ECE 310 - Lecture 4

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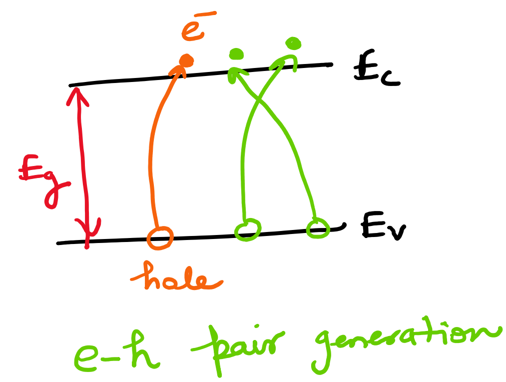
- intrinsic → pristine semiconductor
- extrinsic → with impurities (dopants)

In equilibrium in intrinsic S/C

$n = p = n_i$ ← intrinsic carrier density

p: # of holes cm^{-3}

n: # of free electrons cm^{-3}



In "Equilibrium"

- ↳ no external potential (voltage)
- ↳ no external light on the sample
- ↳ no thermal gradient

$$np = n_i^2$$

Derived from device physics

Important!

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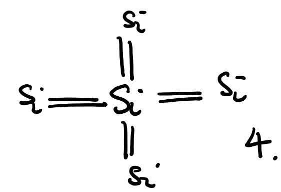
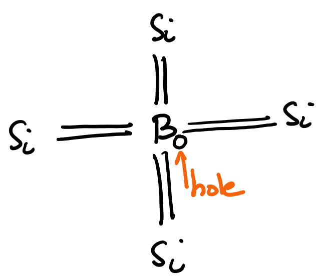
Modification of carrier densities:



III

B → Boron ⇒ 3 $\bar{e}^s$ in outer shell

Acceptor type dopant (or impurity)



$N_A \leftarrow$ doping concentration atoms / cm^3

$N_A \gg n_i$

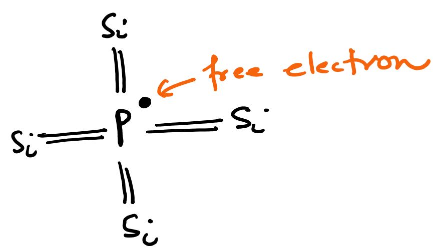
$\Rightarrow p = N_A$

$n = \frac{n_i^2}{p} = \frac{n_i^2}{N_A}$

V

P ← Phosphorus ⇒ 5 electrons in the outer shell

Donor type Dopant

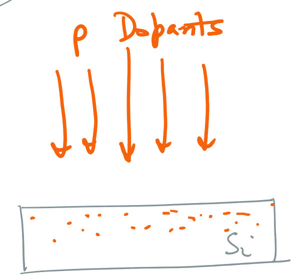


$N_D \leftarrow$ atoms / cm^3

$N_D \gg n_i$

$n \simeq N_D$

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



* ion implantation
* annealing

dopants are activated
↳ they form part of the Si lattice

$np = n_i^2$

Extrinsic Semiconductor in Equilibrium

Acceptor

$p \simeq N_A$

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

$n, p = n_i$ Doping ⟹ $p = N_A$, $n = \frac{n_i^2}{N_A}$

more holes ⟹ p-type semiconductor

p-Si

hole is the majority carrier

electron is the minority carrier

Donor

$n \simeq N_D$

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

$np = n_i^2$

$n, p = n_i$ Doping ⟹ $n = N_D$, $p = \frac{n_i^2}{N_D}$

more electrons ⟹ n-type S/c

n-Si

$\bar{e}$ is the majority carrier

hole is the minority carrier

Q. How can $np = n_i^2$ be maintained if we introduce dopants?

$$n \cdot p = n_i^2$$

$N_D \gg n_i^2$

'p' must fall below n_i

↳ this occurs because many of the new dopants "recombine" with the holes

Ex. $n_i = 1.08 \times 10^{10}$ cm^{-3}

Donor-type dopant, $N_D = 10^{16}$ cm^{-3}

$n \simeq N_D = 10^{16}$ cm^{-3} $\gg n_i$

$$p = \frac{n_i^2}{N_D} = \frac{(1.08 \times 10^{10})^2}{10^{16}} = 1.17 \times 10^4 \; cm^{-3} \ll n_i$$

electrons → 'majority carrier'

holes → 'minority carrier'

$N_D, N_A \simeq 10^{15} - 10^{18}$ cm^{-3}

10^{20} cm^{-3} ⇐ degenerate doping

Transport of Carriers

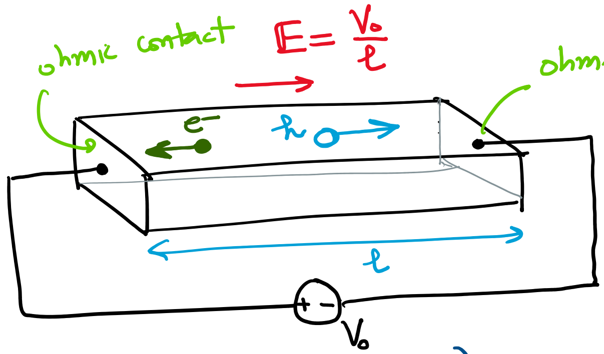
- electron
- hole

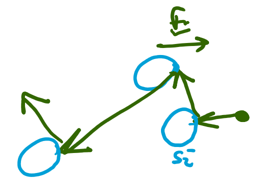
mechanism of movement of carriers in the semiconductor

Two type of transport mechanisms

1. Drift
2. Diffusion

Drift





electrons accelerate due to field 'E' in opposite direction

↳ collide with Si atoms

↳ attain drift velocity (terminal velocity)

Drift velocity

$$v \propto E$$

$$\boxed{v = \mu E}$$

↑ mobility (of carriers) ⇒ $\frac{cm^2}{V \cdot s}$

$\mu = \frac{v}{E}$ in the semiconductor

Ex.

electron ⇒ $\mu_n = 1350 \frac{cm^2}{V \cdot s}$ (ē mobility) ← hole mobility is lower the ē mobility!

hole ⇒ $\mu_p = 480 \frac{cm^2}{V \cdot s}$ (hole mobility)

⇒ from semiconductor physics

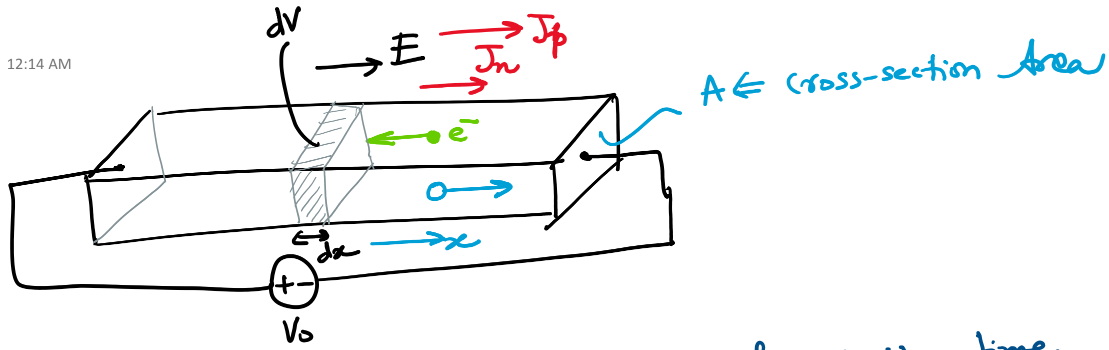
→ holes have "higher effective mass"

↳ are in the valence band

⇒ held tighter by the atom

We can see that for Si

$$\mu_n \simeq 3 \mu_p$$



Electron current ⇒ I_n = charge flow per unit time

$= (n \cdot q) \cdot (dV \text{ in unit time})$

$= qn \cdot A \cdot \left(\frac{dx}{dt}\right)$ ← drift velocity

$dV = A \cdot dx$

$\frac{dV}{dt} = A \cdot \frac{dx}{dt}$

$$\boxed{I_n = qnAv_n}$$

v_n ← electron drift velocity

$q = 1.6 \times 10^{-19}$ C

n

$v_n = \mu_n E$

Current density ⇒ $J_n = \frac{I_n}{A} = qnv_n$

$$\Rightarrow \boxed{J_n = qn\mu_n E}$$

Similarly for holes $J_p = qp\mu_p E$

Total current density ⇒

$$\boxed{J_{tot} = J_n + J_p = q(n\mu_n + p\mu_p)E}$$

J_{tot}: total current density; J_n: e^- current density; J_p: hole current density

'Read chapter 2'