Introduction to Semiconductor Devices
Dr Naresh Kumar Emani
Department of Electrical Engineering
Indian Institute of Technology – Hyderabad

Lecture – 2.2
Intrinsic Carrier Density

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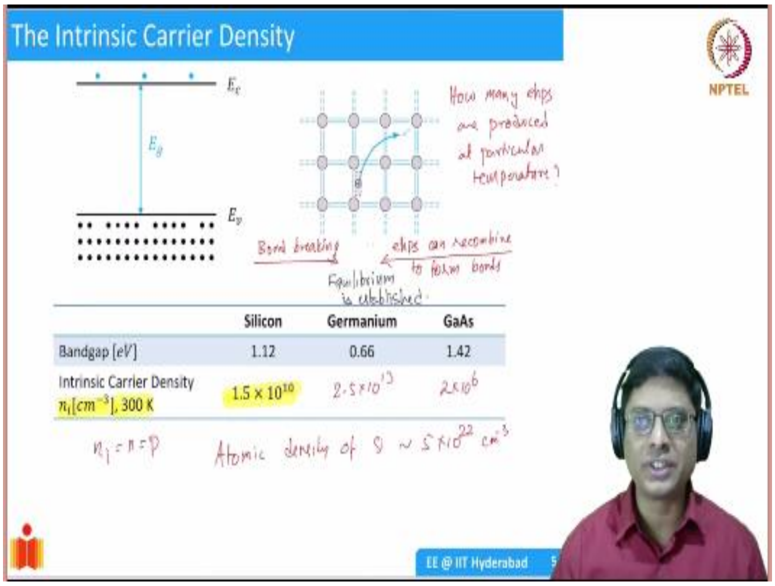

The Intrinsic Carrier Density

How many ehps are produced at particular temperature?

Bond breaking

ehps can recombine to form bonds

Equilibrium is established

	Silicon	Germanium	GaAs
Bandgap [eV]	1.12	0.66	1.42
Intrinsic Carrier Density $n_i[cm^{-3}]$, 300 K	1.5×10^{10}	2.5×10^{13}	2×10^{6}

$n_i = n = p$

Atomic density of Si $\sim 5\times10^{22}\ cm^{-3}$

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A semiconductor with a bandgap has the property of intrinsic carrier density and as the temperature increases, the number of electron-hole pairs (ehps) are produced, i.e., number of ehps are dependent on temperature. This is because, as we transfer more energy onto the material, then most of the bonds are broken.

Due to the incident energy, the ehps are generated because of bond breaking. As a counter process there is a chance of recombination of electron-hole pairs forming bonds (covalent), maintaining equilibrium in the semiconductor. At equilibrium the number of carriers (electrons/holes) are equal to the intrinsic number of carriers in it (as shown in Eq. (1)).

In silicon, at 300° K, the number of carriers, intrinsic carrier density $n_i \sim 1.5 \times 10^{10}$ cm^{-3}, i.e., the number of electron-hole pairs ~ 10^{10} (In solving problems, we use $n_i \sim 1 \times 10^{10}$ cm^{-3}). The intrinsic carrier density is temperature dependent and bandgap dependent (as shown in Eq. (2)). In short, smaller the bandgap, relatively high carrier density (or) larger the bandgap relatively low carrier density.

In an intrinsic semiconductor,

$$n_i = n = p \tag{1}$$

where n_i – intrinsic carrier density, n – no. of electrons, p – no. of holes

If we consider silicon, the atomic density is ~ 5×10^{22} cm^{-3}. So, per unit volume out of 10^{22} atoms, 10^{10} are sort of electron-hole pairs (i.e., not all atoms will not be converted to ehps).

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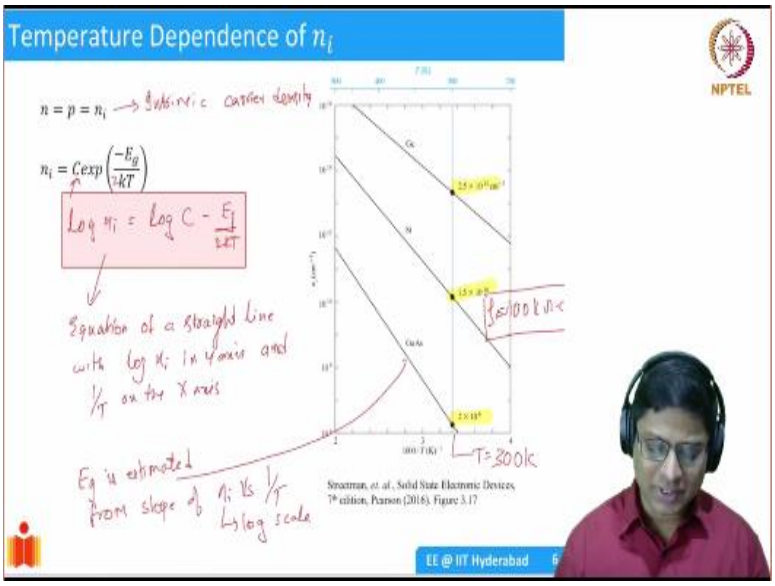

Temperature Dependence of n_i

$n = p = n_i$ → Intrinsic carrier density

$n_i = C\exp\left(\frac{-E_g}{2kT}\right)$

$\boxed{\log n_i = \log C - \frac{E_g}{2kT}}$

↓ Equation of a straight line with $\log n_i$ in y axis and $1/T$ on the X axis

E_g is estimated from slope of n_i Vs $1/T$ ↳ log scale

$\rho \approx 100k\ \Omega$-cm

T = 300K

Streetman, et al., Solid State Electronic Devices, 7th edition, Pearson (2016), Figure 3.17

$$n_i \propto \exp\left(\frac{-E_g}{2kT}\right) \tag{2}$$

$$\log n_i = -\frac{E_g}{2k}\left(\frac{1}{T}\right) + \log C \tag{3}$$

Experimentally, we can estimate the density of the carriers and the bandgap of the material by measuring the conductivity/resistivity of it. For example, take a piece of silicon, calculate the resistivity ~100k Ω-cm. At 300°K, the bandgap of Si can be estimated to 1.1 eV. Eq. (3) represents the straight line (y=mx+c), where the bandgap can be estimated from the slope of

$\log n_i$ vs $\frac{1}{T}$. The table shown below, gives the approximate carrier density in Si, Ge, GaAs at 300°K with corresponding bandgap.

Material	Silicon	Germanium	GaAs
Bandgap $\mathbf{E_g}$ (eV)	1.12	0.66	1.42
Intrinsic carrier density $\mathbf{n_i}$ (cm^{-3}) at 300°K	1.5×10^{10}	2.5×10^{13}	2×10^{6}