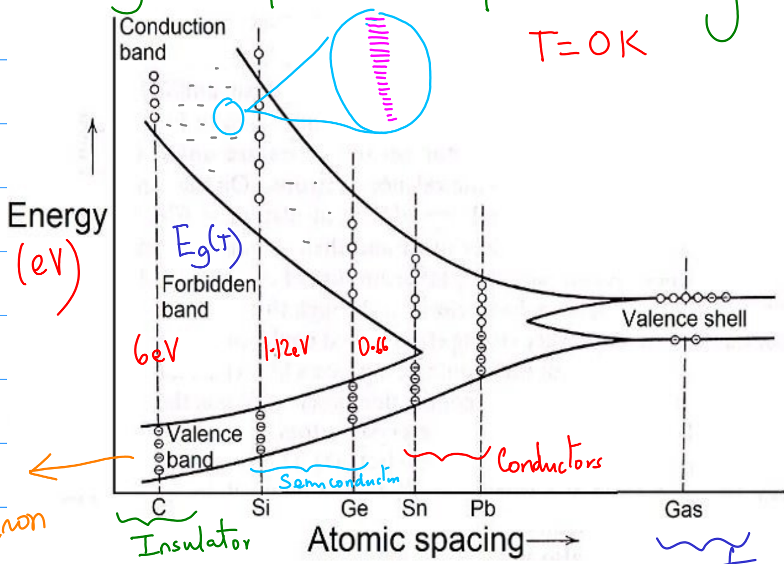
05.01.2022

Charge-Carriers density in Semiconductors

Band diagram of the solids of Carbon group (gr. 14) elements:



$$E_g(T) = E_g(0) - \frac{\alpha T^2}{T+\beta}$$

α, β are the parameters.

For Silicon:

- Lets assume it to be 100% pure.
- T = 0K

at T = 0K ; thermal energy $= k_B T \approx 0$

$\Rightarrow$ all valance electrons remain in the valance band. That is,

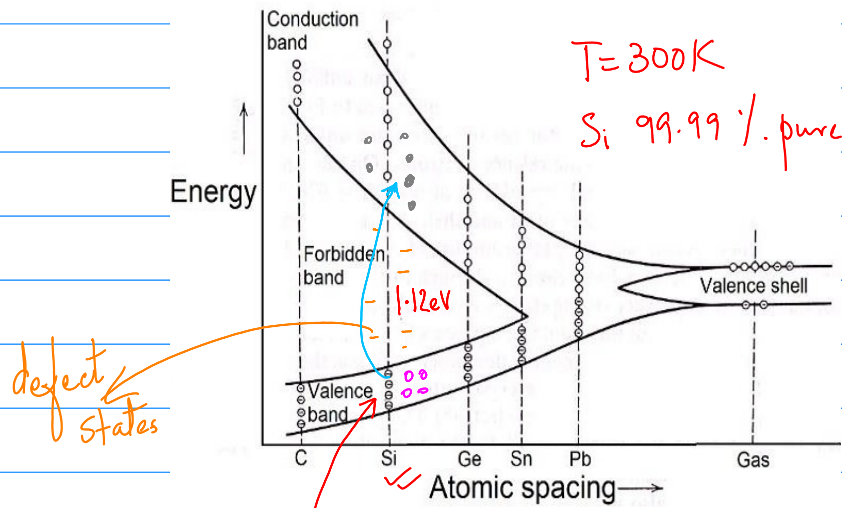
Conduction Band is empty with the electrons.

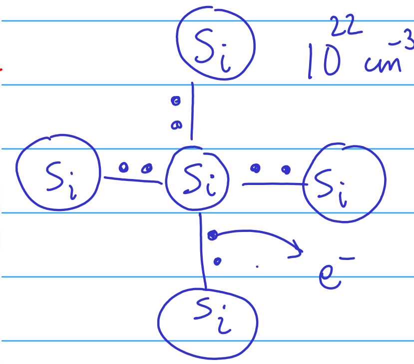
ie, $\boxed{\text{Intrinsically, No "Free" charge-carriers.}}$

$\Rightarrow$ Intrinsic carrier-density at T=0 is "zero".

Case (iii) $T = 300K$; we have 99.99% pure Silicon.

Thermal Energy $= k_B T \approx 25\,meV$





Valance electrons are receiving 25meV of energy.

at this given condition ;

roughly $\sim 10^{10}\,cm^{-3}$ electrons from the Valance band cross the forbidden band (Energy gap) and populate into the conduction band.

Compare this population w.r.t # silicon atoms

$10^{10}\,cm^{-3}$ $\qquad$ $10^{22}\,cm^{-3}$

$\Rightarrow$ Out of one trillion silicon atoms, only one silicon atom got the chance to release its valance electron to the conduction band.

Intrinsically, there are $\sim 10^{10}$ "FREE" electrons at 300K.

n = electron density (cm^{-3})

p = hole (vacancy) density (cm^{-3})

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

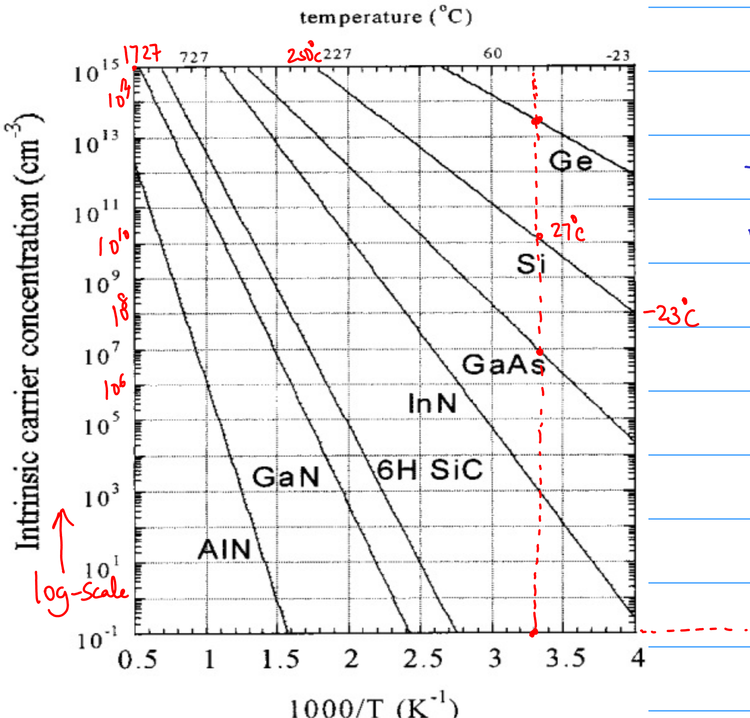
Practical values:

$n_i(\text{silicon}) = 1.5 \times 10^{10}\ cm^{-3}$

$n_i(\text{Germanium}) = 2.4 \times 10^{13}\ cm^{-3}$

$n_i(\text{GaAs}) = 1.8 \times 10^{6}\ cm^{-3}$

at 300K



For Silicon,

$T = -23°C$

$n_i = 10^{9}\ cm^{-3}$

$T = 250°C$

$n_i = 10^{15}\ cm^{-3}$

In silicon,

$\Rightarrow$ Raising the temperature by a factor of 10, raises the

the n_i by $10^5\ cm^{-3}$ (five orders of magnitude)

On earth, even we are at the place with lowest / highest temperature, the variation in intrinsic carrier density of silicon to not much

ie, it varies b/w $\underbrace{10^9\ cm^{-3} \text{ to } 10^{11}\ cm^{-3}}$.

As compared to the "free" carrier density in conductors $(\approx 10^{22}\ cm^{-3})$, these are negligible.

Therefore,

$\Rightarrow$ Intrinsically, the semiconductors are insulators.

For practical devices using semiconductor, the density of intrinsic carriers is not sufficient.

$\Rightarrow$ You need to look for the cond^n, wherein more "free" charge-carriers can be created.

$\Rightarrow$ Extrinsic Mean.