Lecture 2:

Intrinsic & Extrinsic Semiconductors

- Intrinsic Semiconductor: A pure Semiconductor material with no impurity atoms and no lattice defects in the crystal.

  In other words:

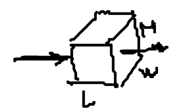
Free electron concentration	=	hole concentration	=	intrinsic electron concentration
n (electron / cm^3)	=	p (hole / cm^3)	=	n_i

- n_i depends <u>only</u> on the type of Semiconductor & temperature
  e.g n_i for S_i at 300 K $\approx$ 1.4×10^{10} cm^{-3}

- Ad T$\uparrow \longrightarrow$ $n_i \uparrow$ (the higher the temperature the higher n_i)

- Intrinsic semiconductors have extremely large Resistivity.

- $R = \rho \frac{L}{A \times section} = \rho \frac{L}{W \times H}$, ρ: Resistivity ($\Omega \cdot cm$)



- $\rho = \frac{1}{\sigma_n + \sigma_p}$

  σ_n : electron conductivity
  σ_p : hole conductivity

$\sigma_n = q \times n \times \mu_n$ μ_n: electron mobility $= \frac{V_e}{\varepsilon}$ → we can find current

$\sigma_p = q \times p \times \mu_p$ μ_p hole mobility

$\uparrow T \longrightarrow \downarrow \mu$ (as temperature goes up , mobility decreases)

$\uparrow$ Impurity concentration $\longrightarrow \downarrow \mu$ (as impurity concentration goes up, mobility decreases)

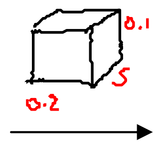
Ex1: for pure Si, assuming electron mobility $\mu_e = 1000\ cm^2/s.V$:

$$\rho = \frac{1}{\sigma_n + \sigma_p} \qquad \sigma_n = 1.6 \times 10^{-19} \times 1.4 \times 10^{10} \times 1000 = 2.44 \times 10^{-6}$$

$$\sigma_p = 1.22 \times 10^{-6}$$

$$\rightarrow \rho = \frac{1}{3 \times 1.22 \times 10^{-6}} = 273\ k\Omega.cm$$

So for a typical transistor-sized piece of Si:



all units in (μm)

$$R = 273 \times 10^3 \times \frac{0.2 \times 10^{-4}}{0.1 \times 10^{-4} \times 5 \times 10^{-4}} = 109 \times 10^7 = 1.09\ G\Omega$$

Impurities

- impurities are added to intrinsic Semiconductors to increase n or p → we get extrinsic Semiconductors
- 2 types of impurities :

  1. Donors: n↑ such as P & As (Group 5)

     - one electron will be donated and becomes free

  2. Acceptors: p↑ such as B & Ar (Group 3) – they accept an electron and create a hole

- mass action law : n p = constant = $n_i^{\,2}$

  - n↑ → p↓ by the same factor

- Donors become +ve charges , Acceptors become –ve charges. However, Semiconductor remain neutral (charge conservation)

  - total +ve charges = total –ve charges
  - $p + N_D = n + N_A$
  - if n > p → n type semiconductor
    if p > n → p type semiconductor

Ex2: for the same piece of S_i in Ex1. If Donors are added at concentration of 10^{16} cm^{-3}.
How much will the Resistance be?

Sol:

$N_D = 10^{16}\ cm^{-3}$

$n \cdot p = n_i^{\ 2} = 10^{20}$

$p + N_D = n + N_A$ ($N_A \to 0$)

$p + 10^{16} = n$

$p = \frac{10^{20}}{n} \rightarrow \frac{10^{20}}{n} + 10^{16} = n$ ✱ solve by iteration (let n = 10^{10} -the min-)

$\frac{10^{20}}{10^{10}} + 10^{16} = n = 10^{10} + 10^{16} \approx 10^{16}$

Substitute the new value in ✱

$\frac{10^{20}}{10^{16}} + 10^{16} = n = 10^{4} + 10^{16} \approx 10^{16}$

$\therefore n = 10^{16}\ cm^{-3}$

Conclusion $n \approx N_D - N_A$ $p = \frac{10^{20}}{10^{16}} = 10^{4}\ cm^{-3}$

Hence, again $\mu_e = 1000\ cm^2/s.V$:

$\rho = \frac{1}{\sigma_n + \sigma_p} = \frac{1}{1.6 \times 10^{-19} \times 10^{16} \times 1000} \approx 0.6\,\Omega.cm$

$R = 0.6\ \frac{0.2}{0.1 \times 0.5 \times 10^{-4}} = 2.4\ k\Omega$