# 1–3 Current in Semiconductor( Intrinsic and Extrinsic)

The way, a material conducts electrical current is important in understanding, how electronic devices operate. You can’t really understand the operation of a device such as a diode or transistor without knowing something about current in semiconductors.

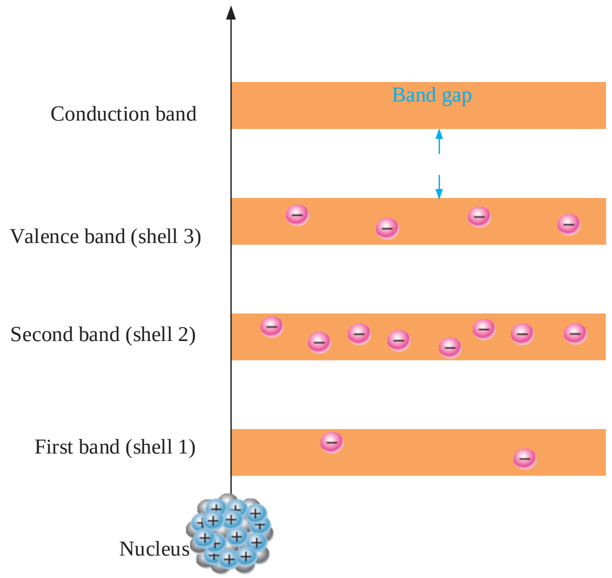
After completing this section, you should be able to

- **Describe how current is produced in an Intrinsic or pure Semiconductor**
  - Discuss conduction electrons and holes
  - Explain an electron-hole pair and their recombination
  - Explain electron and hole current
- **Discuss about Extrinsic semiconductor and it’s the necessity**
  - P Type and N Type semiconductor and their differences

As we have learned, the electrons in a solid can exist only within prescribed energy bands. Each shell corresponds to a certain energy band and is separated from adjacent shells by band gaps, in which no electrons can exist. Figure 1–14 shows the energy band diagram for the atoms in a pure silicon crystal at its lowest energy level. There are no electrons shown in the conduction band, a condition that occurs *only* at absolute 0 K temperatures.

**FIGURE 1–14**

Energy band diagram for an atom in a pure semiconductor cristal at it lowest energy state. There are no electrons in the conduction band 0 K temperature.

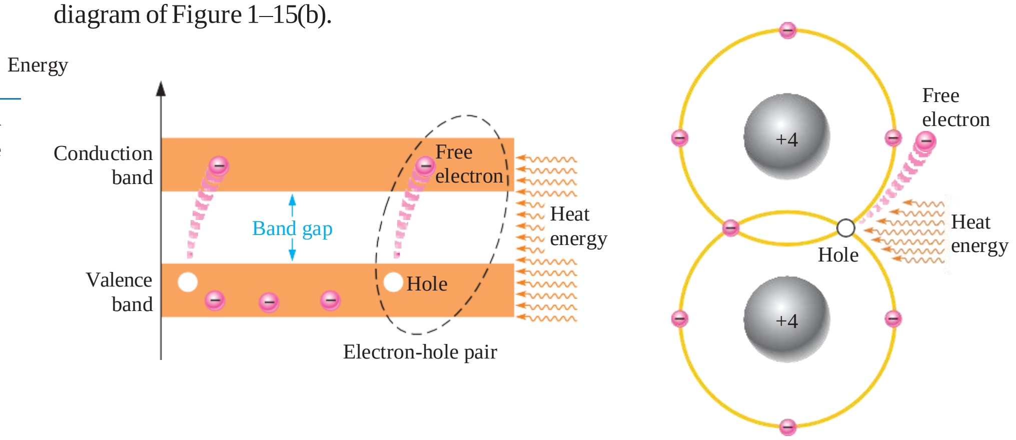


## Conduction Electrons and Holes

Pure semiconductor crystal at room temperature has sufficient heat (thermal) energy for some immovable valence electrons to jump the gap from valence band into the conduction band, becoming movable. These free movable electrons are also called **conduction electrons.** This is illustrated in the energy diagram of Figure 1–15(a) and in the bonding diagram of Figure 1–15(b).

**FIGURE 1–15**

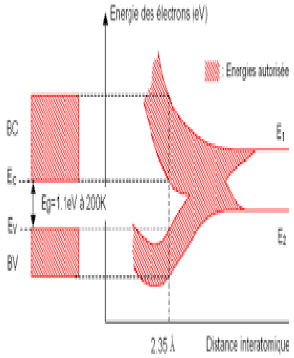
Creation of electron-hole pairs in a silicon crystal. Electrons in the conduction band are free,movable.



(a) Energy diagram for the outer two bands

(b) Bonding diagram

When an electron jumps to the conduction band by external energy, a vacancy is left in the valence band within the crystal. This vacancy is called a **hole,** which is nothing but an empty state available for an electron to occupy. The interesting thing is that holes are also mobile in the valance band. For each electron raised to the conduction band, there is one hole left in the valence band, creating what is called an **electron-hole pair.**



To summarize, a piece of intrinsic silicon at room temperature has, at any instant, a number of conduction band (free) electrons that are unattached to any atom and are essentially drifting randomly throughout the material. There are, also, an equal number of holes in the valence band created when these electrons jump into the conduction band. This is illustrated in Figure 1–15. On the other hand, when a conduction band electron loses energy and falls back into a hole in the valence band, **recombination** occurs.

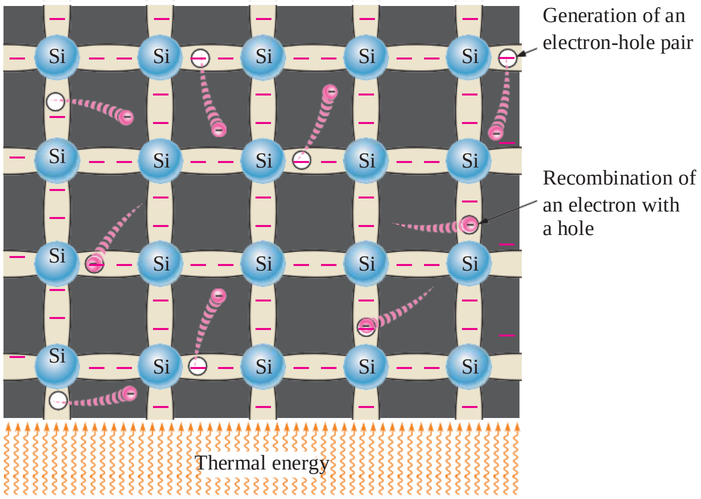


**FIGURE 1–15**

Electron-hole pairs in a silicon crystal. Free electrons are being generated continuously while some recombine with holes.

## Electron and Hole Current

When a voltage is applied across a piece of pure semiconductor, the thermally generated free electrons in the conduction band, which are free to move randomly in the crystal structure, are now easily attracted toward the positive end as shown in Figure 1–16. This movement of free electrons contributes **electron current** in this semiconductive material.

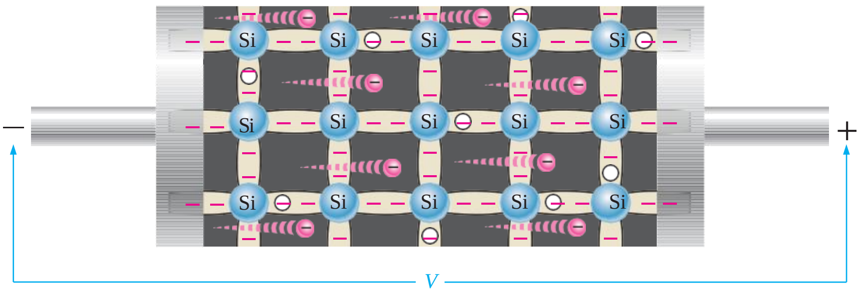


**FIGURE 1–16**

Electron current in pure silicon is produced by the movement of thermally generated free electrons.

Another type of current occurs in the valence band due to the movement of holes created by the electrons lifted to the conduction band. Electrons remaining in the valence band are still attached to their atoms and are not free to move randomly in the crystal structure as the free electrons in the conduction band. However, valence electron can move into nearby hole with little change in its energy level, thus leaving another hole where it came from. Effectively the hole has moved from one place to another in valence band in the crystal structure, as illustrated in Figure 1–17. Although current in the valence band is produced by valence electrons, it is called **hole current** to distinguish it from electron current in the conduction band.

As it is seen, conduction in semiconductors is considered to be either the movement of free electrons in the conduction band or the movement of holes in the valence band, which is actually the movement of valence electrons to nearby atoms, creating hole current in the opposite direction.

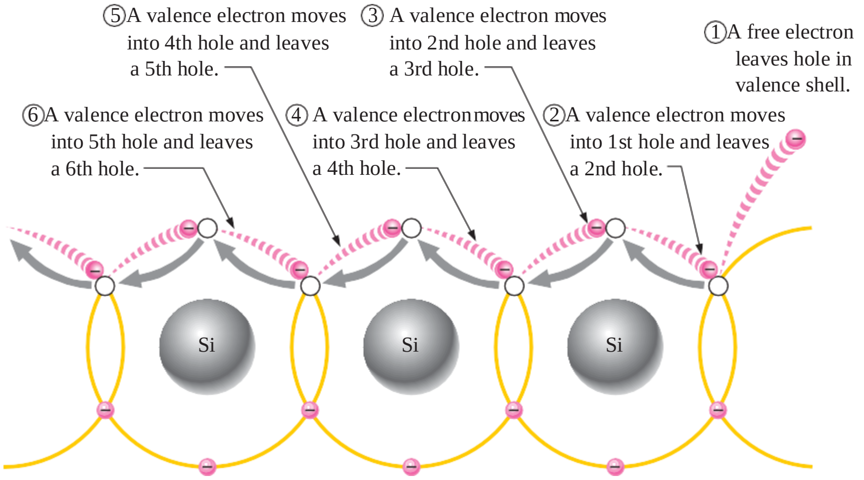
Therefore, the total current *I* is contributed by both electrons in the conduction band and holes in the valance band

$$I = I_{electron} + I_{hole}$$

It is interesting to contrast the movement of charge in a crystalline semi-conductor and in a crystalline metallic conductor. Conductor atoms form a different type of crystal in which the atoms are not covalently bonded to each other but consist of a "sea" of positive ion cores, which are atoms stripped of their valence electrons to the conduction band. The valence electrons are attracted to the positive ion core forming the **metallic bond**. These valence electrons do not belong to a given atom, but to the crystal as a whole and become free to move with the application of a voltage. Therefore, electric current is contributed by the movement of free electrons only because there are no holes in the metallic crystal structure.

**FIGURE 1–17**

Hole current in intrinsic silicon.



When a valence electron moves left to right to fill a hole while leaving another hole behind the hole has moved from right to left. Gray arrows indicate movement of a hole.

The chemically 100% pure crystal of semiconductors like Ge, Si are called **Intrinsic Semiconductor**. Semiconductive materials do not conduct current well and are of limited value of conductivity in their intrinsic state. This is because of the limited number of free electrons in the conduction band and holes in the valence band. But if the temperature be increased, more electron-hole pair generated i.e more electrons are lifted from the valence band to the conduction band and hence the conductivity increases that exhibit lowering of resistance showing negative coefficient of resistance.

(Note that for conductors, conductivity decreases with the rise of temperature).

# Extrinsic Semiconductor

Intrinsic semiconductors are generally poor conductors but their conductivity can be drastically increased by the controlled addition of impurities to the intrinsic (pure) semiconductive material. These impure semiconductors are the key building blocks for most types of semiconductor devices.

After completing this section, you should be able to

- **Discuss about Extrinsic Semiconductor**
- Explain how *p*-type and *n*-type semiconductors are formed
- Describe a majority carrier and minority carrier in *p*-type semiconductor
- Describe a majority carrier and minority carrier in *n*-type semiconductor

Since, electrical conductivity of intrinsic semiconductor at room temperature is too low to be used for practical purposes, it must be modified by increasing the number of free electrons or holes to increase its conductivity. This is done by adding small amount (a few parts per million) of suitable impurities to the pure semiconductor by solid state diffusion method. This process is technically called **Doping** and these impure materials are called extrinsic semiconductors.

Extrinsic semiconductors are of two types - *n*-type and *p*-type depending upon two types of impurities.

**The fifth electron is loosely bound in N Type semiconductor**

The fifth electron is bound to the dopant atom by net attraction of charge +e ; rest of the charge of the nucleus is screened by the other electrons in the atom. Besides this the effect of other neighboring atoms reduces the binding that results those electrons less bound to the impurity atom.

## *N*-Type Semiconductor

To increase the number of conduction-band electrons in intrinsic silicon, **pentavalent** impurity atoms are added. These are atoms with five valence electrons, such as Arsenic (As), Phosphorus (P), Bismuth (Bi), and Antimony (Sb).As illustrated in Figure 1–18, each pentavalent atom (antimony, in this case) forms covalent bonds with four adjacent silicon atoms. Four of the antimony atom's valence electrons are used to form the covalent bonds with silicon atoms, leaving one extra electron outside. This extra electron becomes a conduction electron because it is not involved in bonding. As the pentavalent atom gives up an electron, it is often called a positively charged **donor atom**. The concentration of conduction electrons can be carefully controlled by the number of impurity atoms added to the silicon. A conduction electron, created by this doping process, does not leave a hole in the valence band because it is in excess of the number required to fill the valence band.

FIGURE 1–17
Pentavalent impurity atom in a sili- con

**Majority and Minority Carriers in N Type semiconductor**

Since most of the current carriers are electrons, silicon (or germanium) doped with pentavalent atoms is an *n*-type semiconductor (the *n* stands for the negative charge on an electron). Therefore, electrons are the **majority carriers** in N type material. Although, there are also a few holes that are created when electron-hole pairs are thermally generated. These holes are ***not*** produced by the addition of the pentavalent impurity atoms. So, **minority carriers** in *n*-type material are holes**.**

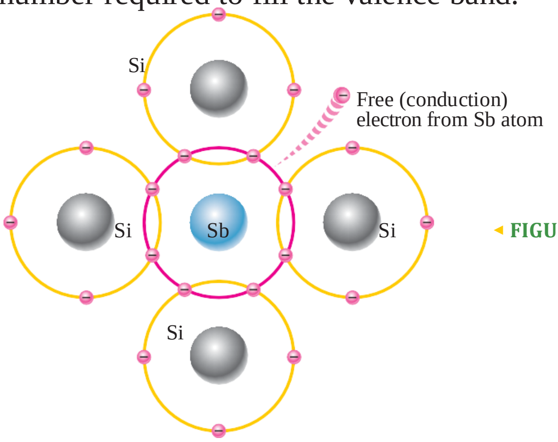


FIGURE 1–18

A Pentavalent Antimony (Sb) impurity atom is shown at the center of a silicon crystal structure. The extra electron from the Sb atom becomes free to move.

### *P*-Type Semiconductor

To increase the number of holes in intrinsic semiconductor, **trivalent** impurity atoms such as boron (B), indium (In), and gallium (Ga) are to be added. As illustrated in Figure 1–19, each of the three valence electrons of the trivalent atom (boron, in this case) forms covalent bond with three out of four adjacent silicon atoms. But there is no fourth valence electron to form the fourth covalent bond, so this vacancy is filled up by an electron from any other covalent bond of neighboring atom that produces a positively charged **hole** that can move throughout the crystal. Therefore each impurity atom produces one hole and concentration of holes can be carefully controlled by the number of trivalent impurity atoms added to the silicon. Because the trivalent atom can take an electron, it is often referred to as a negatively charged ***acceptor atom***. A hole created by this doping process is *not* accompanied by a conduction (free) electron.

**Majority and Minority charge Carriers**

The holes are the majority carriers in *p*-type material doped with trivalent atoms But, although majority of current carriers are holes, there are also a few conduction-band electrons that are created when electron-hole pairs are thermally generated. These conduction-band electrons are *not* produced by the addition of the trivalent impurity atoms. These electrons in *p*-type material are the minority carriers.

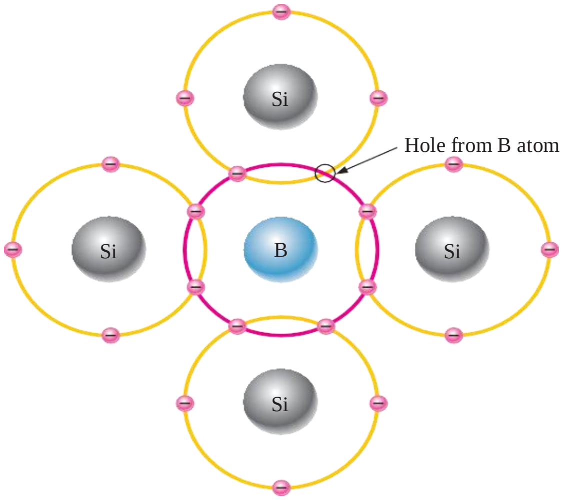


**FIGURE 1–19**

Trivalent impurity atom in a silicon crystal structure. A boron (B) impurity atom is shown in the center.

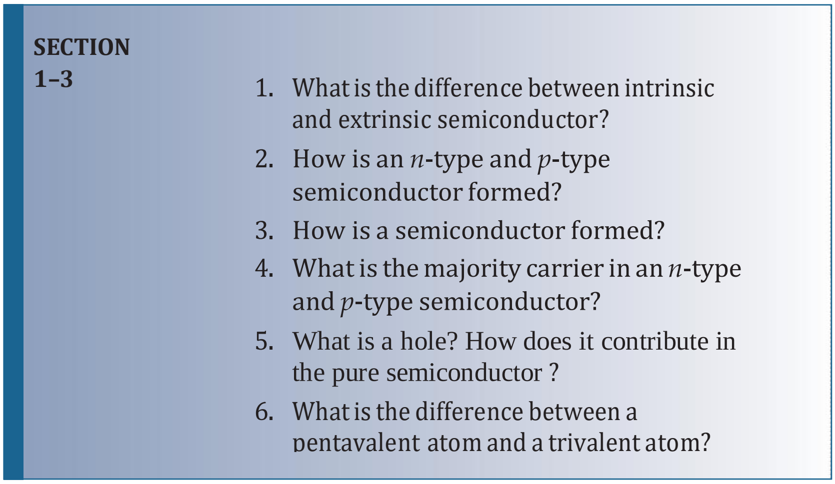
## Why Si is preferred much than Ge in Semiconductor device?

| Si | Ge |
|---|---|
| It is Cheap. Silicon is nothing but the sand which is available plenty in our world | Comparatively not cheap. |
| Si has a larger band-gap (1.1 eV).<br>So, the phenomena of thermal pair generation is smaller in Si. This means that at the same temperature the noise of the Si devices is smaller than the noise of Ge devices | Ge has smaller band gap 0.67 eV. So, the phenomena of thermal pair generation in Ge is larger. |
| They have high Peak Inverse Voltages (PIV).<br>i.e, In the range of 1000Volts. | Comparatively they have low peak inverse voltages (PIV).<br>ie, In the range of 400Volts |
| It can be used in high temperature applications as it has good temperature stability.<br>ie, In the range of 200° C | It can be used in low temperature applications only.<br>ie, Upto 85° C |
| Reverse leakage current $I_{R(leakage)}$ is in nA range. | Reverse leakage current $I_{R(leakage)}$ is in mA range. |
| Forward Voltage drop ($V_f$) to turn ON the diode is called as Threshold Voltage ($V_T$) or firing potential.<br>In Si based diode, $V_T$ = 0.7Volts. | Threshold Voltage($V_T$) in Ge is $V_T$ = 0.3Volts |

## Difference between N type and P Type Semiconductor

| | N Type Semiconductor | | P Type Semiconductor |
|---|---|---|---|
| 1 | Pentavalent impurity like Arsenic is doped | 1 | Trivalent impurity like Boron is doped |
| 2 | Each pentavalent impurity atom donates one conduction electron | 2 | Each trivalent impurity atom is ready to accept an electron. |
| 3 | Electrons and holes are the majority and minority charge carriers respectively. | 3 | Holes and electrons are the majority and minority charge carriers respectively. |
| 4 | Donor energy level lies just below the conduction band. | 4 | Accepter energy level lies just above the valence band. |

## Check Up



**SECTION 1–3**

1. What is the difference between intrinsic and extrinsic semiconductor?
2. How is an *n*-type and *p*-type semiconductor formed?
3. How is a semiconductor formed?
4. What is the majority carrier in an *n*-type and *p*-type semiconductor?
5. What is a hole? How does it contribute in the pure semiconductor ?
6. What is the difference between a pentavalent atom and a trivalent atom?