7. 01. 2022

Extrinsic Semiconductors

Recap :

n_i = Intrinsic charge-carrier density.

$n_i(E,T)$

In Silicon, $n_i(E_g=1.1eV;\ T=0K) = 0\ cm^{-3}$

Si-atom $10^{22}\ cm^{-3}$

$n_i(E_g\approx 1.1eV;\ \underbrace{T\approx 300K}_{25meV}) = 10^{10}\ cm^{-3}$

25meV of thermal Energy

Since, $n = p = n_i$

n = electrons cm^{-3}

p = holes cm^{-3}

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

What is extrinsic mean which controls the carrier-density ?

$$\sigma_e = e\mu n$$

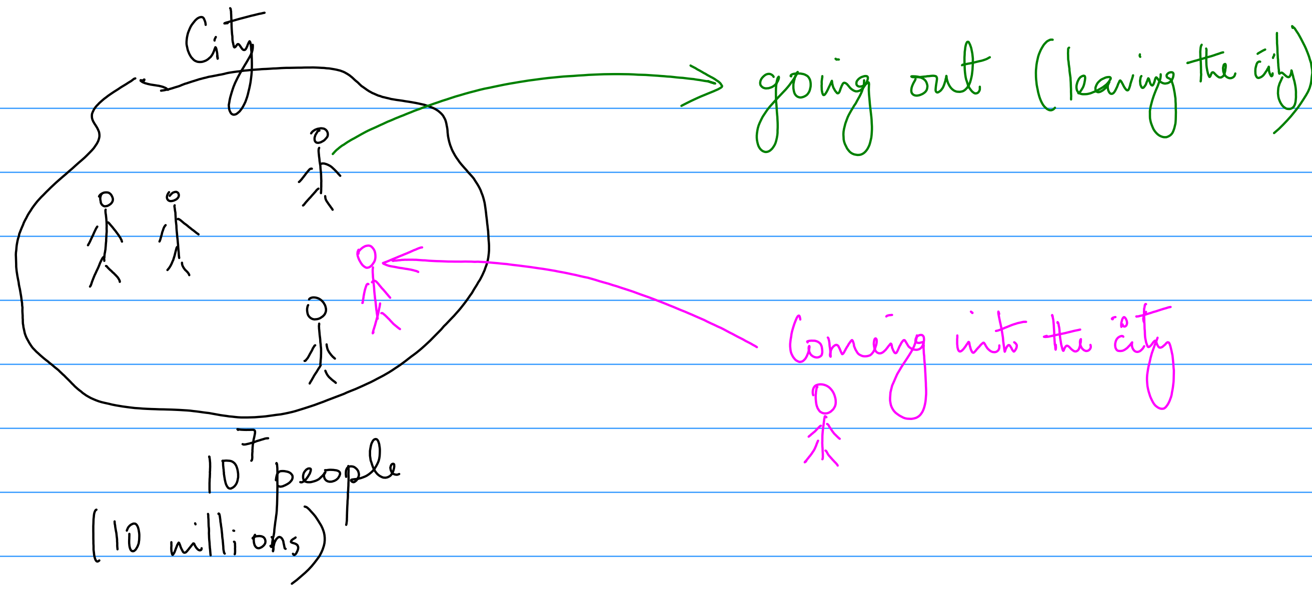
n → electric density (cm^{-3})

e → electronic charge

μ → mobility

if we control the electronic density (n) by some extrisic mean, we can control the conductivity.

Extrinsic Mean — Doping.

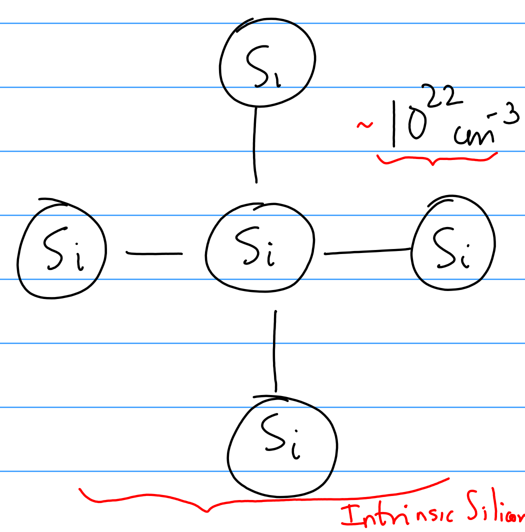


Out of 10 million population, if one is replaced with other, then, effectively there is no-change in the distribution of the people in the city.

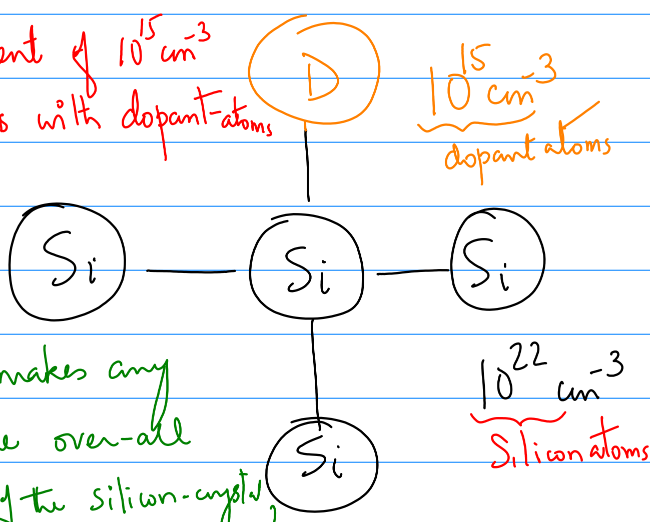
Doping of Silicon:

Silicon atom density : $10^{22}\ cm^{-3}$

Dopant density : $10^{15}\ cm^{-3}$



Replacement of $10^{15}\ cm^{-3}$ Silicon atoms with dopant-atoms



Ques: Will this process of doping makes any change in the over-all properties of the silicon-crystal?

Out of 10^7 Silicon atoms only one Silicon atom is replaced with the Dopant-atom.

As a result, one cannot see any change in the mechanical properties of the Silicon.

However, the electronic properties changes. How?

Lets see dopant is a "donor". (which can donate electrons)

$$\text{Si atomic density} = 5\times10^{22}\ cm^{-3}$$

$$\text{Donor density} = 1\times10^{15}\ cm^{-3}$$

$\Rightarrow$ Out of 5×10^{7} Silicon atoms cm^{-3}, 1 silicon atom is being replaced with the donor-atom.

$\Rightarrow$ The donor is 20 parts per billion (ppb)

Silicon atoms of 1 billion population $\rightarrow$ 20 atoms are the extrinsic one (donor-atom)

Our focus is the electronic effect:

$$\sigma = e\mu n$$

Intrinsic Conductivity $\quad \sigma_i = e\mu n_i \quad \{n = p = n_i = 10^{10}\ cm^{-3}\}$

Extrinsic conductivity (due to doping) $\quad \sigma_{ex} = e\mu n_D \quad n_D = \text{Dopant density } cm^{-3} = 10^{15}\ cm^{-3}$

Ratio of conductivities $= \dfrac{\sigma_{ex}}{\sigma_i} = \dfrac{\cancel{e\mu}\, n_D}{\cancel{e\mu}\, n_i} = \dfrac{10^{15}\,cm^{-3}}{10^{10}\,cm^{-3}} = 10^{5}$

$$\boxed{\sigma_{ex.} = 10^{5}\,\sigma_i}$$

$\Rightarrow$ Conductivity of the Silicon enhances by five Order of magnitude.

Analogy : Wallet is having Rs. 100.

if it is enhanced with five order of magnitude

Rs $100 \cdot 10^{5}$ = Rs 10^{7} = Rs 10 million.

= Rs 1 Crore

Two kinds of dopants :

1) Donors : Releasing electrons $\equiv$ n-type semiconductors

2) Acceptors : Accepting electrons (Releasing holes) $\equiv$ p-type semiconductors

Donors $\rightarrow$ Pentavalent elements P, As, Sb (Antimony)

Acceptors – Trivalent elements B, Al, Ga, In ...

$\Rightarrow$ What would be the distribution of "FREE" charge carriers in CB & VB.?