i.e. $PIV = 2V_m$

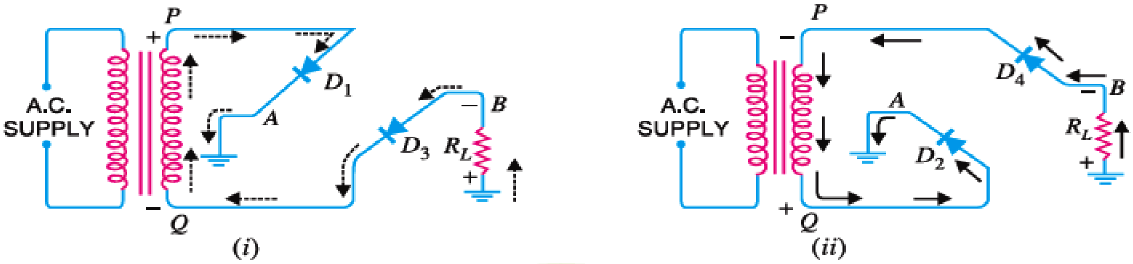
5.2.2 Full-Wave Bridge Rectifier

The need for a centre tapped power transformer is eliminated in the bridge rectifier. It contains four diodes D1, D2, D3 and D4 connected to form bridge as shown in Fig. 6.26. The a.c. supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer. Between other two ends of the bridge, the load resistance RL is connected.





During the positive half-cycle of secondary voltage, the end P of the secondary winding becomes positive and end Q negative. This makes diodes D1 and D3 forward biased while diodes D2 and D4 are reverse biased. Therefore, only diodes D1 and D3 conduct. These two diodes will be in series through the load RL as shown in Fig. The conventional current flow is shown by dotted arrows. It may be seen that current flows from A to B through the load RL . During the negative half-cycle of secondary voltage, end P becomes negative and end Q positive. This makes diodes D2 and D4 forward biased whereas diodes D1 and D3 are reverse biased. Therefore, only diodes D2 and D4 conduct. These two diodes will be in series through the load RL as shown in Fig. The current flow is shown by the solid arrows. It may be seen that again current flows from A to B through the load i.e. in the same direction as for the positive half-cycle. Therefore, d.c. output is obtained across load R_L.



In bridge rectifier, the peak inverse voltage is the maximum voltage $PIV = V_m$
The output frequency of a full-wave rectifier is double the input frequency.

5.2.3 Efficiency of a full wave rectifier

The ratio of d.c. power output to the applied input a.c. power is known as rectifier efficiency i.e.

Rectifier efficiency, = d.c. power output/Input a.c. power

Let $v = V_m \sin\theta$ be the alternating voltage that appears across the secondary winding. Let r_f and R_L be the diode resistance and load resistance respectively.

d.c. power - The output current is pulsating direct current. Therefore, in order to find d.c. power, average current has to be found out.

$$P_{dc} = I_{dc}^2 R_L$$

$$P_{dc} = \frac{2I_m}{\pi}^2 R_L$$

a.c. power input : The a.c. power input is given by

$$P_{ac} = I_{rms}^2 (r_f + R_L)$$

$$P_{ac} = \frac{I_m}{\sqrt{2}}^2 (r_f + R_L)$$

$$\begin{aligned} Efficiency &= \frac{P_{dc}}{P_{ac}} \\ &= \frac{\frac{2I_m}{\pi}^2 R_L}{\frac{I_m}{\sqrt{2}}^2 (r_f + R_L)} \\ &= \frac{0.812}{1 + r_F/R_L} \end{aligned}$$

The efficiency will be maximum if r_f is negligible as compared to R_L. Max. rectifier efficiency = 81.2 %. This is double the efficiency due to half-wave rectifier. Therefore, a full-wave rectifier is twice as effective as a half-wave rectifier

5.3 Ripple Factor

The output of a rectifier consists of a d.c. component and an a.c. component (also known as ripple). The a.c. component is undesirable and accounts for the pulsations in the rectifier output. The effectiveness of a rectifier depends upon the magnitude of a.c. component in the output ; the smaller this component, the more effective is the rectifier.

The ratio of r.m.s. value of a.c. component to the d.c. component in the rectifier output is known as **ripple factor** i.e.

Ripple factor = r.m.s. value of a.c component of voltage (or current)/ value of d.c. component of voltage (or current) = $\frac{I_{ac}}{I_{dc}}$

The smaller the ripple factor, the lesser the effective a.c. component and hence more effective is the rectifier

$$\begin{aligned}
I_{rms} &= \sqrt{I_{ac}^2 + I_{dc}^2} \\
I_{ac} &= \sqrt{I_{rms}^2 - I_{dc}^2} \\
\textit{Dividing throughout by } I_{dc}, & \\
\frac{I_{ac}}{I_{dc}} &= \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2} \\
Ripple\ \ Factor &= \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1}
\end{aligned}$$

For half-wave rectification, $I_{rms} = \frac{I_m}{2} =, I_{dc} = \frac{I_m}{\pi}$

So Ripple factor for half-wave rectification is 1.21

It is clear that a.c. component exceeds the d.c. component in the output of a half-wave rectifier. This results in greater pulsations in the output. Therefore, half-wave rectifier is ineffective for conversion of a.c. into d.c.

For full-wave rectification, $I_{rms} = \frac{I_m}{\sqrt{2}}, I_{dc} = \frac{2I_m}{\pi}$

So Ripple factor for half-wave rectification is 0.48

This shows that in the output of a full-wave rectifier, the d.c. component is more than the a.c. component. Consequently, the pulsations in the output will be less than in half-wave rectifier. For this reason, full-wave rectification is invariably used for conversion of a.c. into d.c.

5.3.1 Average dc Voltages

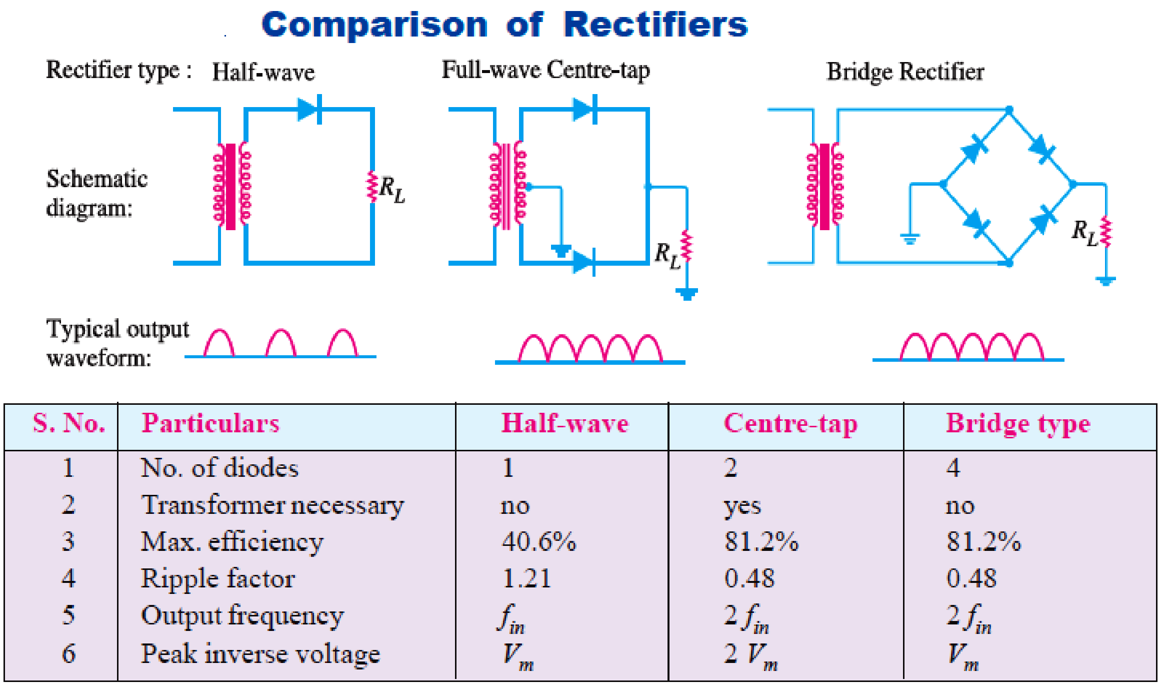
The average dc output voltage of a half-wave rectifier is

$$\boxed{V_{dc} = 0.318(V_m - V_T)}$$

where V_m is the maximum value of ac input signal to be rectified and V_T is the barrier potential of Si diode

For a full-wave rectifier,

$$\boxed{V_{dc} = 0.636(V_m - 2V_T)}$$



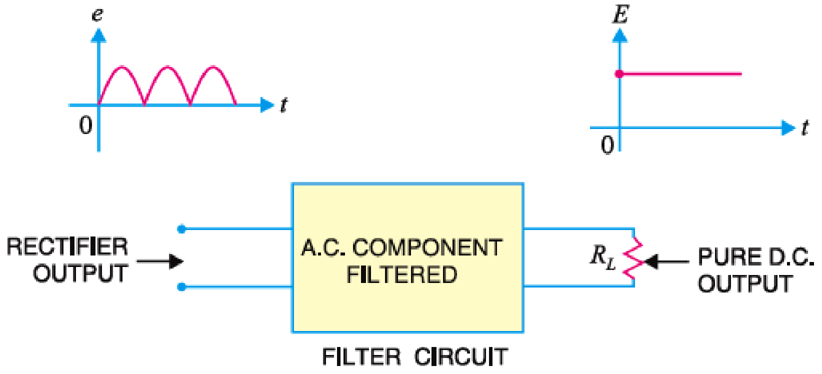
Comparison of Rectifiers

S. No.	Particulars	Half-wave	Centre-tap	Bridge type
1	No. of diodes	1	2	4
2	Transformer necessary	no	yes	no
3	Max. efficiency	40.6%	81.2%	81.2%
4	Ripple factor	1.21	0.48	0.48
5	Output frequency	f_{in}	$2 f_{in}$	$2 f_{in}$
6	Peak inverse voltage	V_m	$2\ V_m$	V_m

6 Filter Circuits

A rectifier is required to produce pure d.c. supply for using at various places in the electronic circuits. However, the output of a rectifier has pulsating *character i.e. it contains a.c. and d.c. components. The a.c. component is undesirable and must be kept away from the load. To do so, a filter circuit is used which removes (or filters out) the a.c. component and allows only the d.c. component to reach the load.

A filter circuit is a device which removes the a.c. component of rectifier output but allows the d.c. component to reach the load.

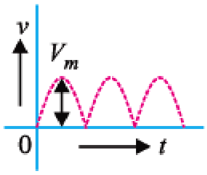


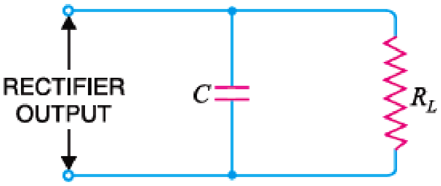
Obviously, a filter circuit should be installed between the rectifier and the load as shown in Fig. A filter circuit is generally a combination of inductors (L) and capacitors (C). The filtering action of L and C depends upon the basic electrical principles. A capacitor passes a.c. readily but does not pass d.c. at all. On the other hand, an inductor opposes a.c. but allows d.c. to pass through it. It then becomes clear that suitable network of L and C can effectively remove the a.c. component, allowing the d.c. component to reach the load.

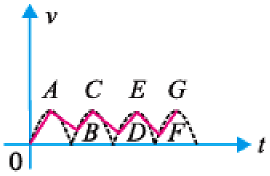
The most commonly used filter circuits are capacitor filter, choke input filter and capacitor input filter or π-filter.

6.1 Capacitor filter

It consists of a capacitor C placed across the rectifier output in parallel with load R_L. The pulsating direct voltage of the rectifier is applied across the capacitor. As the rectifier voltage increases, it charges the capacitor and also supplies current to the load. At the end of quarter cycle, the capacitor is charged to the peak value V_m of the rectifier voltage. Now, the rectifier voltage starts to decrease. As this occurs, the capacitor discharges through the load and voltage across it (i.e. across parallel combination of R-C) decreases as shown by the line AB in Fig. The voltage across load will decrease only slightly because immediately the next voltage peak comes and recharges the capacitor. This process is repeated again and again and the output voltage waveform becomes ABCDEFG. It may be seen that very little ripple is left in the output. Moreover, output voltage is higher as it remains substantially near the peak value of rectifier output voltage. The capacitor filter circuit is extremely popular because of its low cost, small size, little weight and good characteristics.

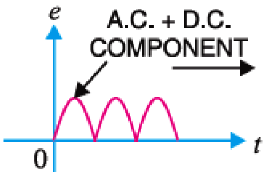


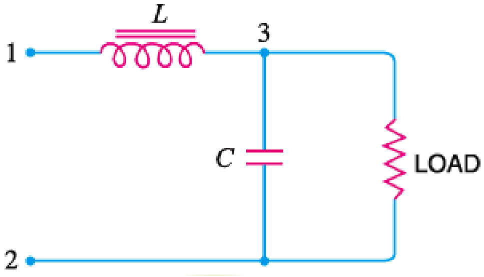


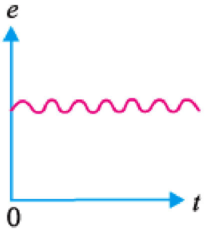


6.2 Choke input filter

It consists of a choke L connected in series with the rectifier output and a filter capacitor C across the load. Several identical sections are often used to reduce the pulsations as effectively as possible. The pulsating output of the rectifier is applied across terminals 1 and 2 of the filter circuit. As discussed before, the pulsating output of rectifier contains a.c. and d.c. components. The choke offers high opposition to the passage of a.c. component but negligible opposition to the d.c. component. The result is that most of the a.c. component appears across the choke while whole of d.c. component passes through the choke on its way to load. This results in the reduced pulsations at terminal 3. At terminal 3, the rectifier output contains d.c. component and the remaining part of a.c. component which has managed to pass through the choke. Now, the low reactance of filter capacitor bypasses the a.c. component but prevents the d.c. component to flow through it. Therefore, only d.c. component reaches the load. In this way, the filter circuit has filtered out the a.c. component from the rectifier output, allowing d.c. component to reach the load.

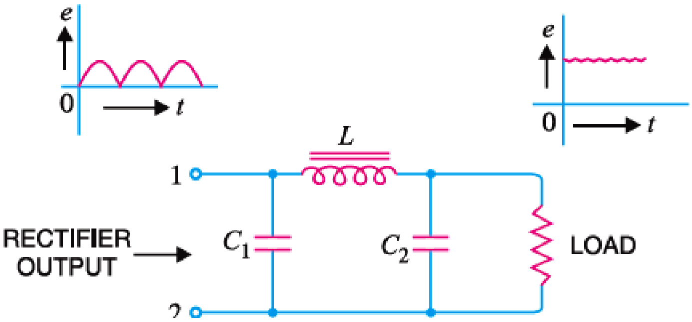






6.3 Capacitor input filter or π - filter

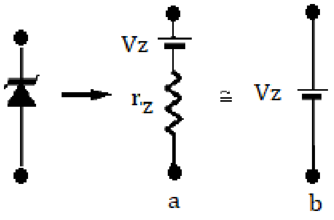
It consists of a filter capacitor C1 connected across the rectifier output, a choke L in series and another filter capacitor C2 connected across the load. The pulsating output from the rectifier is applied across the input terminals (i.e. terminals 1 and 2) of the filter. The filter capacitor C1 offers low reactance to a.c. component of rectifier output while it offers infinite reactance to the d.c. component. Therefore, capacitor C1 bypasses an appreciable amount of a.c. component while the d.c. component continues its journey to the choke L. The choke L offers high reactance to the a.c. component but it offers almost zero reactance to the d.c. component. Therefore, it allows the d.c. component to flow through it, while the *unbypassed a.c. component is blocked. The filter capacitor C2 bypasses the a.c. component which the choke has failed to block. Therefore, only d.c. component appears across the load and that is what we desire.



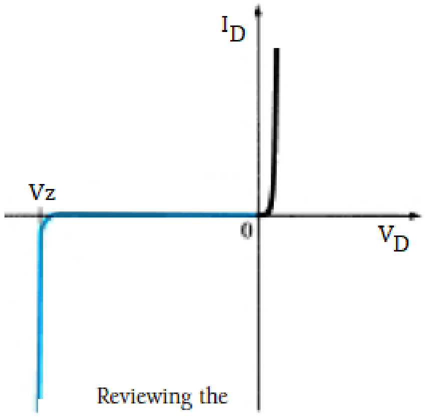
7 Zener diode & Zener diode Voltage Regulator

7.1 Zener Diode

Zener diode is a special type of pn junction diode which is used in reverse biased condition at the breakdown voltage called Zener voltage V_Z. This Zener region of unique characteristics is employed in the design of Zener diodes. The location of the Zener region can be controlled by varying the doping levels. An increase in doping, producing an increase in the number of added impurities, will decrease the Zener potential. Zener diodes are available having Zener potentials of 1.8 to 200 V with power ratings from 0.25 to 50 W. Because of its higher temperature and current capability, silicon is usually preferred in the manufacture of Zener diodes.



Zener equivalent circuit: (a) complete; (b) approximate.

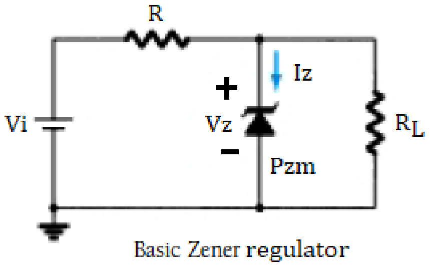


Reviewing the Zener region.

A zener diode is heavily doped to reduce the reverse breakdown voltage. This causes a very thin depletion layer. As a result, a zener diode has a sharp reverse breakdown voltage V_Z. In other words, the zener diode operated in the Zener region will have a relatively constant voltage across it, regardless of the value of current through the device. This permits the zener diode to be used as a voltage regulator.

7.2 Zener diode Voltage Regulator

Zener diode operating in zener region can be used as a voltage regulator to provide a constant voltage from a source whose voltage may vary over sufficient range. The simple voltage regulator using zener diode is shown in figure.

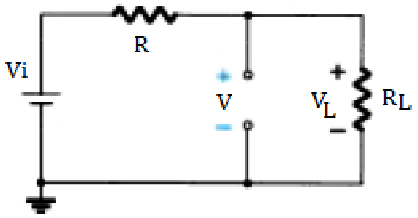


Basic Zener regulator

We get

$$V = V_L = \frac{V_i R_L}{R + R_L}$$

where V_i is the input voltage and R is the series resistance.



Determining the state of the Zener diode.

If $V > V_Z$, the Zener diode is “on” and if $V < V_Z$, the diode is “off”. Since the load resistor R_L and Zener diode are parallel, the voltage across them must be same. That is in ON state we can write

$$I_R = I_Z + I_L$$

and

$$I_Z = I_R - I_L$$

where

$$I_L = \frac{V_L}{R_L}$$

and

$$I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

If the Zener diode is in the “on” state, the voltage across the diode is not V volts. When the system is turned on, the Zener diode will turn “on” as soon as the voltage across the Zener diode is V_Z volts.

7.3 Voltage Regulation

The output voltage V_L must remain as a constant when either input voltage V_i changes or the load resistance R_L changes.

7.3.1 Fixed V_i, Variable R_L - Load regulation

Let the input voltage V_i remains fixed and the load R_L varies.

Due to the offset voltage V_Z, there is a specific range of resistor values (and therefore load current) which will ensure that the Zener is in the “on” state. Too small a load resistance R_L will result in a voltage V_L across the load resistor less than V_Z , and the Zener device will be in the “off” state. This minimum R_L is given by

$$R_{Lmin} = \frac{RV_Z}{V_i - V_Z}$$

Once the diode is in the “on” state, the voltage across R remains fixed at

$$V_R = V_i - V_Z$$

and I_R remains fixed at

$$I_R = \frac{V_R}{R}$$

The Zener current

$$I_Z = I_R - I_L$$

resulting in a minimum I_Z when I_L is a maximum and a maximum I_Z when I_L is a minimum value since I_R is constant. This ensures the output voltage

$$V_L = I_R R_L$$

a constant

7.3.2 Fixed R_L, Variable V_i - Line variation

Let the input voltage V_i varies and the load R_L remains a constant.

For fixed values of R_L, the voltage V_i must be sufficiently large to turn the Zener diode on. The minimum turn-on voltage $V_i = V_{imin}$ is determined by

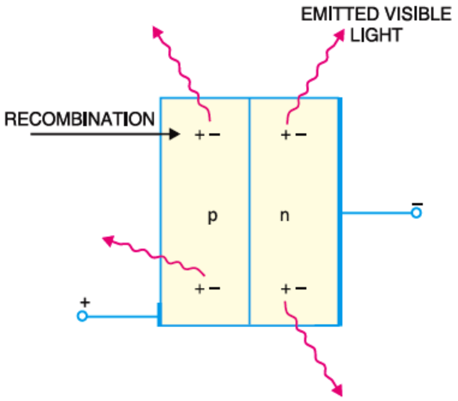
$$V_{imin} = \frac{(R_L + R)V_Z}{R_L}$$

Whenever V_i increases, IR increases; Zener draws more current I_Z increases, so that I_R and $V_L = I_R R_L$ remains a constant. Similarly, whenever V_i decreases, I_R decreases; Zener draws less current I_Z decreases so that I_R and $V_L = I_R R_L$ remains a constant

8 LED and Photodiode

8.1 LED

The light-emitting diode (LED) is a special type of pn junction diode which emits light when forward biased. In any forward-biased p-n junction there is, within the structure and primarily close to the junction, a recombination of holes and electrons. This recombination requires that the energy possessed by the unbound free electron be transferred to another state. In all semiconductor p-n junctions some of this energy will be given off as heat and some in the form of photons. In silicon and germanium the greater percentage is given up in the form of heat and the emitted light is insignificant. In other materials, such as gallium arsenide phosphide (GaAsP) or gallium phosphide (GaP), the number of photons of light energy emitted is sufficient to create a very visible light source. The process of giving off light by applying an electrical source of energy is called **electroluminescence**.



The light-emitting diode (LED) is a solid-state light source. LEDs have replaced incandescent lamps in many applications because they have the following advantages : Low voltage, Longer life (more than 20 years), Fast on-off switching. A LED that emits one colour when forward biased and another colour when reverse biased is called a multicolour LED. They actually contain two pn junctions that are connected in reverse-parallel i.e. they are in parallel with anode of one being connected to the cathode of the other.

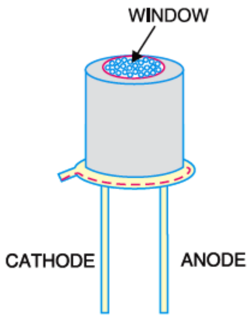
8.2 Photodiode

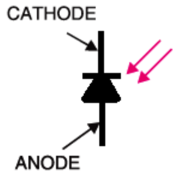
photo-diode is a reverse-biased silicon or germanium pn junction in which reverse current increases when the junction is exposed to light.

The reverse current in a photo-diode is directly proportional to the intensity of light falling on its pn junction. This means that greater the intensity of light falling on the pn junction of photo-diode, the greater will be the reverse current.

When a rectifier diode is reverse biased, it has a very small reverse leakage current. The same is true for a photo-diode. The reverse current is produced by thermally generated electronhole pairs which are swept across the junction by the electric field created by the reverse voltage. In a rectifier diode, the reverse current increases with temperature due to an increase in the number of electron-hole pairs. A photo-diode differs from a rectifier diode in that when its pn junction is exposed to light, the reverse current increases with the increase in light intensity and vice-versa. This is explained as follows. When light (photons) falls on the pn junction, the energy is imparted by the photons to the atoms in the junction. This will create more free electrons (and more holes). These additional free electrons will increase the reverse current. As the intensity of light incident on the pn junction increases, the reverse current also increases. In other words, as the incident light intensity increases, the resistance of the device (photo-diode) decreases.

When no light is incident on the pn junction of photo-diode, the reverse current Ir is extremely small. This is called dark current. The resistance of photo-diode with no incident light is called dark resistance. When light is incident on the pn junction of the photo-diode, there is a transfer of energy from the incident light (photons) to the atoms in the junction. This will create more free electrons (and more holes). These additional free electrons will increase the reverse current. As the intensity of light increases, the reverse current goes on increasing till it becomes maximum. This is called saturation current.



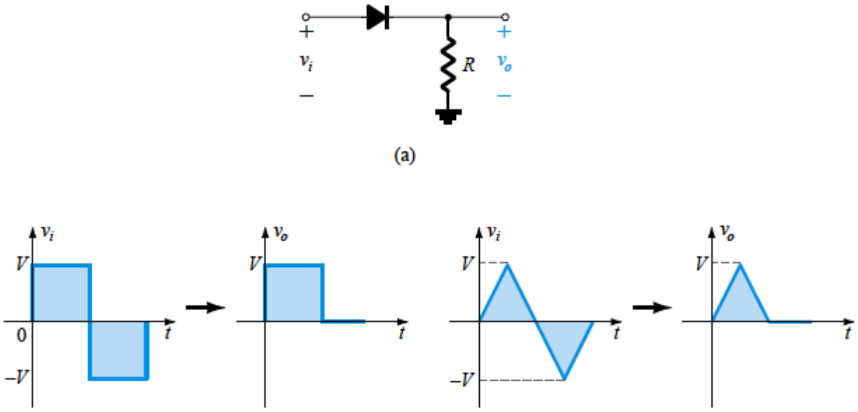


9 Clipping Circuits

There are a variety of diode networks called clippers that have the ability to “clip” off a portion of the input signal without distorting the remaining part of the alternating waveform. The **half-wave rectifier is an example of the simplest form of diode clipper** — one resistor and diode. Depending on the orientation of the diode, the positive or negative region of the input signal is “clipped” off. There are two general categories of clippers: series and parallel. The series configuration is defined as one where the diode is in series with the load, while the parallel variety has the diode in a branch parallel to the load.

9.1 Series Clipper and Parallel clipper

The response of the series configuration of Fig. to a variety of alternating waveforms is provided. The addition of a dc supply can have a pronounced effect on the output of a clipper.

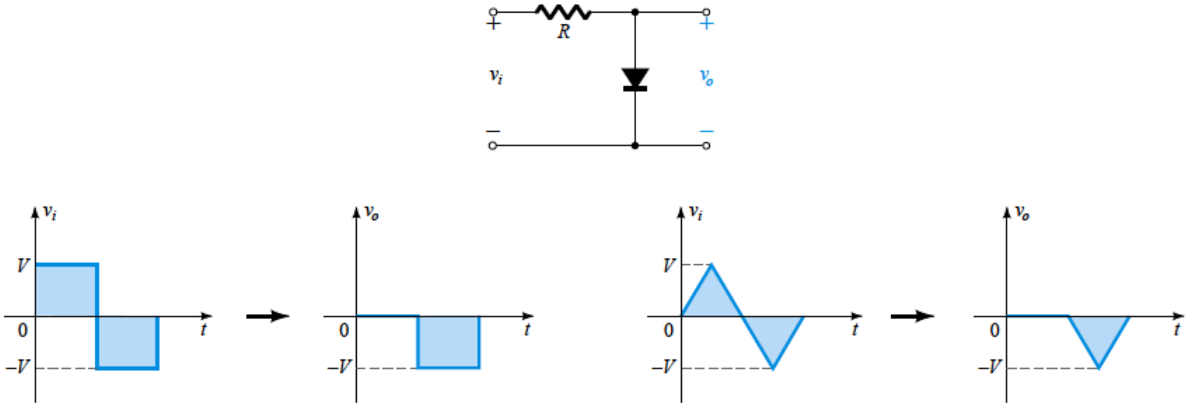


(a)

(b)

Series clipper.

The network of the following Fig. is the simplest of parallel diode configurations. The analysis of parallel configurations is very similar to that applied to series configurations

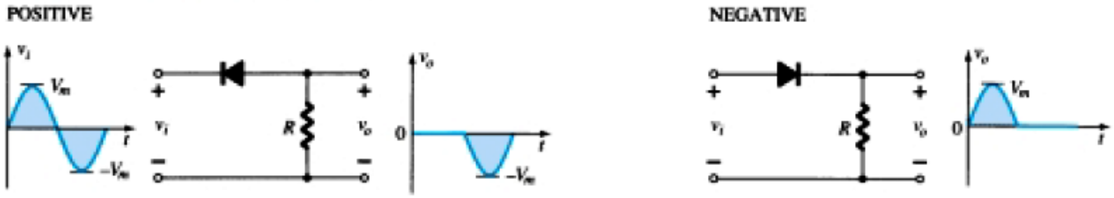


Response to a parallel clipper.

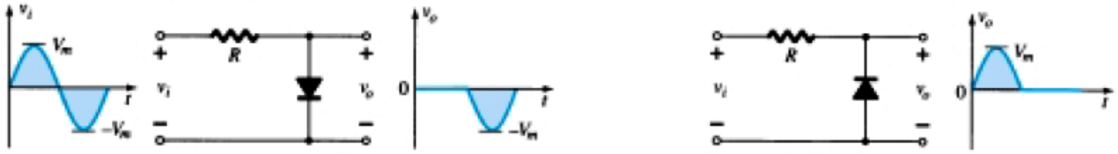
9.2 Positive clipper and Negative Clipper

A positive clipper is that which removes the positive half-cycles of the input voltage. If it is desired to remove the negative half-cycle of the input, the only thing to be done is to reverse the polarities of the diode in the circuit for positive clipper. Such a clipper is then called a negative clipper.

Simple Series Clippers (Ideal Diodes)



Simple Parallel Clippers (Ideal Diodes)



9.3 Biased Clipper

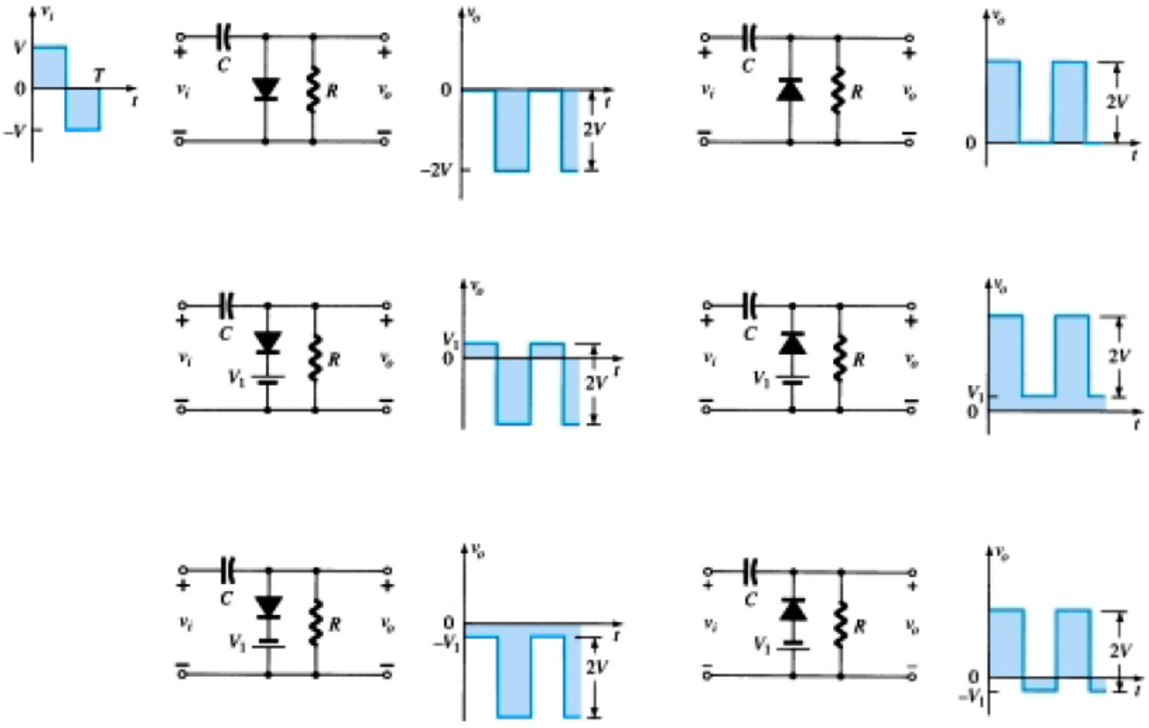
Sometimes it is desired to remove a small portion of positive or negative half-cycle of the signal voltage. For this purpose, biased clipper is used.

10 Clamping Circuits

The clamping network is one that will "clamp" a signal to a different dc level. The network must have a capacitor, a diode, and a resistive element, but it can also employ an independent dc supply to introduce an additional shift. The magnitude of R and C must be chosen such that the time constant $\tau = RC$ is large enough to ensure that the voltage across the capacitor does not discharge significantly during the interval the diode is nonconducting. A clamping circuit (or a clamper) essentially adds a d.c. component to the signal.

A clamper changes the peak value as well as the average value of a waveform.

It may be seen that the shape of the original signal has not changed; only there is vertical shift in the signal. Such a clamper is called a **positive clamper**. The **negative clamper** does the reverse i.e. it pushes the signal downwards so that the positive peaks fall on the zero level.



Clamping circuits with ideal diodes ($5\tau = 5RC \gg T/2$).

11 Questions

1. Classify solids based on energy band diagram
2. What is forbidden energy gap ?
3. Which one is a good conductor - Si or Ge ? Why ?
4. What are semiconductors ?
5. What happens to the properties of a semiconductor when it is heated ?
6. Differentiate between intrinsic and extrinsic semiconductors
7. What is meant by doping ? What are dopants ? What is the necessity of doping ?
8. Explain how p-type and n-type semiconductors are formed ?
9. What are trivalent and pentavalent impurities ?
10. What is the charge of a p-type semiconductor ? Explain
11. Explain how a pn junction is formed ?
12. What is meant by barrier potential
13. Draw the equivalent circuits of an ideal diode and practical diode ?
14. Explain how a diode acts as a switch
15. Discuss the volt-ampere characteristics of a pn junction diode
16. Define dc and ac resistance of a diode
17. Discuss the effect of temperature on a pn junction diode
18. What is a rectifier ? Discuss the construction and working of a halfwave rectifier
19. Discuss the construction and working of two types of full wave rectifiers
20. Compare three types of rectifiers
21. What is meant by ripple factor ? Obtain an expression for it ?
22. What is PIV rating of a diode ?
23. Explain the breakdown mechanisms of a diode ?
24. Explain the working of a LED
25. Explain the working of a photodiode ? What is dark current ?
26. Explain the construction and working of a zener diode voltage regulator
27. Write short notes on clippers and clampers