ECE321 – Electronics I

Lecture 3: Basic Solid State Physics

Payman Zarkesh-Ha

Office: ECE Bldg. 230B
Office hours: Tuesday 2:00-3:00PM or by appointment
E-mail: _pzarkesh.unm.edu

Review of Last Lecture

- Circuits with Nonlinear Devices (Diode)
- Diode Basic Characteristics
- Diode Approximations
- Diode Application Circuits (Rectifiers)

Today's Lecture

- Electrical Property of Materials
- Energy Band Diagrams
- Semiconductor Materials
- n-Type and p-Type Semiconductor Materials
- Mass Action Law

Electrical Property of Materials

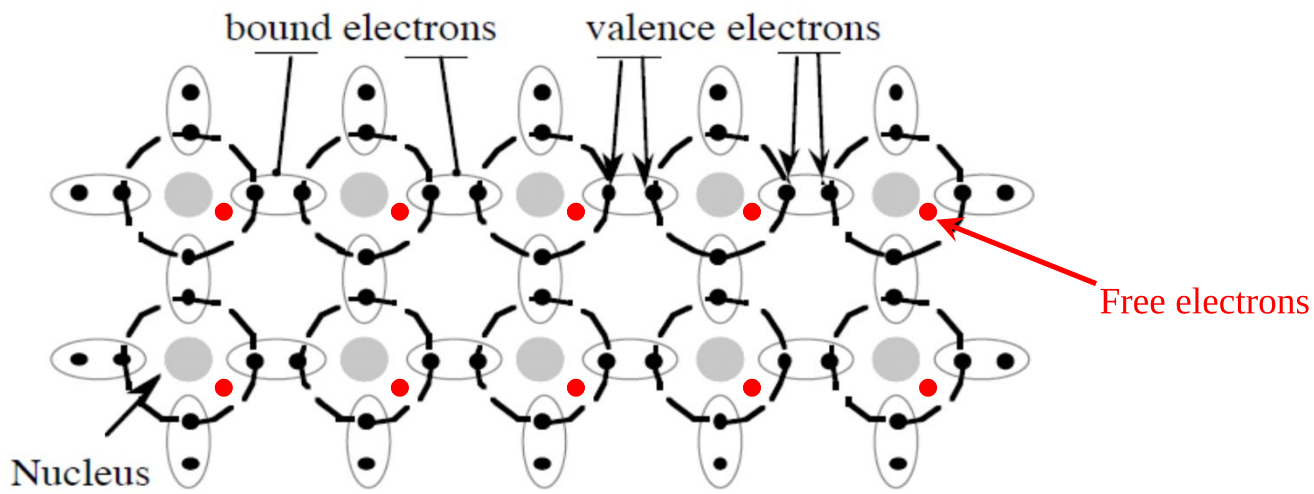
- **Conductor: Low resistance material, like metals, that conducts electricity**

- **Insulator: High resistance material, i.e. almost no current under applied voltage**

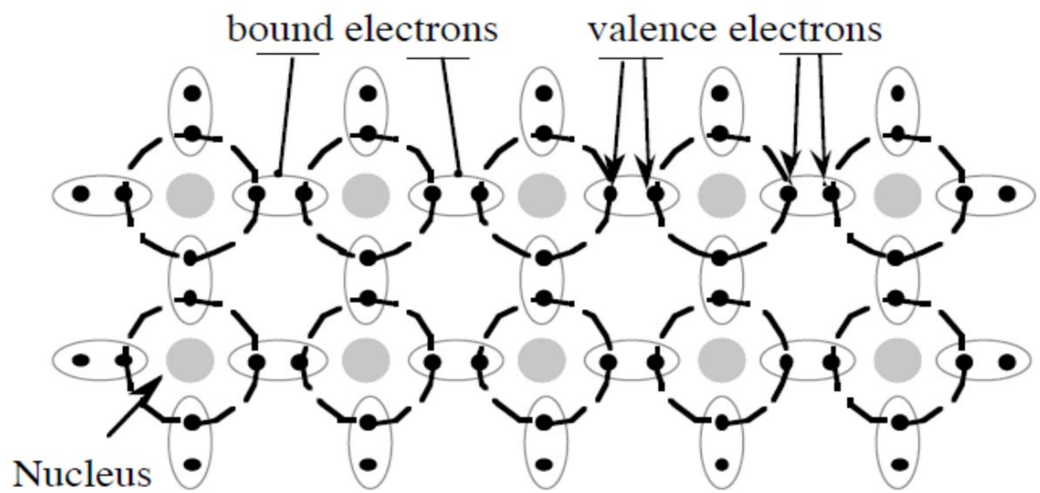
- **Semiconductors: act as conductor or insulator (the basis for diodes and transistors)**

Conductivity from Atomic Perspective

Conductor

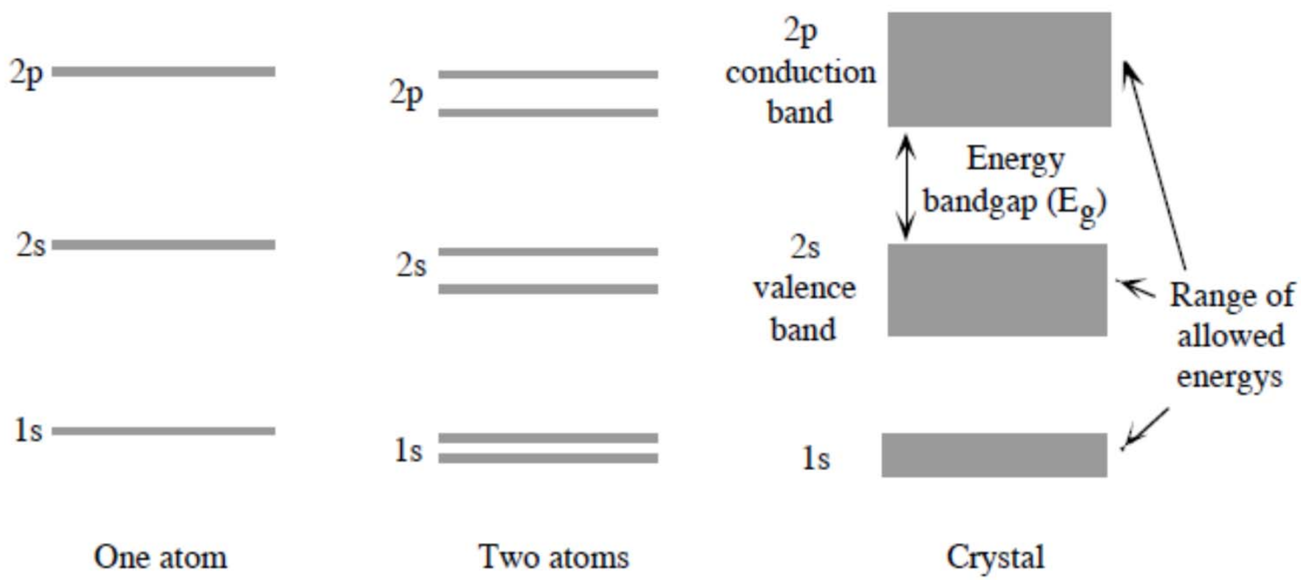


Insulator
_or_
Semiconductor



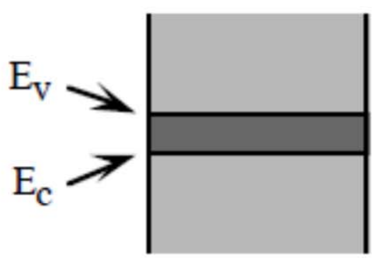
Energy Level and Energy Band Diagram

- The energy band shows the possible energy levels that an electron can obtain.
- The electrical property of the material depends on the energy gap (how tightly an electron is tied to the atom)

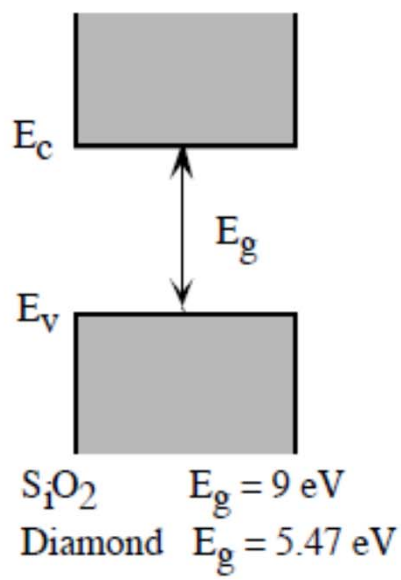


Electrical property using Band Diagram

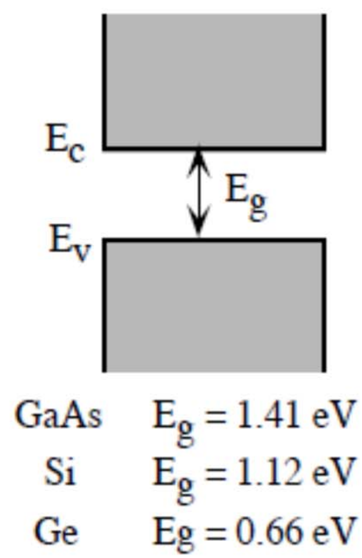
Conductor



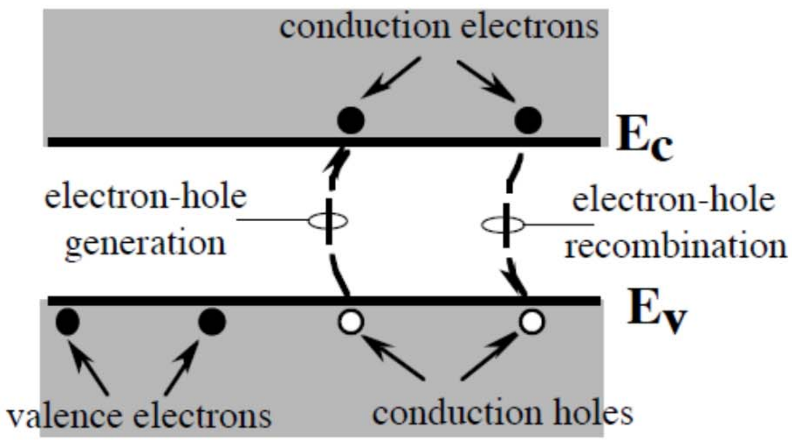
Insulator

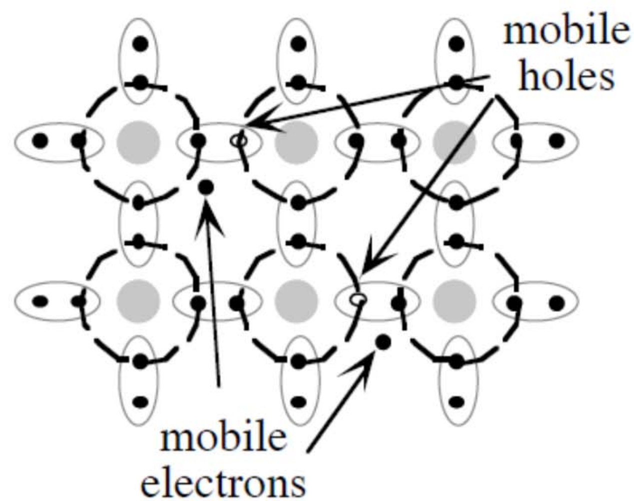


Semiconductor



Electron-Hole Pair Creation in Semiconductors





Density of electrons in intrinsic materials:

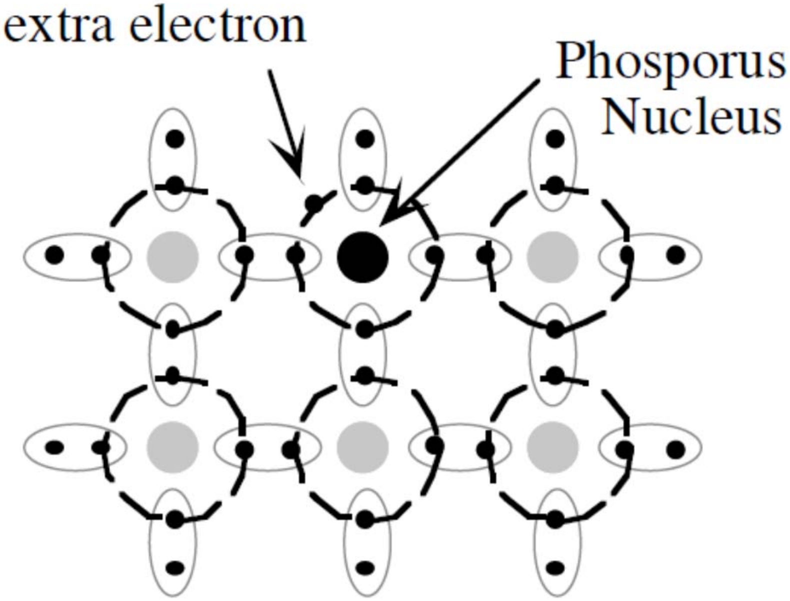
$$n_i = B T^{3/2} e^{\frac{-Eg}{2(kT/q)}}$$

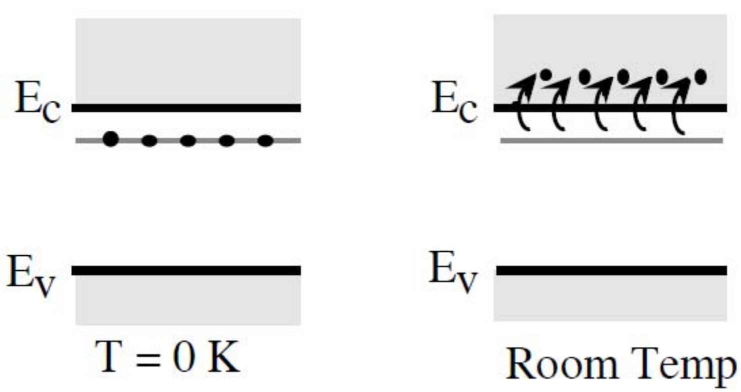
K = 1.381 x 10^{-23} J/K
q = 1.602 x 10^{-19} C
B = Constant (5.23x 10^{15} $K^{-3/2}cm^{-3}$ for Si)
Eg = Band Gap (1.12 ev for Si)

Example: In Silicon n_i at room temperature is 1.062 x 10^{10} electrons/cm^3

Question: What is the density of holes in this case?

Extrinsic Semiconductors: n-Type





How to compute density of electrons and holes in extrinsic material?

Mass Action Law

If n_0 is the electron density and p_0 is the hole density in an extrinsic semiconductor then under thermal equilibrium we have:

$$n_o p_o = n_i^2$$

Let N_D be the density of donor atoms in an n-type semiconductor. At room temperature almost all of the donor atoms are ionized i.e. $n_0 = N_D$

Therefore:

$$n_o p_o = n_i^2 = N_D p_o \quad \Rightarrow \quad p_o = \frac{n_i^2}{N_D}$$

Example: n-Type Semiconductor

If $N_D = 10^{16}$ (donor atoms/cm^3), calculate the minority concentration at $T = 300$ K.

Solution

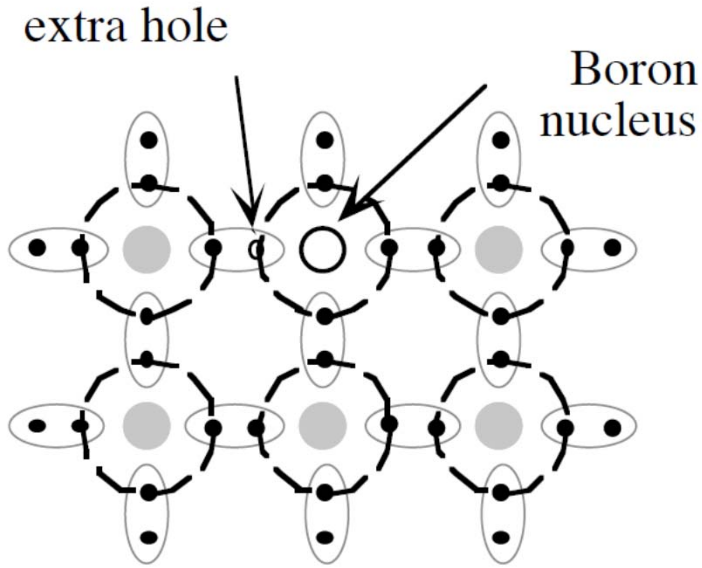
$n_o \approx N_D = 10^{16}$ (electrons/cm^3) and

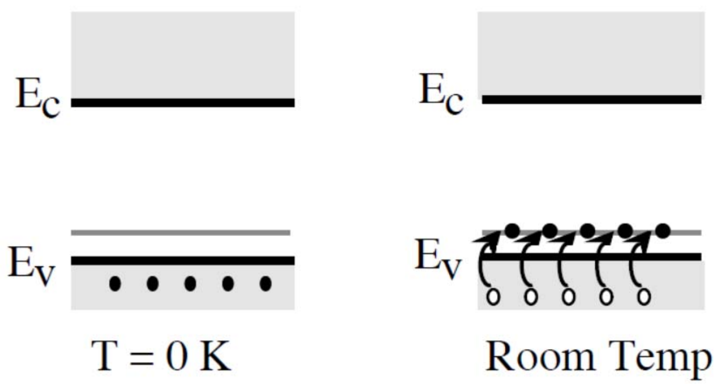
$$p_o = \frac{(1.062 \times 10^{10})^2}{10^{16}} = 1.128 \times 10^4 \left(\frac{\text{holes}}{\text{cm}^3}\right)$$

n-Type semiconductor: Very large density of electrons but very small density of holes

Electrons : Majority Carrier
Holes : Minority Carrier

Extrinsic Semiconductors: p-Type





How to compute density of electrons and holes in extrinsic material?

Hole Density of p-Type Semiconductor

Let N_A be the density of acceptor atoms in an p-type semiconductor. At room temperature almost all of the acceptor atoms are ionized i.e. $p_0=N_A$

Therefore:

$$n_o p_o = n_i^2 = n_0 N_A \Longrightarrow n_0 = \frac{n_i^2}{N_A}$$

Example: p-Type Semiconductor

If $N_A = 5\text{x}10^{17}$ (acceptor atoms/cm^3) calculate the minority carrier concentration at $T = 300$ K.

Answer:

$$n_o = 226\left(\frac{\text{electrons}}{\text{cm}^3}\right)$$

p-Type semiconductor: Very large density of holes but very small density of electrons

Holes : Majority Carrier
Electrons : Minority Carrier