Extrinsic semiconductor

The electrical conductivity of Intrinsic semiconductor is very small. To increase the conductivity of Intrinsic semiconductor a small percentage of trivalent or pentavalent atoms (impurities) is added to the pure semiconductor in the process of crystallisation, which is called doping & results the impure semiconductor being called extrinsic semiconductor.

The conductivity of extrinsic semiconductor is much higher, say for example 12 times than Intrinsic semiconductor when an impurity is added 1 part in 10^8.

The Impurity atom has a size which is almost of the same order of the host lattice. Since percentage of Impurity atoms is very small. so every atom is surrounded by normal lattice So basic structure of crystal will not get altered after doping.

There are two types of extrinsic Semiconductor

N-type & P-type.

N-type Semiconductor

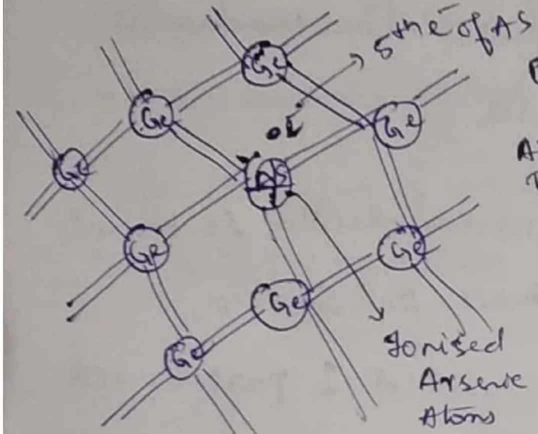
When Intrinsic Germanium is doped. (It is a process of homogeneous mixing of a small quantity of known Impurity into the host material) with one of the group V elements.

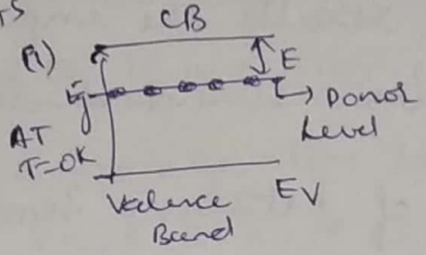
Since the host germanium atoms are tetravalent (4). only four of the five valence electrons of the

Impurity are able to form covalent bond, leaving one electron weakly bounds to its parent atom.

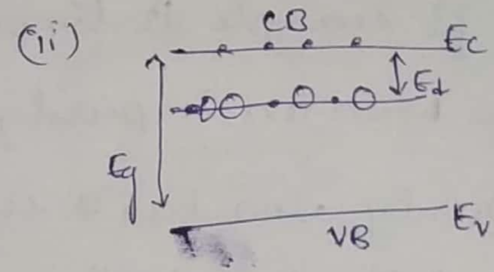
This electron can be easily excited into the CB by supplying an energy equal to $E_d = 0.013$ eV.

this $\bar{e}$ leaves the atom & is free to move in the Germanium lattice, such an $\bar{e}$ behaves as conduction $\bar{e}$





[Energy levels of one of the 5 $\bar{e}$s of every Arsenic atoms are donor levels]



T>0K.

In Terms of Band theory, the energy levels of 5^{th} $\bar{e}$ of Impurity atoms occupy position between VB & CB as shown these levels are at a distance E_d (0.013eV) below the CB.

At T=0K all these levels are occupied but at even moderately low Temp most of the $\bar{e}$s move to CB becoz of small E_d. The remaining +ve charge (a hole) on Arsenic atom is localized & doesnot take part in electrical conductivity

the Impurities are called donors which supply $\bar{e}$s without simultaneously creating holes. ∴ $\bar{e}$s are majority charge carriers & holes in VB is minority charge carriers

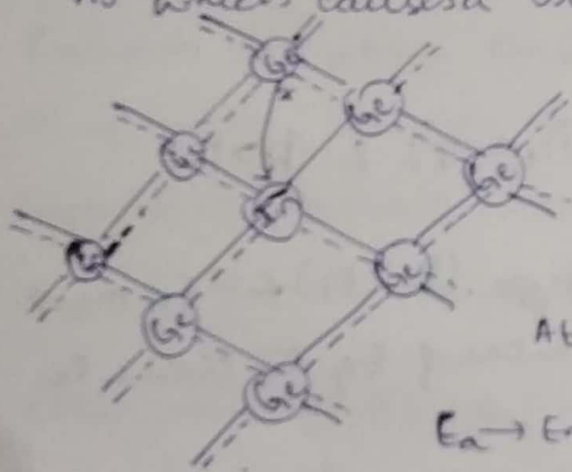
The Semi-conductor doped with donor Impurity is called N-type semiconductor.

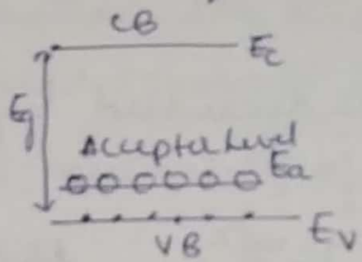
ex!

p-type Semiconductor

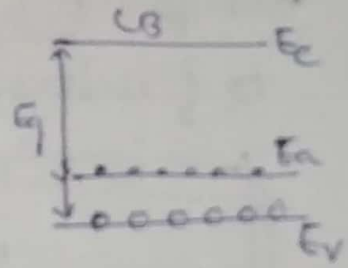
when the Germanium/Silicon is doped with a trivalent impurity such as Indium. It is found that impurity atoms occupy the sites normally occupied by Ge atoms. The Indium atom is short of one $\bar{e}$ to establish bonds with all the four nearest neighbours.

However, it can borrow the required $\bar{e}$ from a Ge atom if an energy equal to $E_a \simeq 0.01eV$ is supplied to system. The transfer of an $\bar{e}$ from Ge atom leaves a hole in the VB which causes a break in one of the neighbouring Ge bonds





At T=0K



T>0K

$E_a \rightarrow$ Energy levels of unpaired bonds of Indium atoms are acceptor levels $\simeq 0.01eV$

The Impurities which trap $\bar{e}$'s & add holes to VB of parent atom without simultaneously adding conduction $\bar{e}$'s are termed as acceptors

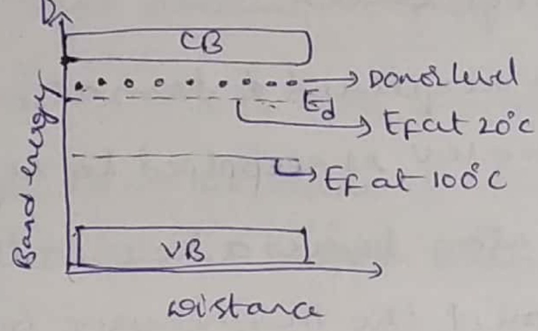
The semiconductors doped with acceptor impurities are known as p-type semiconductors

In this case the holes are majority carriers in the VB & $\bar{e}$'s in CB (if any) are minority carriers

Fermi-Level in an Extrinsic Semi-Conductor

In an Intrinsic semi-conductor $(n = p) = n_i$
e^-s = holes

But in N-type extrinsic semiconductor no of e^-s is increased due to doping of pentavalent atoms $(n_e > n_i)$
& no of holes is decreased by $(p_e < p_i)$

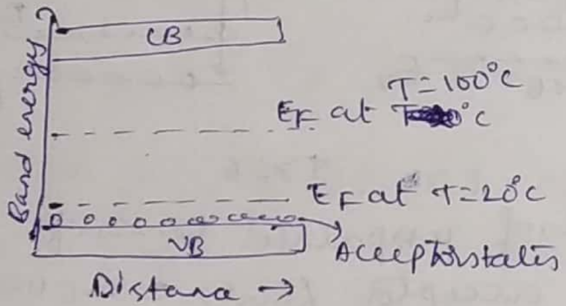


At low Temp E_F lies closer to CB. $n_e > p_e$.

At High Temp E_F lies in between CB & VB.

My for P-type

no of electrons are decreased by $(n_e < n_i)$ & $(p_e > p_i)$



for P-type $(p_e > p_i)$ so E_F must move centre of E_g to closer to VB.

As the Temp rises the material becomes more & more Intrinsic & Fermi level moves closer to Intrinsic position i.e., at the centre of Energy gap.

Charge carrier density in extrinsic Semi-conductor

In both n-type & p-type semi-conductors e^-s which create the ions recieve relatively higher energy than needed to create $(e^- - p)$ pairs. ∴ it is possible to establish conductivity at low temp compare to Intrinsic
Hence the density of conduction e^-s can be assumed to be equal to the density of Donor impurity (N_D)
Likewise.

the density of holes in VB is equal to density of Acceptor Impurities (N_A).

It is to be noted that conc of majority charges is increased over its intrinsic value by doping. The conc of minority charges is found to decrease by by same amount to maintain conc product n_i^2 const.

is, $$n_p P_p = n_i^2 \longrightarrow (1)$$ mass Action Law $(n_i p_i = n_i^2)$

where $n_i \rightarrow$ Intrinsic $\bar{e}$ density

$n_p, p_p \rightarrow \bar{e}$ & hole densities in p-type material.

Based on the above consideration, the amount of reduction in minority charges can be determined by use of eqn expressing overall charge neutrality of material is.

$$p + N_D = n + N_A \longrightarrow (2)$$

Now use eqn (1) $np = n_i^2$ where

$$n = \frac{n_i^2}{p} \quad \& \quad p = \frac{n_i^2}{n}$$

so, eqn (2) becoms

$$p + N_D = \frac{n_i^2}{p} + N_A$$

$$p^2 + (N_D - N_A)p - n_i^2 = 0 \longrightarrow (3)$$

If it is n-type semiconductor

$N_A = 0$ & $n \gg p$

$\therefore N_D \simeq n$

where $n_n \rightarrow \bar{e}$ conc in n type

$P_n \rightarrow$ hole conc in p-type

From mass action Law $n.p = n_i^2 \Rightarrow P_n = \frac{n_i^2}{n_n} = \frac{n_i^2}{N_D}$

Illy for p-type $N_D = 0$ $p \gg n$, $N_A \simeq p$

$$n_p = \frac{n_i^2}{P_p} = \frac{n_i^2}{N_A}$$