10.01.2022
(10:15 – 11:15 AM)

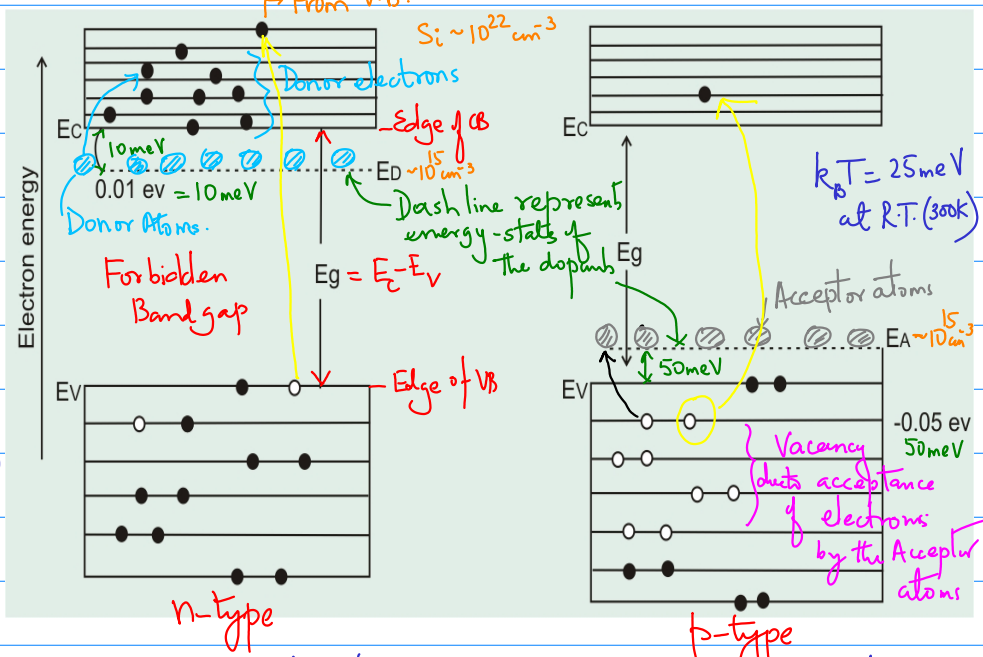
DIV

Charge-Carrier Density in Semiconductors

For Silicon:

$n = p = n_i(T) = 10^{10}\ cm^{-3}$ at T=300K

Extrinsic – Dopants { Donors / Acceptors



Note:

1) Since dopant (donor or acceptor) density is very-very low as compared to the density of atoms in the semiconductors, they formed discrete energy levels within the band-gap of the semiconductor.

- Since the dopant energy levels lie below (or above) the band-edge energy, the dopant atoms can release (or accept) the electrons from the CB (or VB).

Typically, at T=300K, the donor atoms release electrons to the CB.

$n_{\text{Donor atoms}} = 10^{15}\ cm^{-3}$

$n_i = 10^{10}\ cm^{-3}$

$n_{\text{Donor atoms}} \gg n_i$

$\Rightarrow$ Semiconductor is n-type (electron dominated)

Comparing $n_{\text{Donor atoms}}$ and n_i, we conclude that

Also, all Acceptor atoms accept electrons from the valance band leaving behind vacancies (holes).

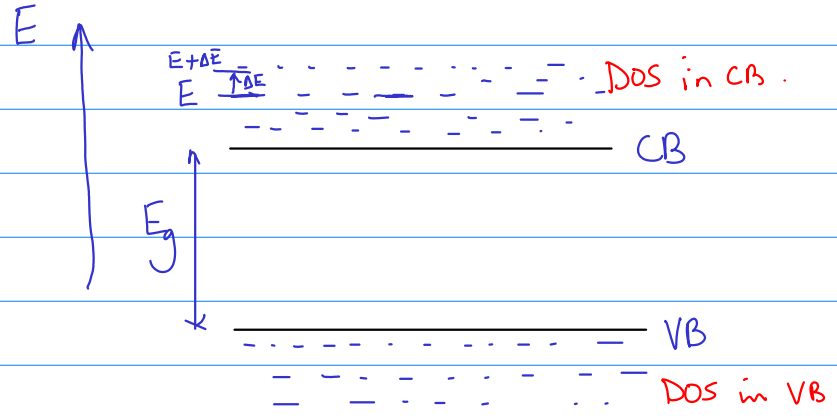
Therefore, at $T = 300\,K$

$p = 10^{15}\ cm^{-3}$ (Acceptor atoms)

$n_i = 10^{10}\ cm^{-3}$

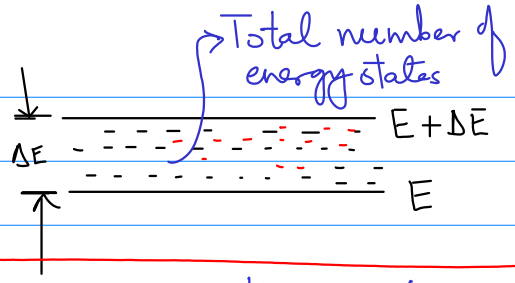
Comparing, we conclude $p \gg n_i$ (Acceptor Atoms)

$\Rightarrow$ The semiconductor is hole dominated and termed as p-type.



- Each energy band (CB or VB) is a collection of discrete energy states.
- Let us consider two energy levels E and E+ΔE. and we count the number of energy states in the energy interval of E & E+ΔE

We define density of energy states (DOS) as



$$D = \frac{\text{Total number of energy states between two energy levels i.e, } E \text{ \& } E+\Delta E}{\Delta E}$$

$\Rightarrow$

D = Number of energy states per unit energy interval.

$$D = (\quad)\ cm^{-3}\ eV^{-1}$$

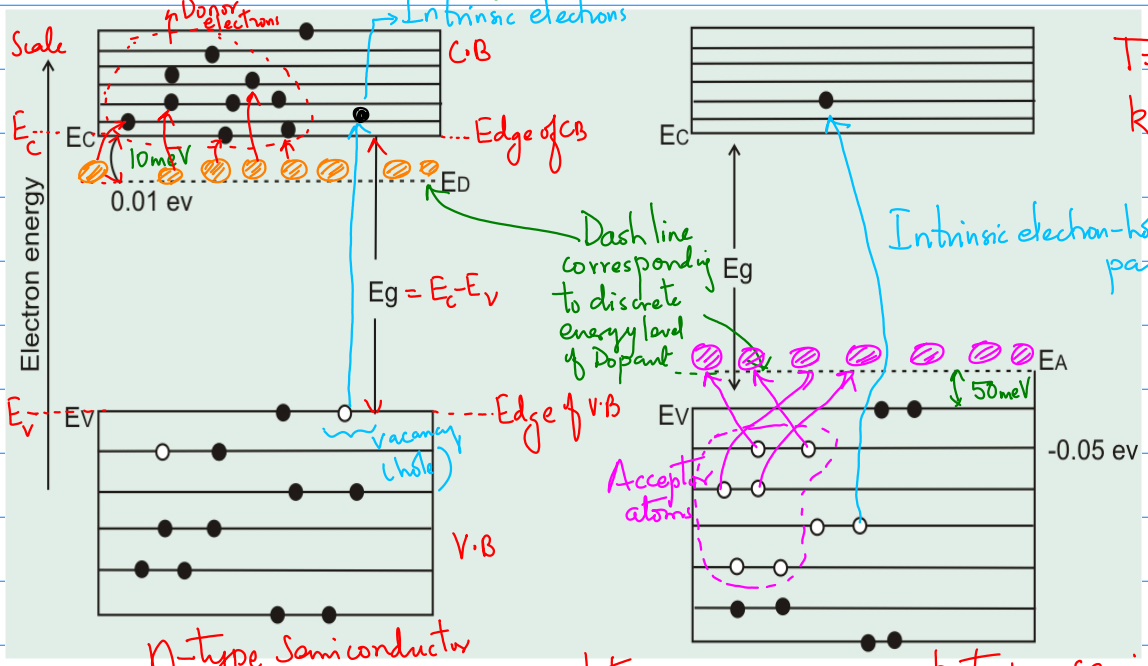
$$D_c(E) \propto \sqrt{(E - E_c)}$$

E_c: Energy level of the edge of the CB.

GNR (SEC-1)

10.01.2022
(11:30 AM – 12:30 PM)

Charge-Carrier Density in Semiconductors



- For Silicon:

$$n = p = n_i = 10^{10}\ cm^{-3}$$

$n_i(T)$ & varies with varying T.

- Extrinsic Semiconductor → Dopants { Donors, Acceptor }

- Dopant density << Atomic Density

eg. for Silicon; atomic density $\sim 10^{22}$ atoms cm^{-3}

Dopant density $\sim 10^{15}$ atoms cm^{-3}
(Moderate doping level)

⇒ Dopants are 20 parts per billion.

Note:

- Since dopant density is much-much lower than the atomic density of the solid (semiconductor); the dopants do not constitute to energy band.

$\Rightarrow$ We observe discrete energy levels of the dopant atoms within the energy-gap of the semiconductor.

At $T = 300K$, ie, $k_B T = 25\,meV$

Following observations are there:

- All donor atoms gain this thermal energy and release extra electrons to the conduction band.

$$n_{\text{Donor atoms}} \sim N_D = 10^{15}\ cm^{-3}$$

- The valance electrons gain energy & populate in conduction band.

$$n_i = 10^{10}\ cm^{-3}$$

- This means that at any instant of Time, the conduction band is populated with two kinds of "FREE" electrons.

$$n_{\text{Donor atoms}} = 10^{15}\ cm^{-3}$$

$$n_i = 10^{10}\ cm^{-3}$$

Comparing the two; $n_{\text{Donor atom}} \gg n_i$

Therefore, we term the semiconductor as n-type since the electrons in conduction band is much-much higher than the holes in Valance band.

- Also, all acceptor atoms accept electrons from the valance band leaving behind vacancies (holes).
- In valance band, we have two kinds of vacancies,

$$p_{\text{Acceptor atoms}} = N_A = 10^{15}\ cm^{-3}$$

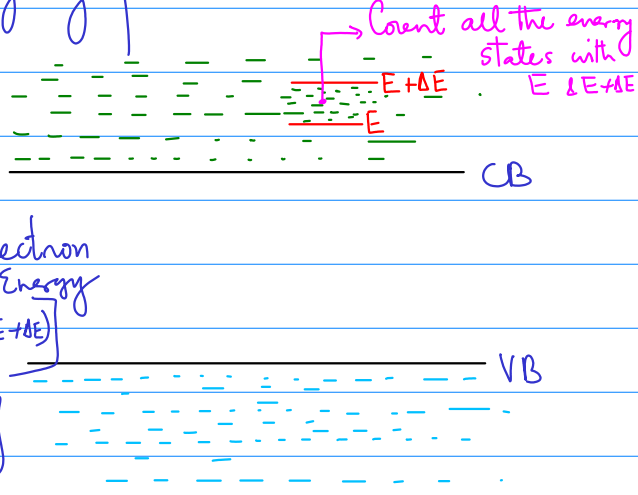
$$n_i = p = 10^{10}\ cm^{-3}$$

- Comparing the two, $p_{\text{Acceptor Atoms}} \gg n_i$

Therefore, we term the semiconductor as p-type.

Idea of Density of Energy States (DOS)

- Each energy band (ie, CB or VB) is a collection of discrete energy levels separated by very-very small energy gap.



We define, density of energy-states as:

$$D = \frac{\left[\text{the number of energy states available between two energy levels (here, } E \text{ \& } E+\Delta E\right)}{\left[\text{Difference of the two energy levels (here } \Delta E\right)}$$

D = Number of energy states per unit energy interval.

$D = (\ ?\ )\ \underbrace{cm^{-3}\, eV^{-1}}_{\text{unit of DOS}}$

For conduction band:

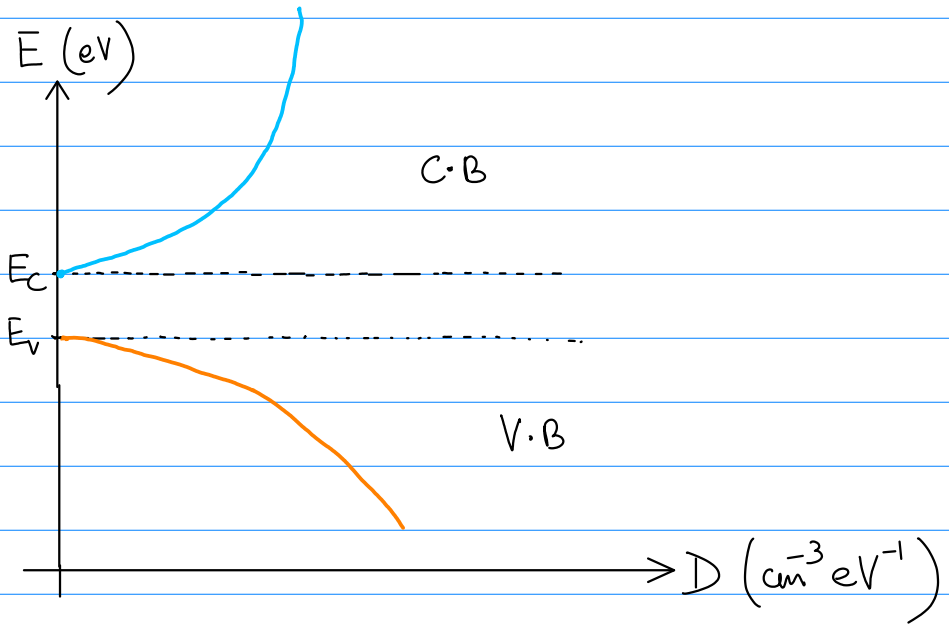
$$D \propto \sqrt{(E - E_c)}$$

where E_c = Edge of CB.

↑ depends non-linearly on the energy E

for example: if $E = E_c$; $D = 0$

if $E \gg E_c$; $D = \sqrt{E}$



$$D_c(E) = \frac{8\pi m_n^* \sqrt{2 m_n^* (E - E_c)}}{h^3}$$

when m_n^* = effective mass of the electrons in CB.

h = Planck's constant.