# SEMICONDUCTOR MATERIALS

## Energy Bands Theory in Solids

### Energy levels

The angular momentum of an electrons is always quantized and is integral multiple of $\frac{h}{2\pi}$. Thus the electrons can have certain orbital radii. The electrons in these orbits have only a certain values of energy. These certain values of energy of electrons in an atom are called the energy levels of the atom.

The energy levels of an isolated single atom are will defined usually represented by series of horizontal lines. When the two identical atoms are close to each other, their electrons move under the influence electromagnetic fields of two atoms. As the result, each energy level split into two levels, one higher and other lower than the corresponding level of the isolated atom.

### Energy Band

When the numbers of atoms are brought together, as in a crystal, they interact with one another. As the result, each energy level splits up into several sub-levels. A group of such energy sub-levels are called an energy band.

The number of energy sub-levels in a band is equal to the number of atoms in a crystal. The energy band in a crystal corresponds to the energy level in an atom. And an electron in a crystal can have an energy that falls within one of these bands.

### Forbidden Bands

The energy bands are separated by gaps in which there is no energy level. Such energy gaps are called forbidden bands. The electron may jump from one energy band to another by acquiring energy equal to the energy of forbidden energy gap.

### Valence Bands

The electrons in the outermost shell of an atom are called valance electrons. Therefore, the energy band occupied by valance electrons is called the valance band. The valance band may be either completely filled or partially filled with the electrons but can never be empty.

### Conduction Band

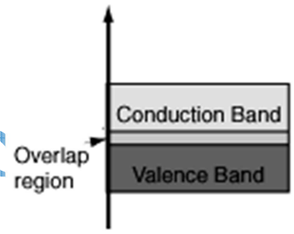
The energy band next to the valance band is called the conduction band. The valance and conduction bands are separated by forbidden energy gaps. The conduction band may be empty or partially filled. The electrons in the conduction band can drift freely in the materials and are called free or conduction electrons.

The width of forbidden energy gap between valance and conduction band decide whether a material is a conductor, insulator or a semiconductor.

## Distinction between Conductors, Insulators and Semiconductors on the basis of Band Theory of Solids

### Conductors

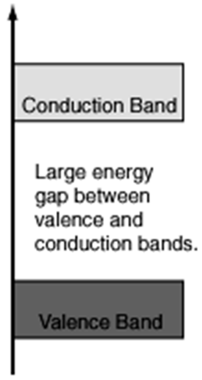
All metals are good conductors of electricity and their resistivity is of the order of $10^{-8}\ \Omega - m$. In case of conductors, there is no forbidden energy gap between the valance and the conduction band. The valance band and conduction band are partially filled at room temperature. So the electrons can easily jump from valance band to the conduction band. Due to this reason, the current can easily pass through conductors.



Conductor

### Insulators

The insulators have the very large value of resistivity which is of the order of $10^{10}\ \Omega - m$. In case of insulators, the valance band is completely filled and the conduction band is empty. The energy gap between the valance and conduction band is very large. Thus, no electron can jump from valence band to conduction band. As there are no free electrons in insulator, hence no current can pass through insulators.

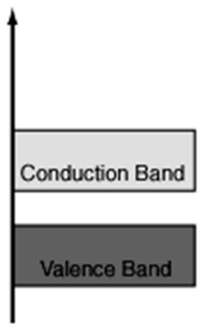


Insulator

### Semiconductors

The materials which have intermediate values of resistivity (of the order of $10^{2}\ \Omega - m$) called semiconductor materials. The energy gap between the valance and conduction band is very small.

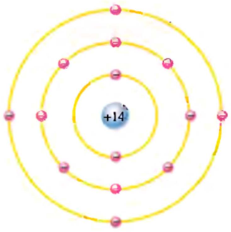
A semiconductor is a material that is between conductors and insulators in its ability to conduct electrical current. A semiconductor in its pure (intrinsic) state is neither a good conductor nor a good insulator. The most common single-element semiconductors are silicon,germanium, and carbon. Compound semiconductors such as gallium arsenide are also commonly used.



Semiconductor

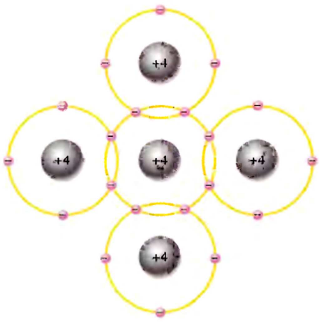
## Intrinsic Semiconductors

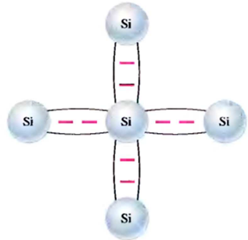
A pure semiconductor is known as intrinsic semiconductor. The most common examples of intrinsic semiconducting materials are silicon. Each atom of silicon has four valance electrons. Moreover each atom of silicon is surrounded by four atoms.

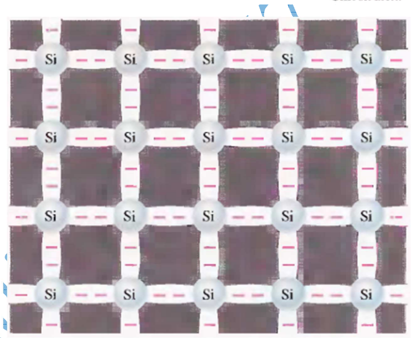


Silicon atom

A silicon (Si) atom with its four valence electrons shares an electron with each of its four neighbors to form covalent bond. This effectively creates eight shared valence electrons for each atom and produces a state of chemical stability.



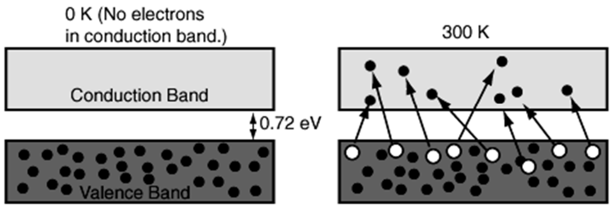




The semiconducting materials have negative temperature coefficient of resistivity. At low temperatures, the valence band is completely filled and conduction band is completely empty. Thus the semiconducting materials behave like insulator at low temperatures.

At comparatively higher temperature, the electrons in valance band acquire sufficient energy to jump in conduction band. As the temperature increases, the probability of the electrons to jump from valance to conduction band increases. Therefore, the conductivity of semiconductors increases with increase in temperature.

At absolute zero, the intrinsic semiconducting materials behaves like insulators because they have no free electrons. But as the temperature of increases, the thermal agitation in the atoms breaks some covelent bonds which result in formation of electron hole pairs. The electrons jump from valance band to conduction band by absorbing the thermal energy. As the result, the conductivity of semiconductor increases with increase in temperature.

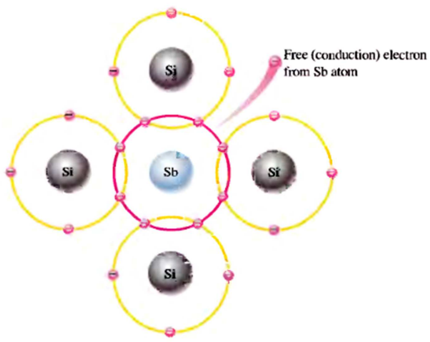


## Extrinsic Semiconductors

The semiconductors doped with some impurity are called extrinsic semiconductors. The conductivity of silicon and germanium can be drastically increased by the controlled addition of impurities to the intrinsic (pure) semiconductive material. This process, called doping, increases the number of current carriers (electrons or holes). The two categories of impurities are n-type and p-type.

## N-Type Semiconductor

To increase the number of conduction-band electrons in intrinsic silicon, pentavalent impurity atoms e.g., arsenic (As), phosphorus (P), bismuth (Bi), and antimony (Sb) are added. 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. This extra electron becomes a conduction electron because it is not attached to any atom.



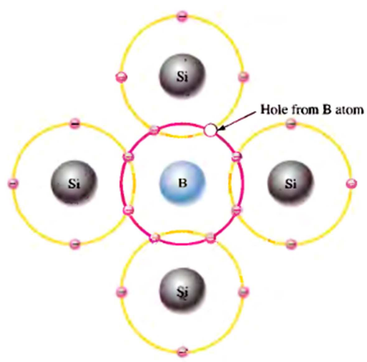

Because the pentavalent atom gives up an electron, it is often called a donor atom. The number of conduction electrons can be carefully controlled by the number of impurity atoms added to the silicon.

## Majority and Minority Carriers in N-Type Semiconductor

In an n-type semiconducting material, most of the current carriers are electrons. So, the electrons are called the majority carriers in n-type material. Although the majority of current carriers in n-type material are electrons, there are also a few holes that are created when electron-hole pairs are thermally generated. Holes in an n-type material are called minority carriers.

## P-Type Semiconductor

To increase the number of holes in intrinsic silicon, trivalent impurity atoms e.g., boron (B), indium (In), and gallium (Ga) are added. All three of the boron atom's valence electrons are used in the covalent bonds; and, since four electrons are required, a hole results when each trivalent atom is added. Because the trivalent atom can take an electron, it is



often referred to as an acceptor atom. The number of holes can be carefully controlled by the number of trivalent impurity atoms added to the silicon.

**Majority and Minority Carriers in P-Type Semiconductor**

In a p-type semiconducting material, most of the current carriers are holes. Holes can be thought of as positive charges because the absence of an electron leaves a net positive charge on the atom. The holes are the majority carriers in p-type material. Although the majority of current carriers in p-type material are holes, there are also a few free electrons that are created when electron-hole pairs are thermally generated. Electrons in p-type material are the minority carriers.

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