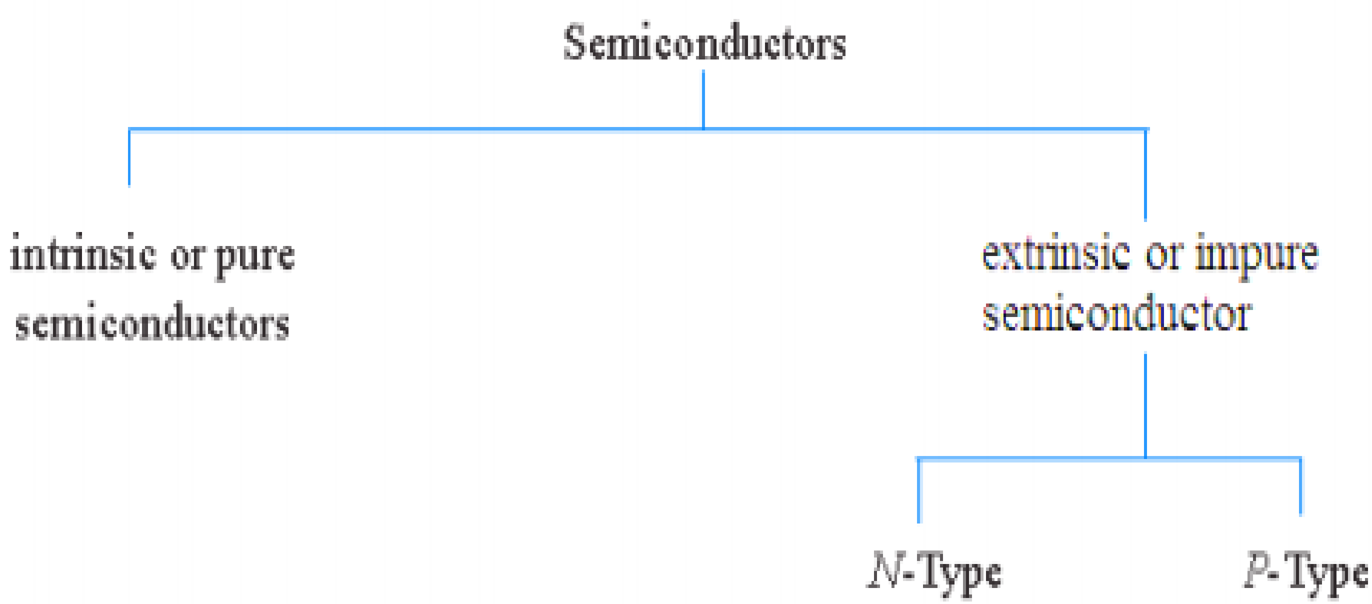
INTRINSIC/EXTRINSIC SEMICONDUCTORS

On the basis of impurity level semiconductor materials can be categorized as follows



Intrinsic Semiconductors

A crystal of pure and regular lattice structure is called intrinsic semiconductor. .

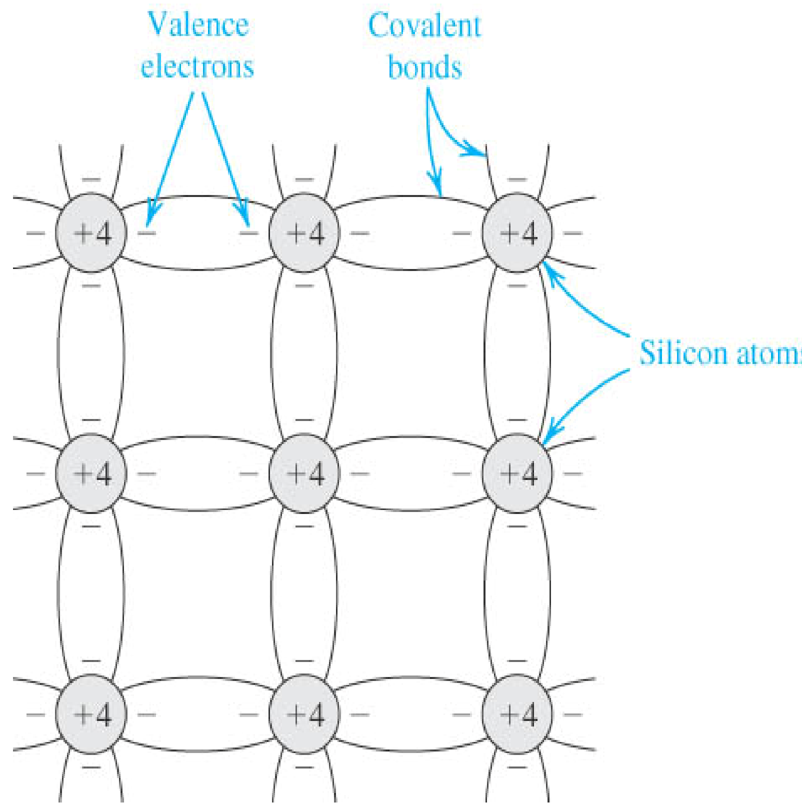
or

An intrinsic semiconductor may be defined as one in which the number of conduction electrons is equal to the number of holes. Examples of such semiconductors are: pure germanium and silicon which have forbidden energy gaps of 0.72 eV and 1.1 eV respectively.

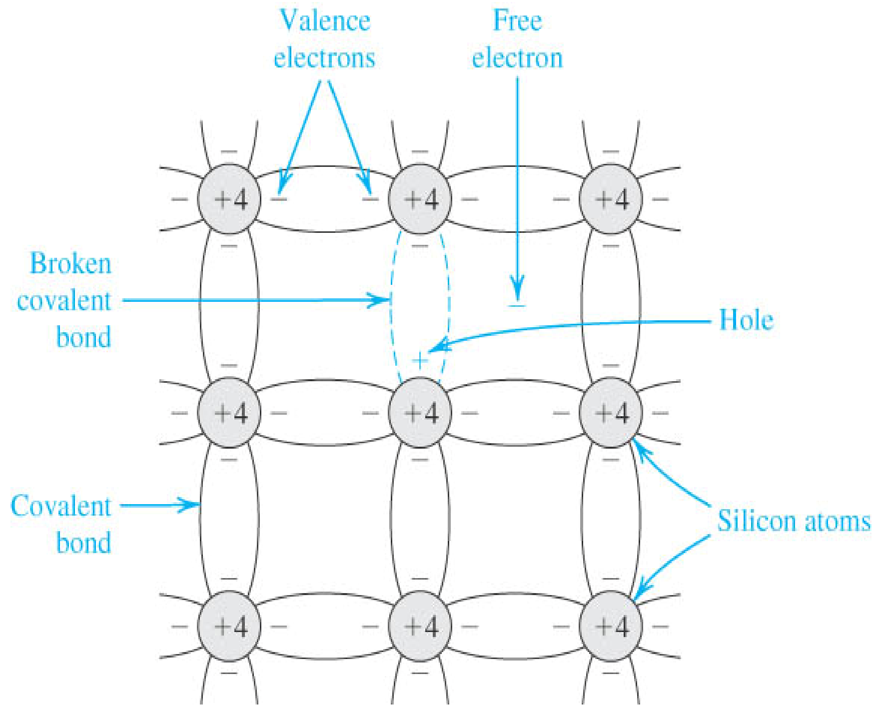
- Silicon---today's IC technology is based entirely on silicon
- Germanium---early used
- Gallium arsenide---used for microwave circuits

Two-Dimensional Representation of the Silicon Crystal

The circles represent the inner core of silicon atoms, with +4 indicating its positive charge of +4q, which is neutralized by the charge of the four valence electrons. Observe how the covalent bonds are formed by sharing of the valence electrons. At 0 K, all bonds are intact and no free electrons are available for current conduction.



At room temperature, some of the covalent bonds are broken by thermal ionization. Each broken bond gives rise to a free electron and a hole, both of which become available for current conduction.



Extrinsic Semiconductors

Those intrinsic semiconductors to which some suitable impurity or doping agent or doping material has been added in extremely small amounts (about 1 part in 10^8) are called impure [or] extrinsic semiconductor

DOPING

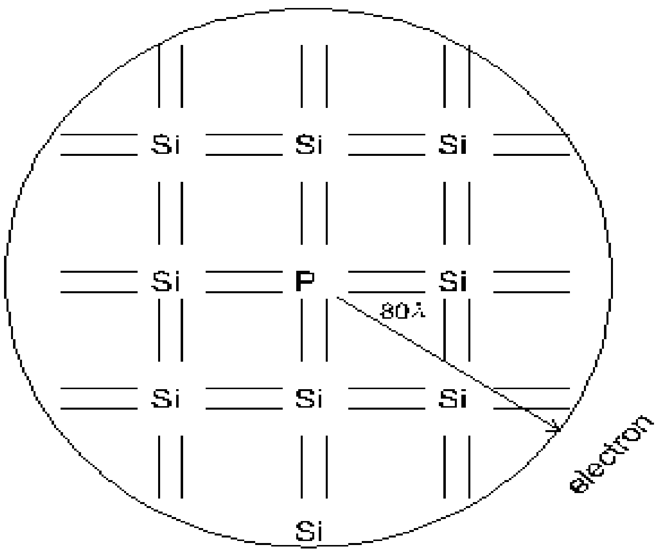
The method of adding impurities to a pure semiconductor is known as DOPING, and the impurity added is called the dopping agent(Ex-Ar,Sb,P,Ge and Al).

The addition of impurity would increases the no. of free electrons and holes in a semiconductor and hence increases its conductivity. . Depending on the type of doping material used, extrinsic semiconductors can be sub-divided into two classes:

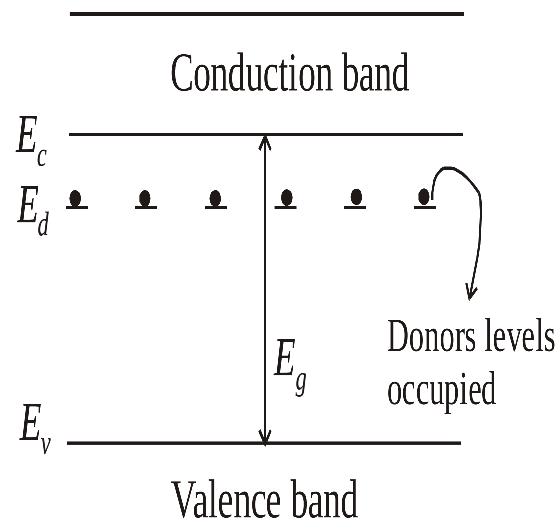
(i) N-type semiconductors and
(ii) P-type semiconductors

N – type semiconductor

When pentavalent impurity is added to the intrinsic semiconductors, n type semi conductors are formed.



n - type semiconductor



At T = 0K

- When small amounts of pentavalent impurity such as phosphorous are added during crystal formation, the impurity atoms lock into the crystal lattice[see above Fig).

- Consider a silicon crystal which is doped with a fifth column element such as P, As or Sb.

- Four of the five electrons in the outermost orbital of the phosphorus atom take part in the tetrahedral bonding with the four silicon neighbours.

- The *fifth electron* cannot take part in the discrete covalent bonding. It is *loosely* bound to the parent atom.

- It is possible to calculate an orbit for the fifth electron assuming that it revolves around the positively charged phosphorus ion, in the same way as for the "1s" electron around the hydrogen nucleus.

- The electron of the phosphorus atom is moving in *the electric field of the silicon crystal* and not in free space, as is the case in the hydrogen atom.

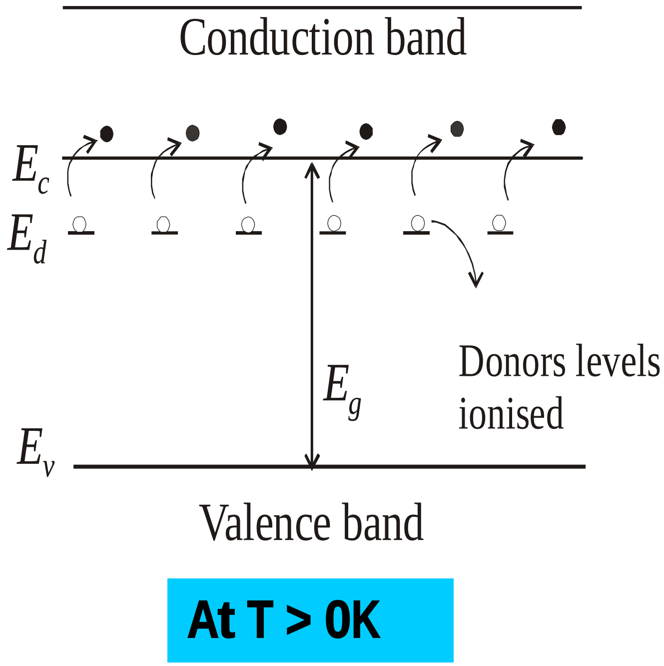
- This brings in the dielectric constant of the crystal into the orbital calculations, and the radius of the electron orbit here turns out to be very large, about 80 Å, as against 0.5 Å for the hydrogen orbit. Such a large orbit evidently means that the fifth electron is almost free and is at an energy level close to the conduction band.

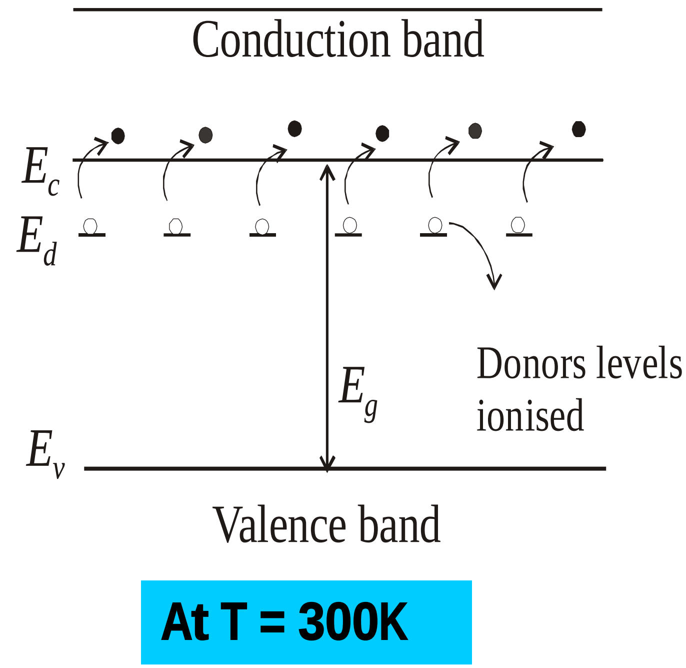
- At 0^0 K, the electronic system is in its lowest energy state, all the valence electron will be in the valence band and all the phosphorous atoms will be un-ionised.

- The energy levels of the donor atoms are very close to the conduction band.

- In the energy level diagram, the energy level of the fifth electron is called donor level. The donor level is so close to the bottom of the conduction band.

- Most of the donor level electrons are excited into the conduction band at room temperature and become majority charge carriers.





If the thermal energy is sufficiently high, in addition to the ionization of donor impurity atoms, breaking of covalent bonds may also occur thereby giving rise to generation of electron hole pair.

The Fermi energy for n – type semiconductor

$$E_F = \frac{(E_c + E_d)}{2} + \frac{kT}{2} \ln \left[\frac{N_d}{2\left(\frac{2\pi m_e^* kT}{h^2} \right)^{3/2}} \right]$$

At 0 K,

$$E_F = \frac{(E_c + E_d)}{2}$$

Variation of Fermi level with temperature

$$E_F = \left(\frac{E_d + E_c}{2} \right) + \frac{kT}{2} \ln \frac{N_d}{2\left[\frac{2\pi m_e^* kT}{h^2} \right]^{3/2}}$$

Let

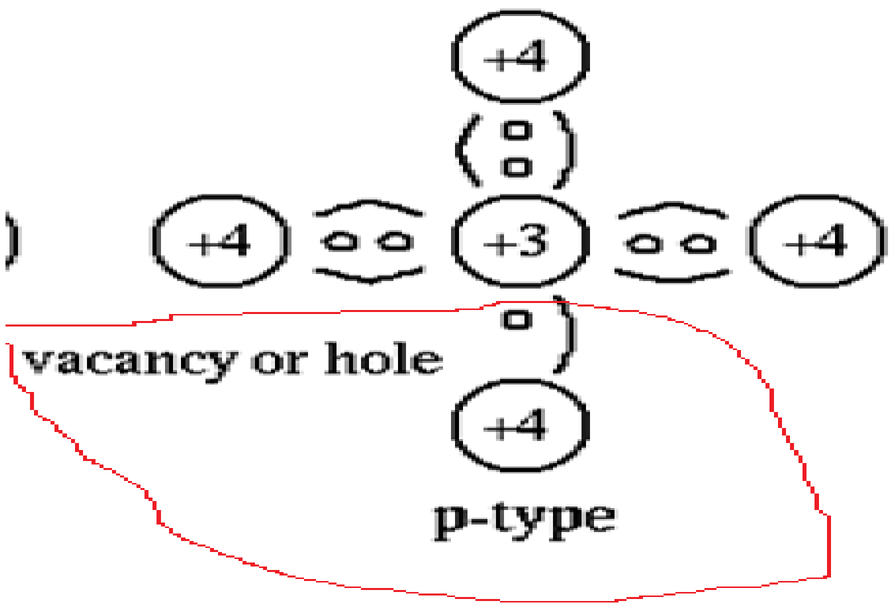
$$2\left[\frac{2\pi m_e^* kT}{h^2} \right]^{3/2} = N_x$$

$$= \left(\frac{E_d + E_c}{2} \right) - \frac{kT}{2} ln \left(\frac{N_d}{N_x} \right)^{-1}$$

P -Type Semiconductor

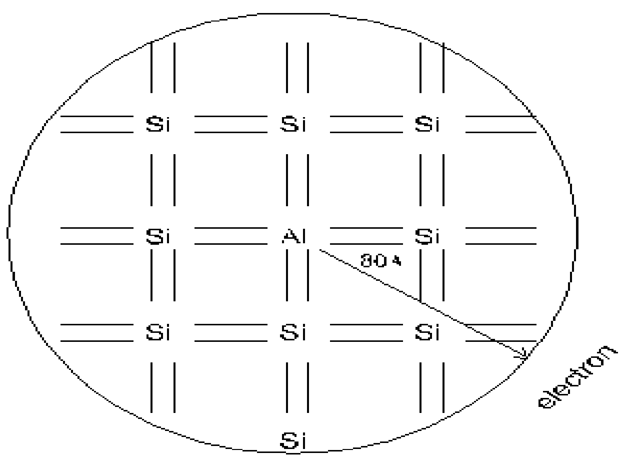
When trivalent impurity is added to intrinsic semiconductor, P type semi conductors are formed.

Al has three electrons in the outer orbital. While substituting for silicon in the crystal, it *needs an extra- electron* to complete the tetrahedral arrangement of bonds around it.

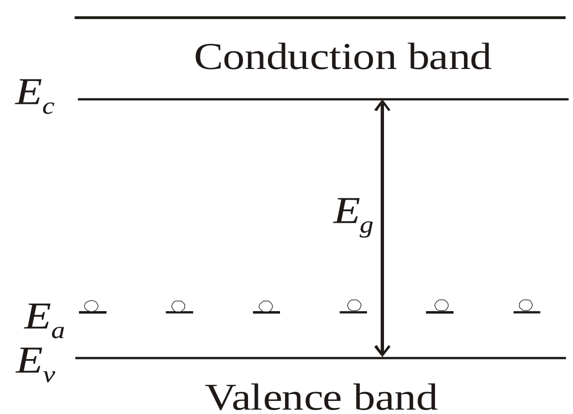


The extra electron can come only from one of the neighboring silicon atoms, thereby creating a vacant electron site (hole) on the silicon.

The aluminium atom with the extra electron becomes a negative charge and the hole with a positive charge can be considered to resolve around the aluminium atom, leading to the same orbital calculations as aboveT.



p - type semiconductor



At T = 0K

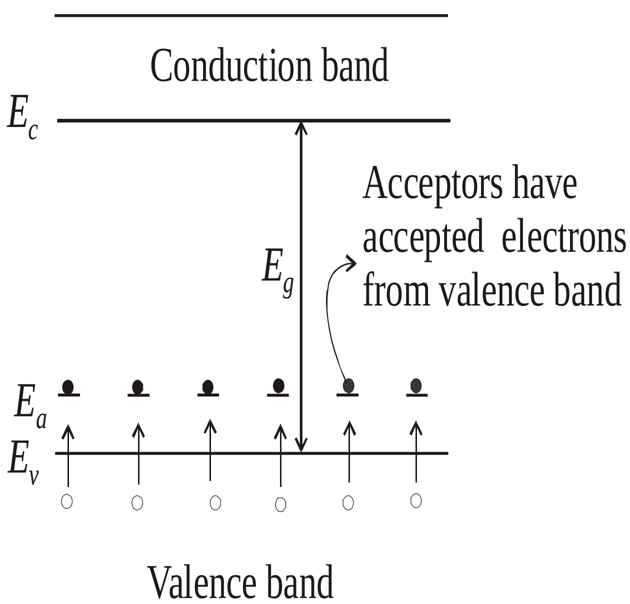
Since the trivalent impurity accepts an electron, the energy level of this impurity atom is called acceptor level. This acceptor level lies just above the valence bond.

Even at relatively low temperatures, these acceptor atoms get ionized taking electrons from valence bond and thus giving to holes in the valence bond for conduction.

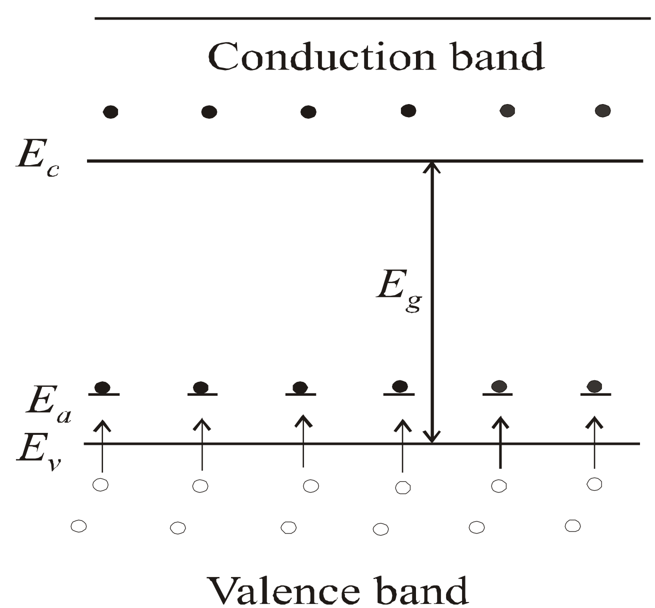
Due to ionization of acceptor atoms, only holes and no electrons are created.

If the temperature is sufficiently high, in addition to the above process, electron-hole pairs are generated due to the breaking of covalent bonds.

Thus holes are more in number than electrons and hence holes are majority carriers and electrons are minority carriers



(a) At T > 0K



(b) At T = 300K

The Fermi energy for p – type semiconductor is given by

$$E_F = \left(\frac{E_v + E_a}{2}\right) - \frac{kT}{2} ln\left[\frac{N_a}{2\left(\frac{2\pi m_h^* kT}{h^2}\right)^{3/2}}\right]$$

At 0 K,

$$E_F = \frac{E_v + E_a}{kT}$$

At 0^0 K, Fermi level is exactly at the middle of the acceptor level on the top of the valence band.

Variation of Fermi level with temperature

$$E_F = \left(\frac{E_v + E_a}{2}\right) - \frac{kT}{2} ln \left(\frac{N_a}{2\left(\frac{2\pi m_h^* kT}{h^2}\right)^{3/2}}\right) = \left(\frac{E_v + E_a}{2}\right) - \frac{kT}{2} ln \left(\frac{N_a}{N_y}\right)$$

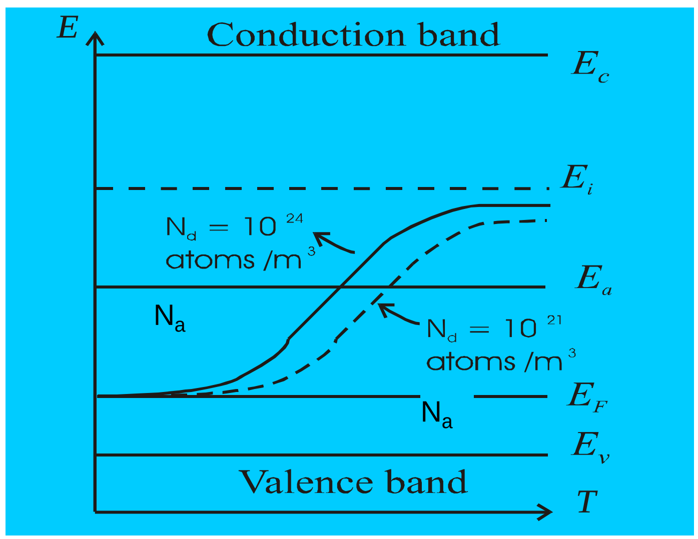
where $N_y = 2 \left(\frac{2\pi m_h^* kT}{h^2}\right)^{3/2}$

and therefore $E_F = \left(\frac{E_v + E_a}{2}\right) + \frac{kT}{2} ln \left(\frac{N_a}{N_y}\right)$

From the above eqn, it is seen that E_F increases slightly as the temperature increases.

As the temperature increases, more and more acceptor atoms are ionised.

For a particular temperature all the acceptor atoms are ionized. Further increase in temperature results in generation of electron-hole pair due to the breaking of covalent bonds and the material tend to behave in intrinsic manner. The Fermi level gradually moves towards the intrinsic Fermi level.



Variation of Fermi level with acceptor concentration and temperature