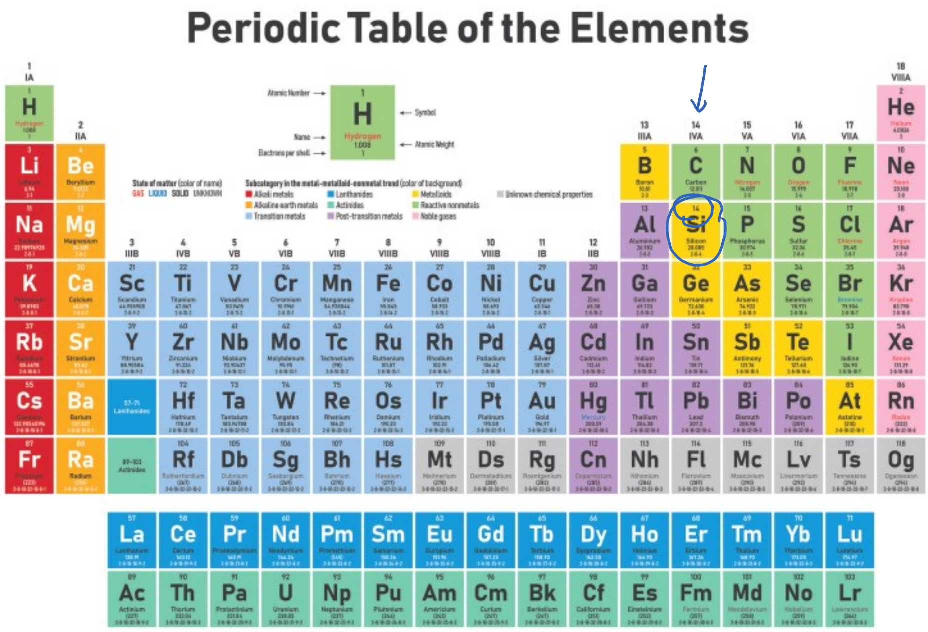
Reading

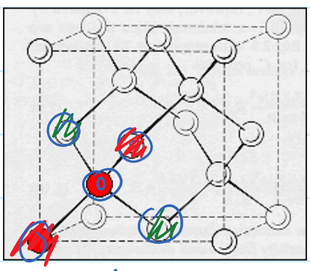
Adel S. Sedra and Kenneth C. Smith, **Microelectronic Circuits** 7th Edition, *Oxford University Press*, 2014.

- Chapter 3.1-3.3

Si Atom

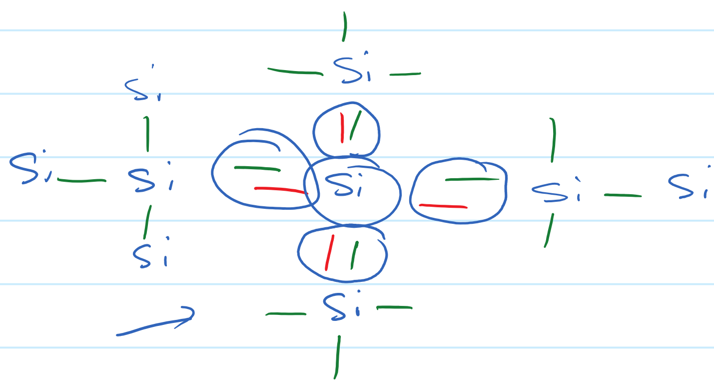


$$14 \rightarrow \underbrace{1s^2}_{2}\ \underbrace{2s^2 2p^6}_{8}\ \underbrace{3s^2\ 3p^2}_{4} \quad 3p^6$$



4

3D

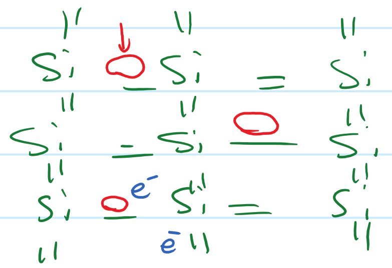


2D

Intrinsic Si

$3p^6$

$3 = 3$



$T \sim 10K \rightarrow T \sim 300K$

insulator   bad conductor

band gap $= 1.12\ eV$

$$\boxed{n_i = B \cdot T^{3/2}\, e^{-E_g/2kT}}$$

$7.3 \times 10^{15}\ cm^{-3} K^{-3/2}$

$6 \times 10^{23} \times 14$

$n = p = n_i$

#e/cm^{-3} #h/cm^{-3}

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

Example

Calculate the value of n_i for silicon at room temperature ($T \simeq 300$ K).

eV

e^-

1.12eV

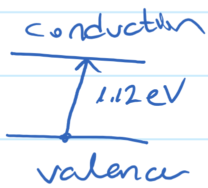
Si = Si

$$n_i = B\,T^{3/2}\,e^{-E_g/2kT}$$

$$= 7.3\times10^{5}\cdot 300^{3/2}\cdot e^{-1.12/(2\times 8.62\times10^{-5}\times 300)}$$

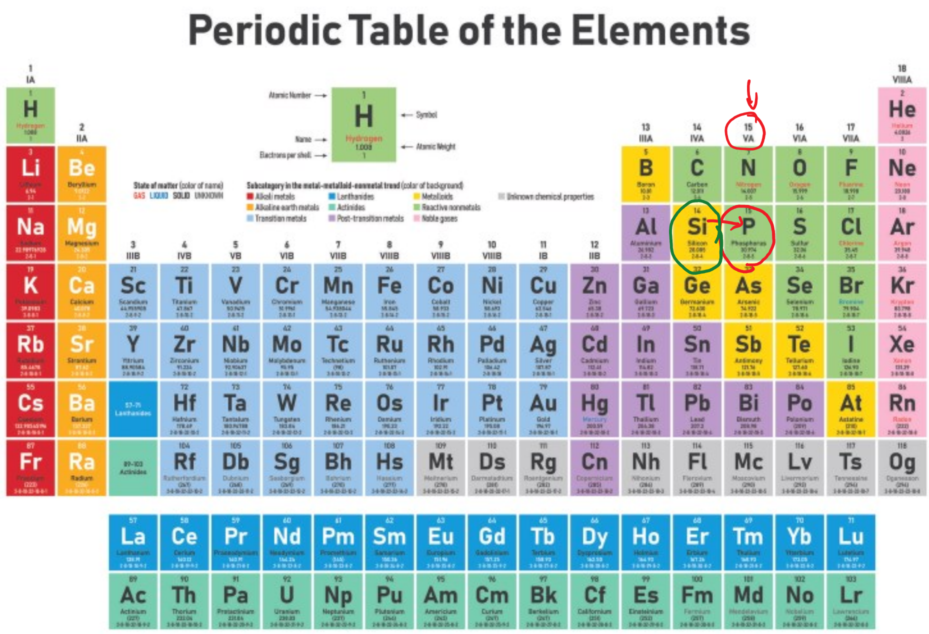
$$\boxed{n_i = 1.5\times10^{10}\ \text{carriers/cm}^3}$$

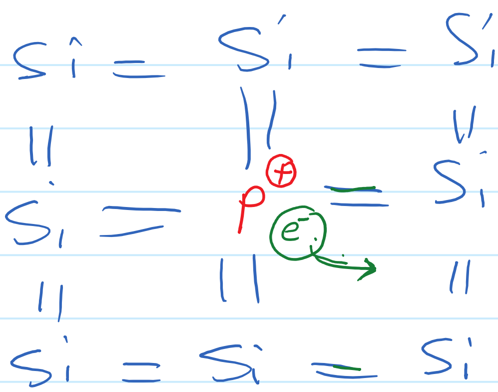
Si



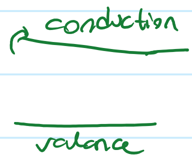
$\rightarrow n = n_i = p$

N-Type Semiconductor





$3s^2 3p^6$



10^{18} p $/cm^3$

10^{15}

$N_D \gg n_i$

$n = N_D + n_i \cong N_D$

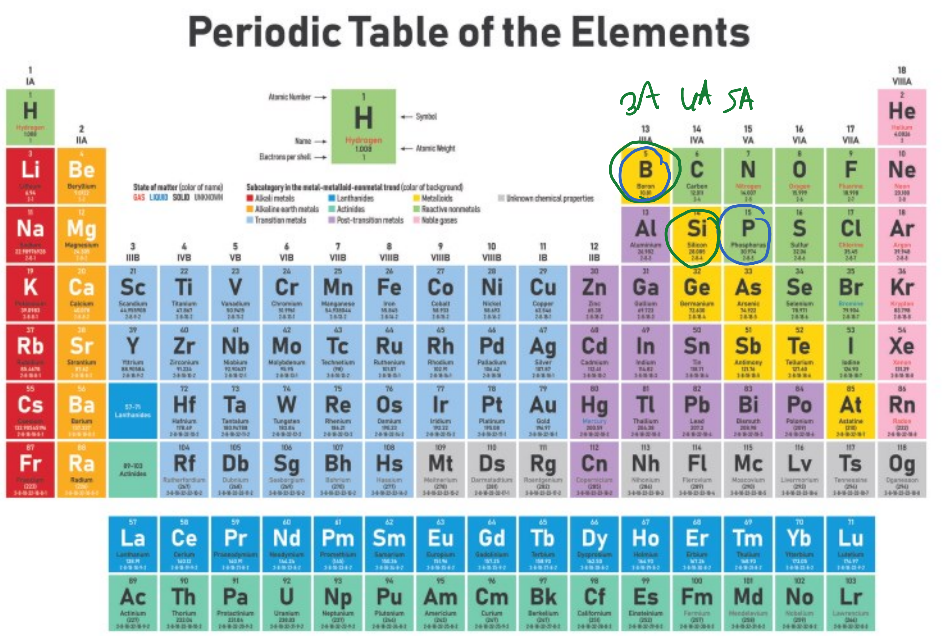
P n-type e^- $n = N_D$ majority

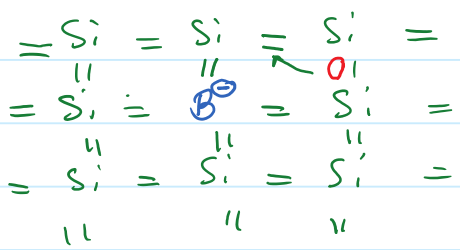
$$np = n_i^2 \Rightarrow p = \frac{n_i^2}{n} \Rightarrow p = \frac{n_i^2}{N_D}$$

#n #h

$$\boxed{n = N_D}$$

P-Type Semiconductor



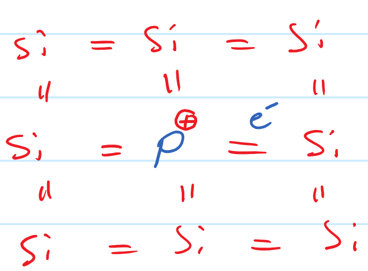


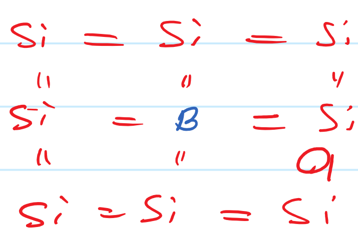
$N_A \quad 10^{18}\ B\ cm^{3}$

$$\boxed{p = N_A}$$

P-type → hole → $p = N_A$

$np = n_i^2 \Rightarrow n = \frac{n_i^2}{p}$ (N_A)





$1P \rightarrow 1$

$N_D \rightarrow \boxed{N_D = n}$

$1B \rightarrow 1h$

$N_A \rightarrow N_A = p$

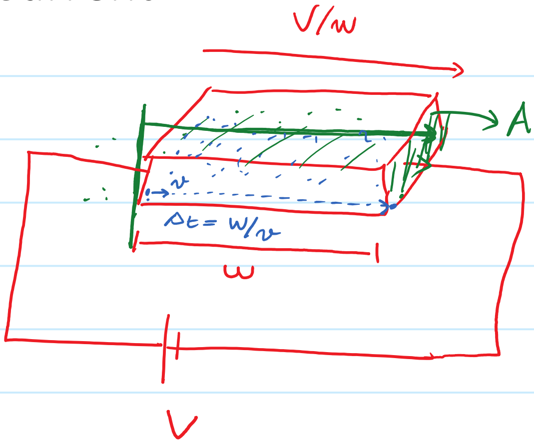
Example

Consider an n-type silicon for which the dopant concentration $N_D = 10^{17}/\text{cm}^3$. Find the electron and hole concentrations at $T = 300$ K.

$\boxed{n = N_D = 10^{17}\ e^-/cm^3}$

$pn = n_i^2 \Rightarrow p = \dfrac{n_i^2}{N_D} = \dfrac{(1.5\times10^{10})^2}{10^{17}} = 2.25\times10^3\ h/cm^3$

Drift Current



$$v_p = E \cdot \mu_p$$

$\cancel{cm^3}$ $\#holes/cm^3$

$$\Delta Q = w \cdot A \cdot p \cdot q$$

$$I = \frac{\Delta Q}{\Delta t} = \frac{w A . p . q}{w/v}$$

$$I = \frac{\cancel{w} A\, p . q}{\cancel{w}} . E \mu_p$$

$$I/A = J = p q . E \mu_p$$

$$J = p q E \mu_p - n q E \mu_n = E \underbrace{(q p \mu_p - q n \mu_n)}_{\sigma}$$

$$\frac{1}{\sigma} = \rho$$

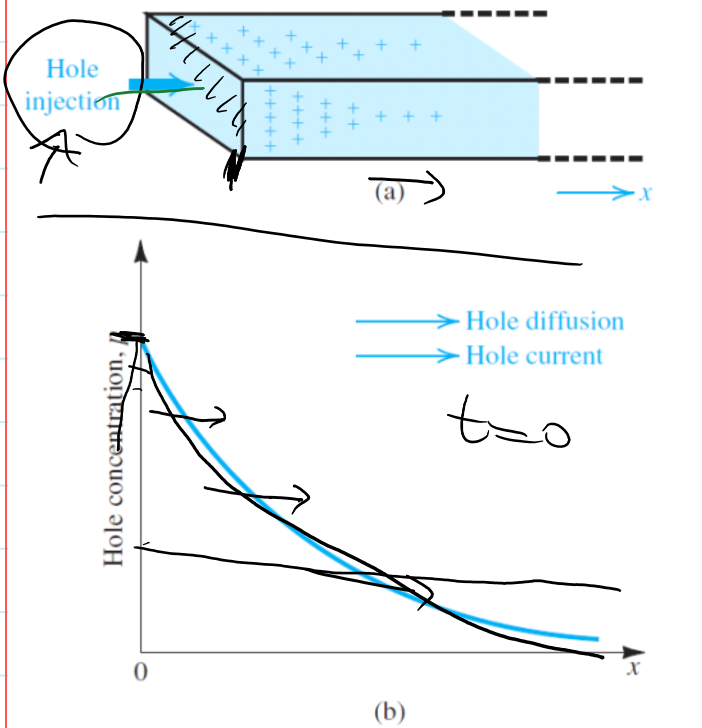
$$R = \frac{\rho . l}{A}$$

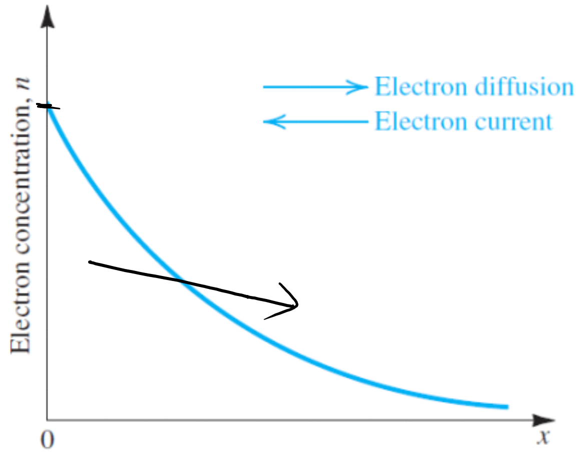
$$J = \sigma E \Rightarrow \frac{I}{A} = \sigma . \frac{V}{w} \Rightarrow V = \left(\frac{1}{\sigma} \frac{w}{A}\right) . I$$

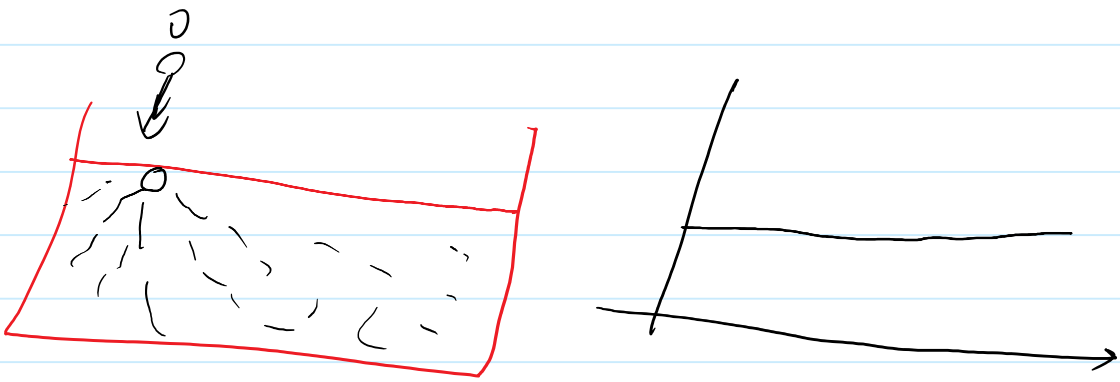
Example

Find the resistivity of (a) intrinsic silicon and (b) p-type silicon with $N_A = 10^{16}/\text{cm}^3$. Use $n_i = 1.5 \times 10^{10}/\text{cm}^3$, and assume that for intrinsic silicon $\mu_n = 1350\ \text{cm}^2/\text{V}\cdot\text{s}$ and $\mu_p = 480\ \text{cm}^2/\text{V}\cdot\text{s}$, and for the doped silicon $\mu_n = 1110\ \text{cm}^2/\text{V}\cdot\text{s}$ and $\mu_p = 400\ \text{cm}^2/\text{V}\cdot\text{s}$. (Note that doping results in reduced carrier mobilities.)

Diffusion Current







Example

Consider a bar of silicon in which a hole concentration profile described by

$$p(x) = p_0 e^{-x/L_p}$$

is established. Find the hole-current density at $x = 0$. Let $p_0 = 10^{16}/\text{cm}^3$, $L_p = 1\ \mu\text{m}$, and $D_p = 12\ \text{cm}^2/\text{s}$. If the cross-sectional area of the bar is $100\ \mu\text{m}^2$, find the current I_p.

$$J_p = -qD_p \frac{dp(x)}{dx}$$

$$J_n = qD_n \frac{dn(x)}{dx}$$

$$J_p = q \frac{D_p}{L_p} p_0 = 192 A/cm^2$$