Lecture #9

From Chapter 2 of Jaeger, Chapter 2 of Spencer

Semiconductor Basics

Outline/Learning Objectives:

- Solve simple electrical conduction problems in one-dimensional silicon semiconductors.

Selected problems:

2.7, 2.23, 2.31, 2.45

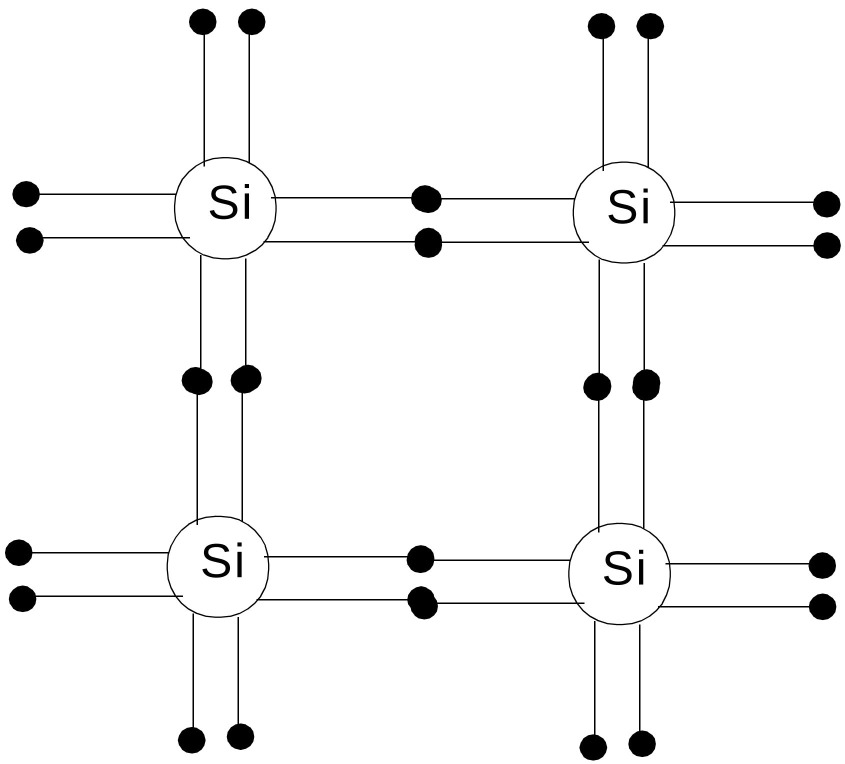
Why Study Semiconductor Device Theory?

Background Information and Physical Models of Diodes

Conduction Mechanisms

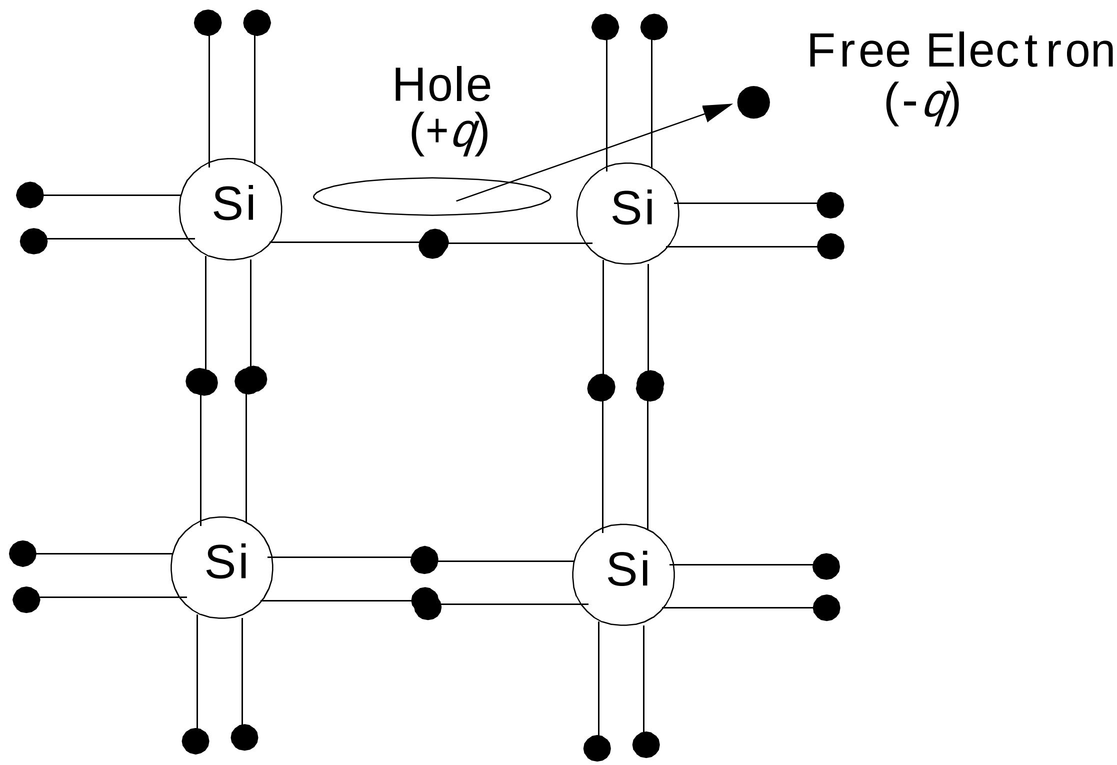
Semiconductors

resistivity of semiconductor is between that of insulators and conductors



valence electrons are shared by atoms to form covalent bonds

Semiconductors



above absolute zero some electrons gain enough energy to break the covalent bond and become free electrons leaving holes behind

Few Points to Remember

The rate of carrier generation through covalent bond breaking is equal to the recombination rate so that the concentration of free carriers remains the same

For a pure semiconductor material $n_i = p = n \Rightarrow n_i^2 = p \times n$

For pure silicon $n_i = p = n = 1.5 \times 10^{10} / cm^3$

If an electric field is applied electrons move opposite to the field direction while holes move in the field direction

Mobility of holes is less than mobility of electrons $\mu = |v/E|$

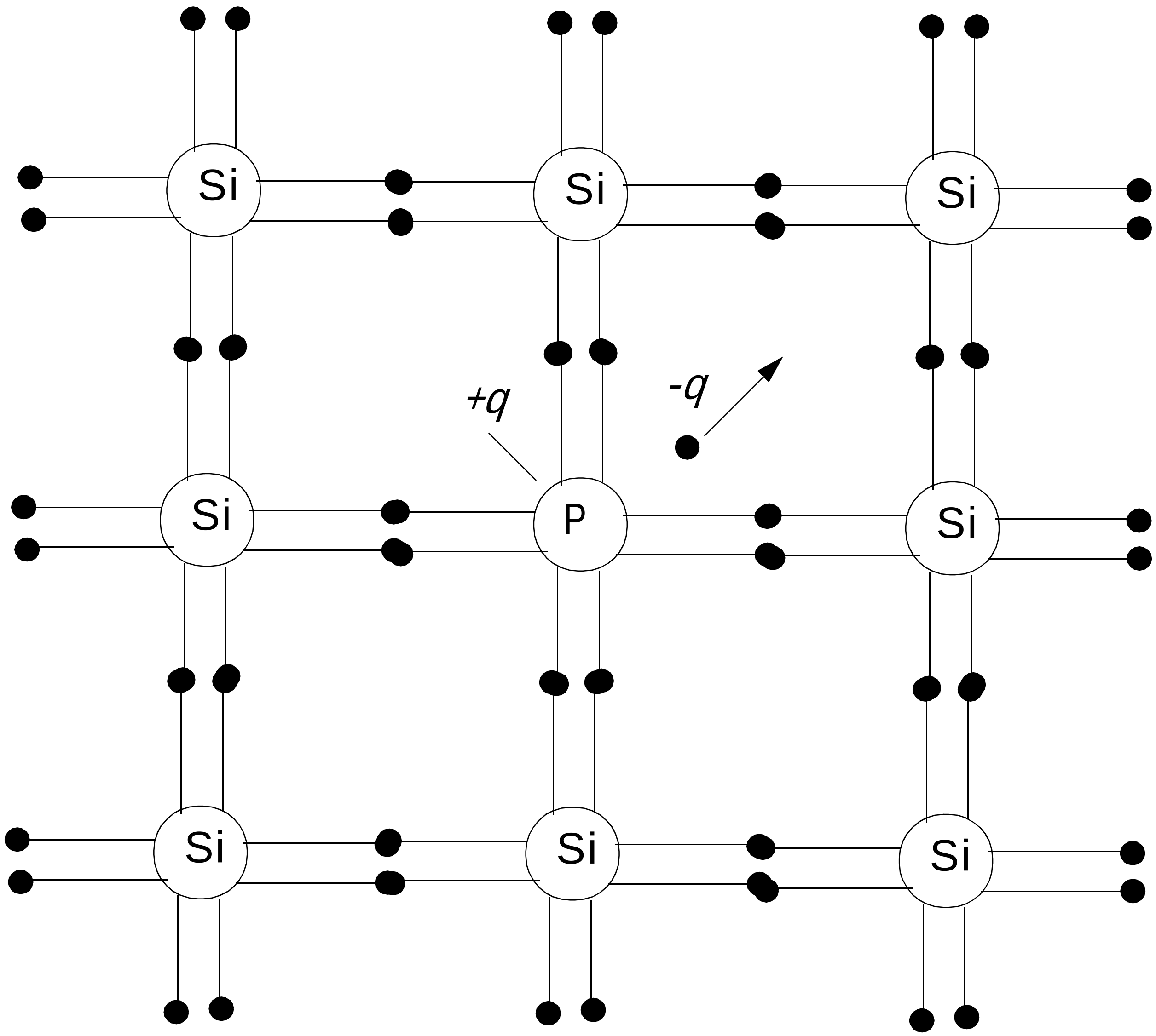
$j_n = Q_n v_n = -qn \times (-\mu_n E) = qn\mu_n E$ drift current due to electrons

$j_p = Q_p v_p = qp \times (\mu_p E) = qp\mu_p E$ drift current due to holes

$j_T = j_n + j_p \Rightarrow j_T = \sigma E, \sigma = (qn\mu_n + qp\mu_p)$

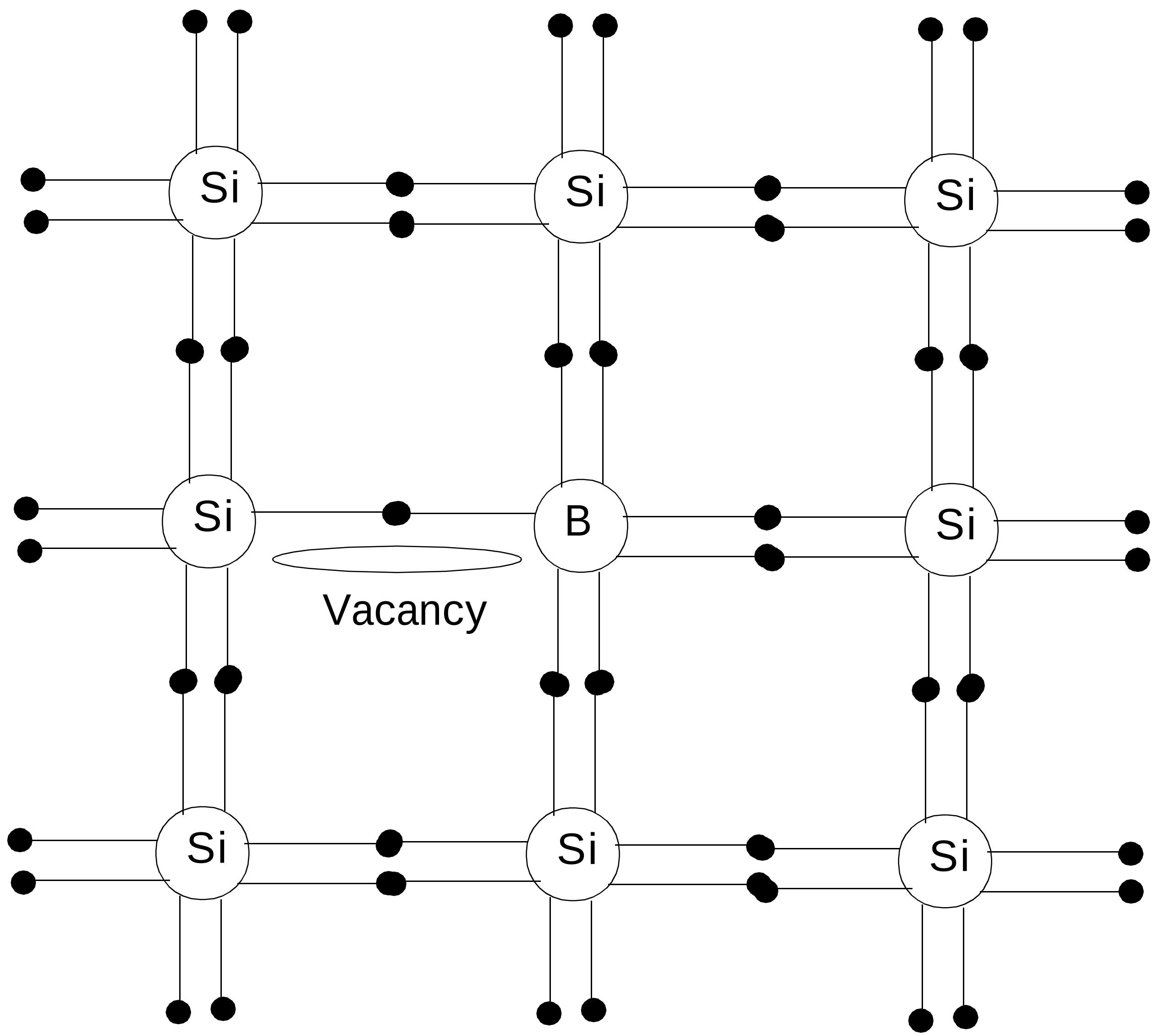
conductivity can be increased by increasing free carrier concentration

n-type material



N_D concentration of donor atoms (atom/cm3)

p-type material



N_A concentration of acceptor atoms (atom/cm3)

Current Mechanisms

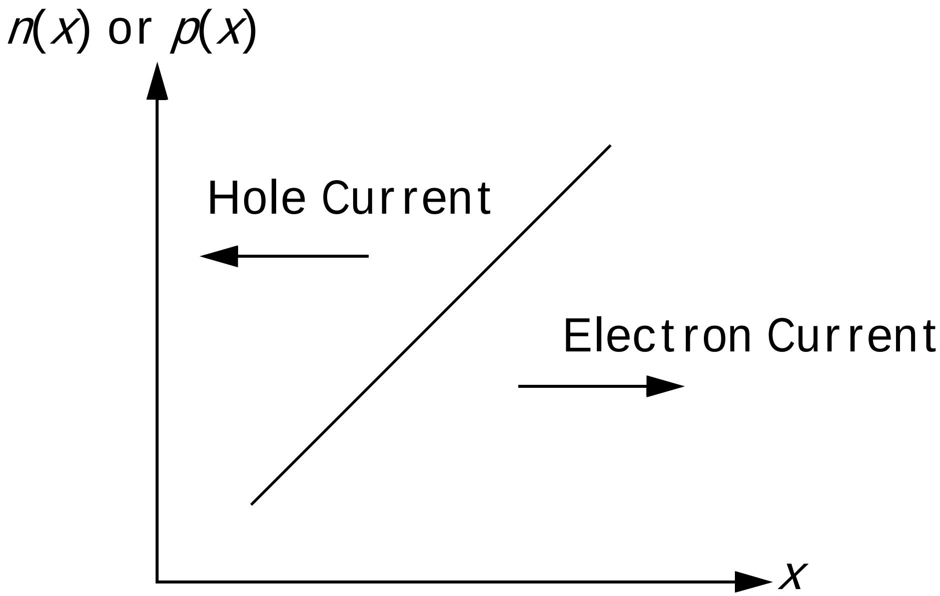
DRIFT - conduction in a semiconductor due to two separate and independent particles carrying opposite charges and drifting in opposite directions under an electric field E.

Drift current density - $J_{drift} = q(n\mu_n + p\mu_p)E = \sigma E$

DIFFUSION - motion of charges due to a concentration gradient. Requires a non-uniform doping so that the concentration of charges is non-uniform. Here, no force is required and the net transfer of charges is due to a statistical redistribution of charges.

Diffusion current density - $J_{diff} = q\left(D_n\frac{dn}{dx} - D_p\frac{dp}{dx}\right)$

If $\frac{dn}{dx} > 0$, then the resulting motion of negative charge particles is in the -x direction, or positive current in the +x direction.



General Remarks

Einstein relation - $\frac{\mu_n}{D_n} = \frac{\mu_p}{D_p} = \frac{q}{kT}$.

For Charge neutrality we have $q\,(N_D + p - N_A - n) = 0$

The relation $n_i^2 = pn$ apply even for doped semiconductors

total current is the sum of both drift and diffusion currents for both the electrons and the holes

Example

if $n_i = 1.5 \times 10^{10} / cm^3$ for a silicon material doped with an acceptor dopant with concentration $N_A = 2.0 \times 10^{14} / cm^3$, determine the concentration of free electrons and holes. Calculate the conductivity of the material due only to free electrons. Calculate the total conductivity of the material. Assume that $\mu_n = 1300 cm^2 / volt - \text{sec}$ and $\mu_p = 480 cm^2 / volt - \text{sec}$

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Solution Since $N_A \gg n_i$ we have $p = N_A = 2.0 \times 10^{14} / cm^3$

The minority carrier concentration is given by

$$n = \frac{n_i^2}{p} = \frac{(1.5 \times 10^{10})^2}{2.0 \times 10^{14}} = 1.125 \times 10^6 / cm^3$$

$$\sigma_n = qn\mu_n = 1.6 \times 10^{-19} \times 1.125 \times 10^6 \times 1300 = 2.34 \times 10^{-10} S / cm$$

$$\sigma_p = qp\mu_p = 1.6 \times 10^{-19} \times 2.0 \times 10^{14} \times 480 = 1.54 \times 10^{-2} S / cm$$

it follows that $\sigma \approx \sigma_p$