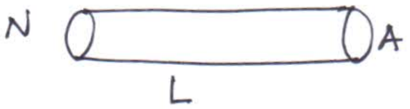
Ct Flow in Semiconductors

§ Conduction in metal



$$I = \frac{Nq}{T} = \frac{NqL}{T.L}$$

$$= \frac{Nq\,V_d}{L}$$

$$n = \frac{N}{AL}$$

N : total no. of charge carrier

n : carrier density. i.e. carrier/vol

$$J = \text{current density} = \frac{I}{A} = \frac{qNV_d}{AL} = q(n)V_d$$

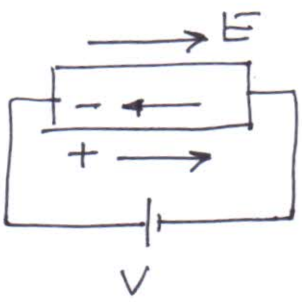
If $\vec{E}$ is the applied Electric field.

μ : mobility $\quad V_d = \mu\vec{E} \quad$ V_d : Drift velocity

$$J = qnV_d = (qn\mu)\vec{E} = \sigma\vec{E}$$

$\sigma = qn\mu$ conductivity

§ Ct in semiconductor.



An electric field $\vec{E}$ is established in a semiconductor,

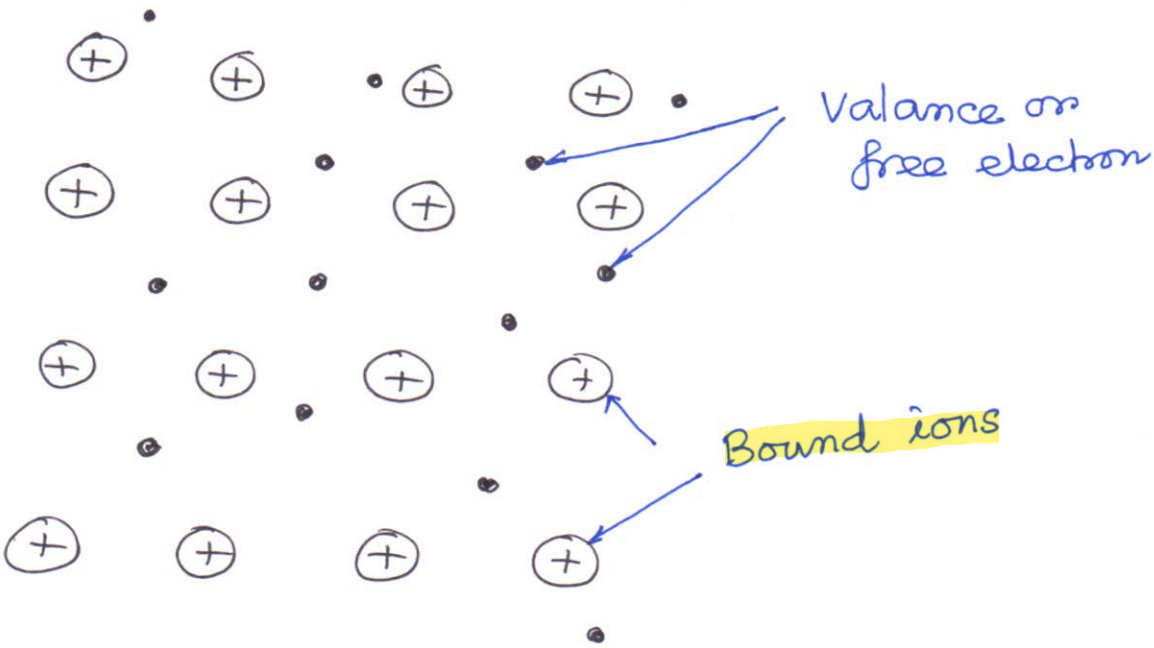
holes are accelarated in d.c. of E

electrons are " in opposite dc of E

$V_{p\,drift} = \mu_p E \quad$ μ_p : hole mobility

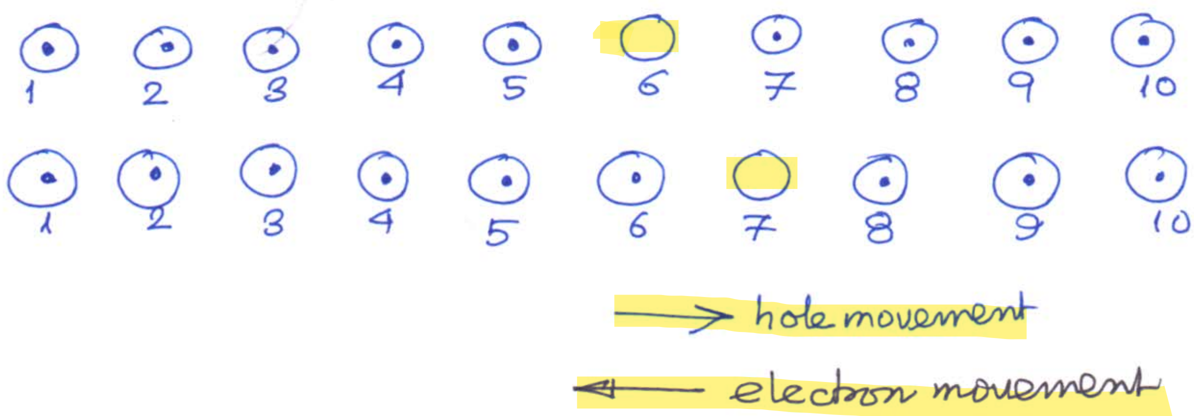
For intrinsic Si $\mu_p = 480\ cm^2/V.s$

Conduction in Metals



electrons of one atom are as much associated with one ion as with another, so electron attachment to any individual atom is zero. Valance electrons can wander freely from atom to atom in the metal

Conduction in Intrinsic Semiconductors



Breaking a covalent bond results in both a free electron and a hole.

hole conc. (p) and electron Conc (n) are equal

$$p = n = n_i$$

Free electrons acquire a drift velocity

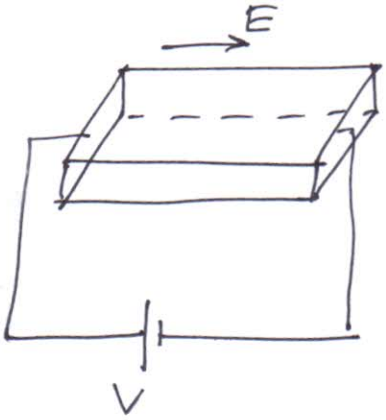
$v_{n\,drift} = -\mu_n E$

electrons move in direction opposite to E

μ_n is 'e' mobility

for intrinsic Si 1350 $cm^2/V.s$.

$\mu_n \cong 2.5\mu_p$ electrons move with much greater ease through Si than holes.



Let us now return to single Crystal Si:

Let conc. of holes be 'p' and that of free electrons 'n'.

Ct. component due to flow of holes

$$I_p = Aqp\,v_{p\_drift}.$$

In one sec, hole charge that crosses the plane will be $Aqp\,v_{p\text{-}drift}$ ~~col~~ coulombs.

$$\boxed{I_p = Aqp\,v_{p\_drift} = Aqp\mu_p E}$$

hole current density $\boxed{J_p = \frac{I_p}{A} = qp\mu_p E}$

Current Component due to drift of electron

$$\boxed{I_n = -Aqn\,v_{n\_drift} = -Aqn\mu_n E}$$

electron current density $J_n = -Aqn\mu_n E$

total drift ct density $J = J_p + J_n$

$$J = q(p\mu_p + n\mu_n)E$$

$$J = \sigma E$$

Thus conductivity $\sigma = q(p\mu_p + n\mu_n)$

resistivity $\rho = \frac{1}{\sigma} = \frac{1}{q(p\mu_p + n\mu_n)}$

Ex: Find the resistivity of (a) intrinsic Si
(b) p type Si with $N_A = 10^{16}/cc$. Use $n_i = 1.5 \times 10^{10}/cc$
Assume $\mu_n = 1350\ cm^2/V.s$ and $\mu_p = 480\ cm^2/V.s$.
for eintrinsic Si, and for dopped Si
$\mu_n = 1110\ cm^2/V.s$ and $\mu_p = 400\ cm^2/V.s$

(Note doping reduces carrier mobility)

Soln. (a) $p = n = n_i = 1.5 \times 10^{10}/cc$.

$$\rho = \frac{1}{q(p\mu_p + n\mu_n)} = \frac{1}{1.6 \times 10^{-19} \times 1.5 \times 10^{10}\ (1350 + 480)}$$

$$= 2.28 \times 10^5\ \Omega\ cm.$$

(b)
For p type Si $p_p = N_A = 10^{16}/cc$

$$n_p = \frac{n_i^2}{N_A} = 2.25 \times 10^4/cc$$

$$\rho = \frac{1}{q(p\mu_p + n\mu_n)} = 1.56\ \Omega\ cm$$

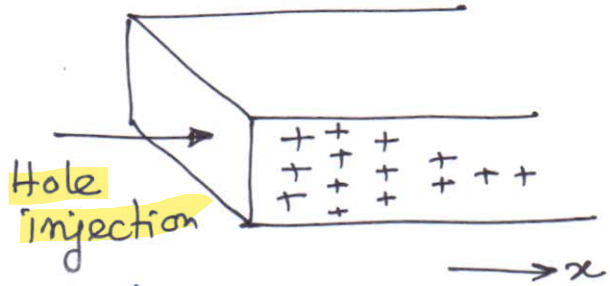
$$= \frac{1}{1.6 \times 10^{-19} (10^{16} \cdot 400 + 2.25 \times 10^4 \times 1110)}$$

Observe that doping the Si reduces its resistivity by a factor of 10^5.

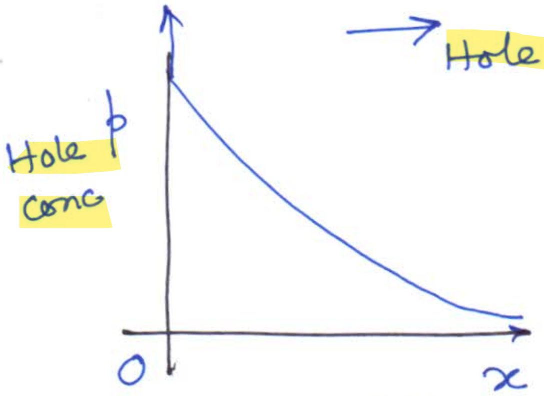
- resistivity of p type Si is determined almost entirely by doping concentration.

Diffusion ct.

Diffusion of charge carrier $\Rightarrow$ Diffusion ct.



$\longrightarrow$ Hole diffusion



$$J_p = -q D_p \frac{dp(x)}{dx}$$

Magnitude of ct is proportional to slope of conc. profile or conc. gradient

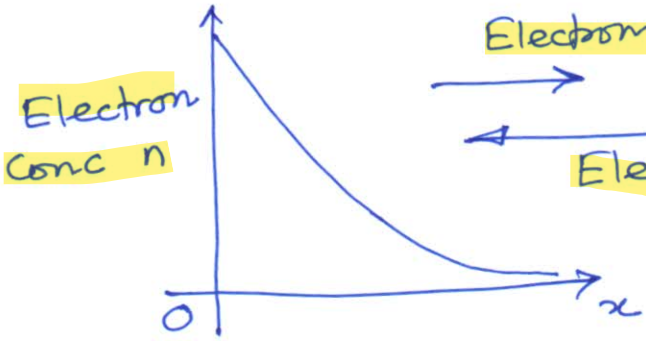
Conc. profile

Hole Diffusion $\longrightarrow$

$\longrightarrow$ Hole ct.

J_p : Hole ct density

D_p : Diffusion Const. of hole



Electron Diffusion $\longrightarrow$

$\longleftarrow$ Electron ct.

$$J_n = q D_n \frac{dn(x)}{dx}$$

D_n : Diffusion Const of electron.

* $\frac{dp(x)}{dx}$ is −ve, so J_p is +ve along x axis

For holes and electrons diffusing in intrinsic Si, typical values $D_p = 12\ cm^2/s$, $D_n = 35\ cm^2/s$.

Ex: Consider a bar of Si in which a hole conc prifile described by

$p(x) = p_0 e^{-x/L_p}$ is established.

Find the hole ct. density at $x=0$.
Let $p_0 = 10^{16}/cm^3$ $L_p = 1\ \mu m$. Cross sectional Area of bar is $100\ \mu m^2$. Find the ct I_p.

$$J_p = -qD_p \frac{dp(x)}{dx} = \frac{qD_p\, p_0}{L_p} e^{-x/L_p}$$

$$J_p(0) = qD_p \frac{p_0}{L_p} = 192\ A/cm^2$$

$$I_p = J_p(0).A = 192\ \mu A$$

Relationship ~~b~~ between D and μ.

<u>Einstein relationship.</u>

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T \qquad V_T = \frac{kT}{q} \quad \text{thermal voltage}$$

At room temp ~~@~~ $T = 300\ K$, $V_T \simeq 26\ mV$.

Mass Action Law

Addition of n type empurities causes no. of holes to ~~increase~~ decrease.

Similarly doping with p type impurities decreases the conc. of free electrons below the intrinsic level.

Under thermal equilibrium, the product of free negetive and positive concentration is a constant independent of the amount of donor and acceptor impurity doping.

This is called ~~as~~ the mass action law

$$\boxed{np = n_i^2}$$

The law of Mass action asserts that at a constant temperature, the product of the number of electrons in the conduction band and the number of holes in the valence band remains constant, regardless of the quantity of donor and acceptor impurities added.
(n is number of electrons in the conduction band ,p is number of holes in the valence band)

Carrier Concentrations

At temp T > 200k, sufficient kinetic energy is obtained to ionize all the impurities.

Let N_D be conc. of donor atoms
N_A be conc. of acceptor atoms.

Since they are ionized, they produce N_D^+ and N_A^- respectively

Let N_D be the conc. of donor atoms and N_A be conc. of acceptor atoms.

$$\boxed{N_D^+ + p = N_A^- + n}$$

For the crystal lattice to be neutral,the number of electrons and the number density of acceptor atoms should be equal to the sum of total number of holes and number density of donor atoms in a semiconductor.

to maintain the electrical neutrality of the crystal.

total positive ion density = total negative ion density

Now consider an n type material with $N_A = 0$,

Since no. of electrons in an n-type semiconductor is much greater than no. of holes $n \gg p$

We have $\boxed{n \approx N_D^+}$

$\Rightarrow$ In an n type material the free electron conc is approx $\approx$ density of donor atoms.

Conc. of p holes in the n type semiconductor

$$\boxed{p = \frac{n_i^2}{N_D}}$$

Similarly in a p type semiconductor $\boxed{p \approx N_A^-}$

$$\boxed{n = \frac{n_i^2}{N_A}}$$