EE 320

2/5/14

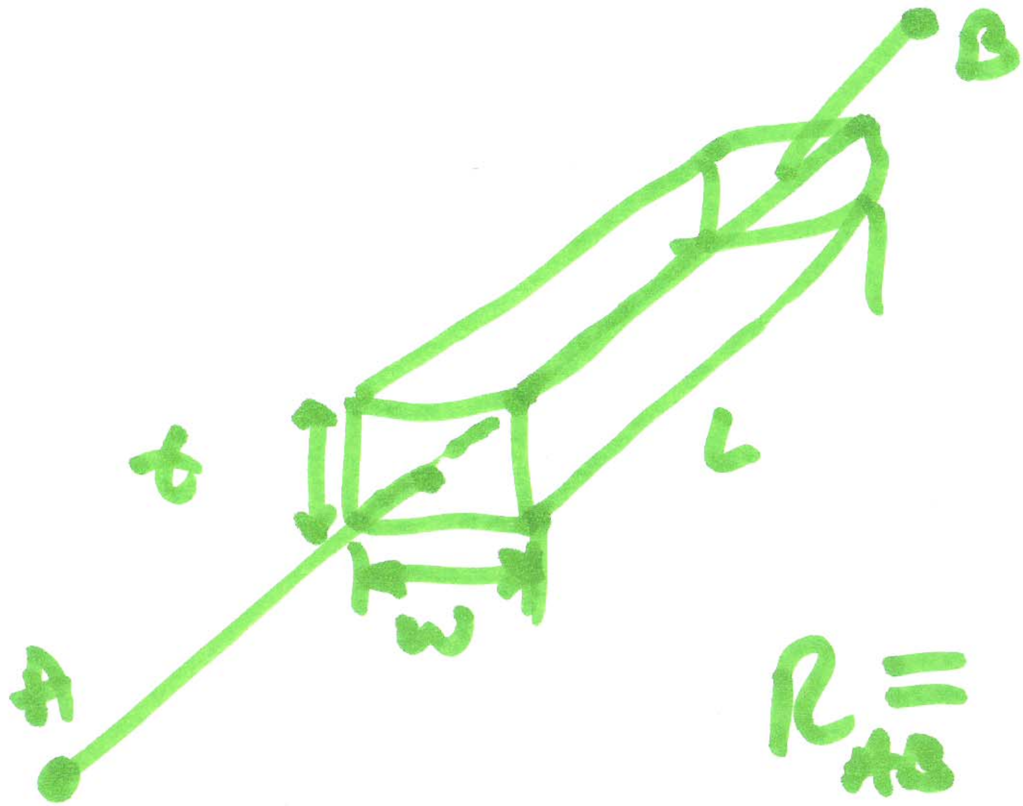
Lecture 5

Ch. 2 Solid-State Electronics

TABLE 2.1

$\Omega \cdot cm$ ↓ resistivity

Insulators	$10^5 < \rho$
Semiconductors	$10^{-3} < \rho < 10^5$
Conductors	$\rho < 10^{-3}\ \Omega \cdot cm$



$\Omega \cdot cm$

$$R_{AB} = \frac{\rho}{t} \cdot \frac{L}{W}$$

Conductors have few valence electrons

Si – 4 valence electrons

Cu – 1e valence

Al – 2e valence

SiO_2 – 8e

Silicon dioxide

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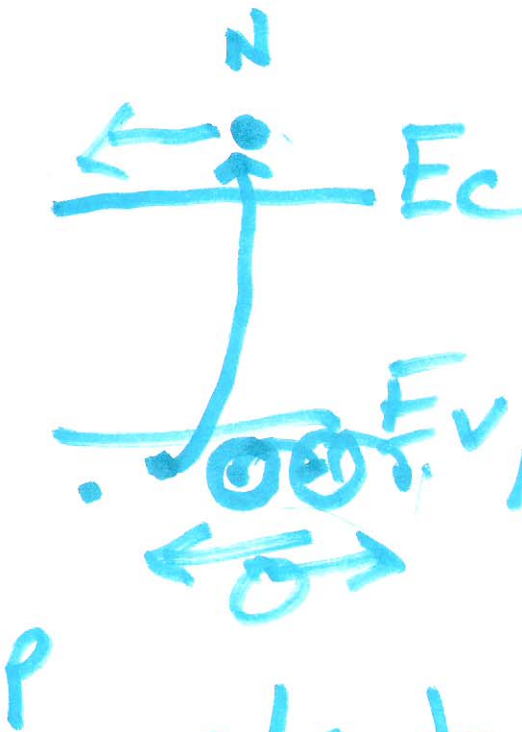
Put Si: Atoms together



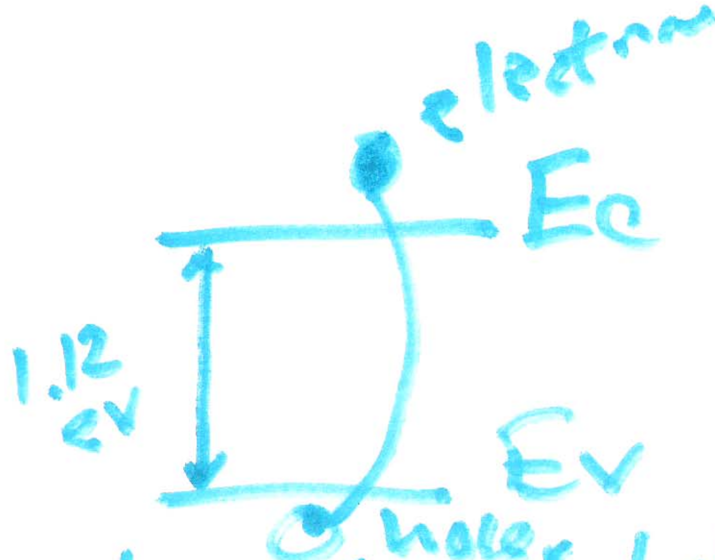
energy levels

conduction band

valence

electrons & holes

Si at room temp



p = density of holes

holes/cm^3

n = electrons/cm^3

n_i = intrinsic # of carriers = 6.73×10^9 carriers/cm^3

# of Si Atoms

10^{22} Si Atoms/cm^3

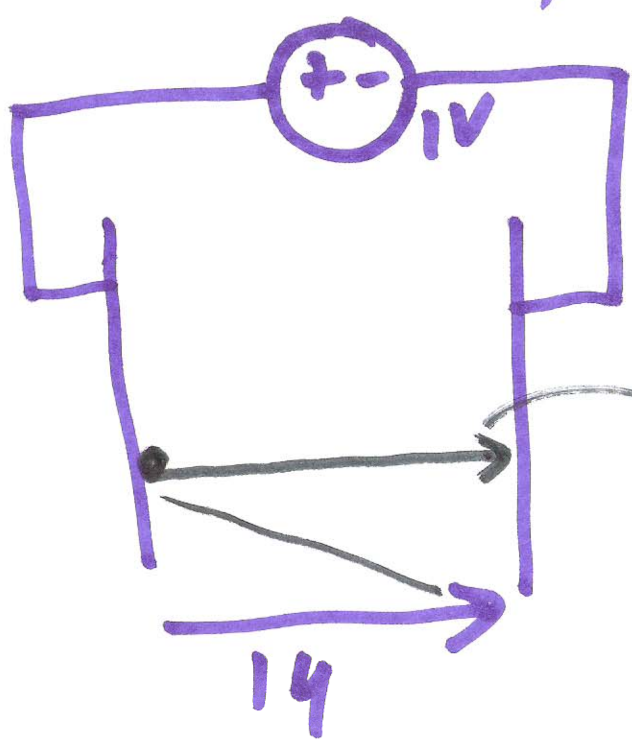
Mobility

free carriers
- electrons
- holes

$$\mu = \frac{\text{Velocity, cm/s}}{\mathcal{E}\text{, Electric field V/cm}}$$

μ ← mobility

$$\mu \ \frac{cm^2}{V \cdot s}$$



$$\mathcal{E} = \frac{1V}{1\mu} = 10^6 \frac{V}{m} = 10^4 V/cm$$

two types of currents

drift → has electric field

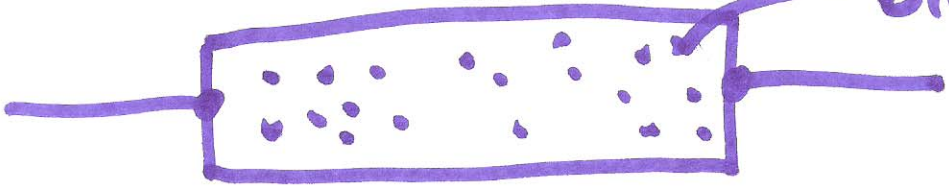
diffusion → no electric field

$$J = Q \cdot v$$

J: current density A/cm^2

Q: charge density $\frac{C}{cm^3}$

v: velocity $\frac{cm}{s}$



$N \cong N_D + N_i$

$10^{16} + 10^{10}$

$$N \approx N_D$$

N_D ← # of donor atoms

$10^{16} \frac{\text{atoms}}{\text{cm}^3}$

Dope Si with 10^{15} Boron atoms

What type of s/c is it?

What is its carrier concentration?

p-type semiconductor

$N_A = 10^{15} \frac{\text{Atoms}}{cm^3}$ = # of acceptor atoms

$p = N_A + n_i \simeq N_A$

$p = 10^{15}$ holes$/cm^3$

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$$p \cdot n = n_i^2 \quad \text{Under equilibrium}$$

MASS action law

n-type $\quad n = N_D + n_i \approx N_D$

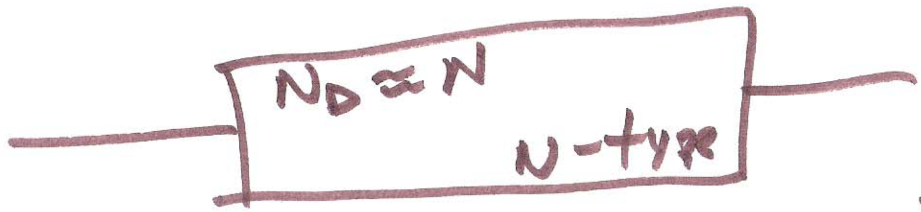
$$p \approx \frac{n_i^2}{N_D}$$

p-type $\quad p = N_A + n_i \approx N_A$

$$n \approx \frac{n_i^2}{N_A}$$

Drift Current

$$J = Q \cdot v$$



$$Q_N = q \cdot N$$

N ← $\frac{\text{\# of electrons}}{cm^3}$

q ← electron charge

$$v = \mu_N \cdot \mathcal{E}$$

μ_N ← electron mobility

$$J_N = q \cdot N \cdot \mu_N \cdot \mathcal{E}$$

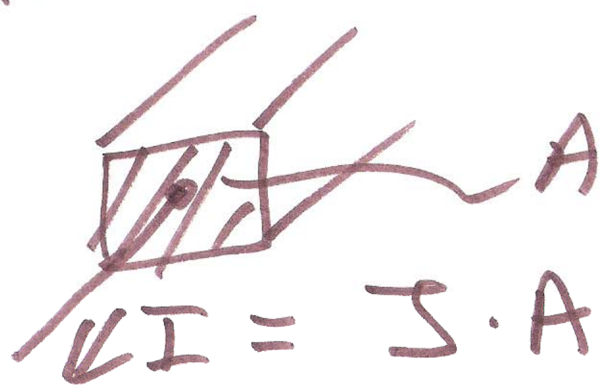
↖ electron movement in conduction band

$$J_P = q \cdot p \cdot \mu_P \cdot \mathcal{E}$$

↖ hole movement in valence band

$$J_{Total} = J_N + J_P = q \cdot \mathcal{E}\left(N \cdot \mu_N + p\,\mu_P\right)$$

↑ $\mathcal{E}$ field



$$I = J \cdot A$$

$$\mathcal{E} = J \cdot \frac{1}{q \cdot (N\mu_n + P \cdot \mu_p)}$$

V/cm ; A/cm^2 ; $\rho = \Omega \cdot cm$

$$\sigma = q(N \cdot \mu_n + P\mu_p)$$

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

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Si - doped with 10^{16} phosphorous $\frac{\text{Atoms}}{cm^3}$

$t = 10\mu m = 10 \cdot 10^{-6} m = 10^{-5} m = 0.001 cm$

$W = 10\mu m = 0.001 cm = 0.00001 m$

$L = 100\mu m = 0.01 cm$, $\mu_N = 600 \frac{cm^2}{V \cdot S}$

Calculate N

$N_i = 10^{10} \frac{\text{carriers}}{cm^3}$

$N = 10^{16} + 10^{10} \simeq 10^{16} \frac{\text{electrons}}{cm^3}$

Calculate P

$P = \frac{N_i^2}{N} = \frac{10^{20}}{10^{16}} = 10^{4} \frac{\text{holes}}{cm^3}$

10,000

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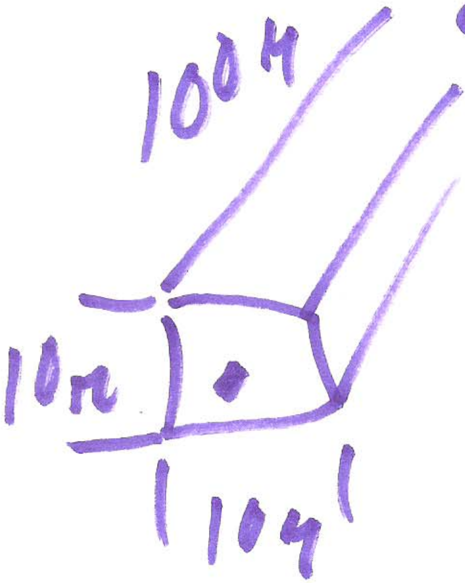
$$\rho = \frac{1}{q(n\mu_n + p\cdot\mu_p)} \approx \frac{1}{q n \mu_n}$$



$$= \frac{1}{1.6\times10^{-19}\,C \cdot \frac{10^{16}}{cm^3} \cdot 600\,\frac{cm^2}{V\cdot s}}$$

$$= 1.04\ \Omega\cdot cm$$

$$R = \frac{\rho}{t}\cdot\frac{L}{W} = \frac{1.04\cdot 0.01\,cm}{0.001\cdot 0.001}$$

$$R = 10.4\ k\Omega$$

Quiz do for Bonus

2.10) $\mathcal{E} = 2{,}500\ V/cm$

$\mu_N = 700\ \frac{cm^2}{V s}$, $\mu_P = 250\ \frac{cm^2}{V \cdot s}$

$N = 10^{17}/cm^3$ $\quad p = 10^{3}/cm^3$

$J_N = q \cdot N \cdot \mathcal{E} \cdot \mu_N$

$J_P = q \cdot p \cdot \mathcal{E} \cdot \mu_P$

2.14)

$$\mu = \frac{v}{\mathcal{E}} \rightarrow v = \frac{\mu}{\mathcal{E}}$$

$$J_N = qN \cdot \mu_N \cdot \mathcal{E}$$

$$J_P = q \cdot p \cdot \mu_p \cdot \mathcal{E}$$