XMUT204 Electronic Design

Tutorial 1: Semiconductor and Diode Properties

Section A: Atomic and Material Properties

1. If the atomic number of a neutral atom is 6, how many electrons does the atom have? How many protons? [2 marks]

2. What is the number of electrons that can exist in the 3rd shell of an atom? [2 marks]

3. For each of the energy band shown on the figure given below, determine the class of materials based on relative comparisons. [3 marks]

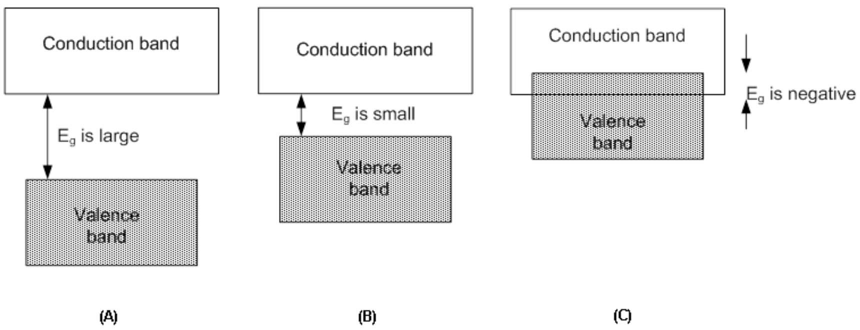


Figure 1: Various materials according to a number energy band configurations

4. A certain atom has four valence electrons. What type of atom is it? [2 marks]

5. In a silicon crystal, how many covalent bonds does a single atom form? [2 marks]

6. Calculate conductivity of carbon nanotubes material if it has 16 x 10^{23} conduction electrons per cm^3 and the mobility of electron is 150 cm^2/Vs. [2 marks]

7. What is the resistance of a tungsten wire that has diameter of 2 mm and length of 5 m? Note that a tungsten has resistivity coefficient, $\rho = 4.76 \times 10^{-8}\,\Omega$m. [4 marks]

Section B: Semiconductors

1. What happen when heat is added to silicon? [2 marks]

2. Name the two energy bands at which current is produced in silicon? [2 marks]

3. Describe the process of doping and explain how it alters the atomic structure of silicon. [2 marks]

4. What is antimony? What is boron? [4 marks]

5. How is the electric field across the pn junction created? [2 marks]

6. Because its barrier potential, can a diode be used as a voltage source? Explain? [2 marks]

7. Determine the number of atom in a lattice of GaAs crystal as shown below. Calculate the number of Ga and As atoms in the lattice for one cm^3 of material (note that length of each side of the lattice is 1.2 nm). [8 marks]

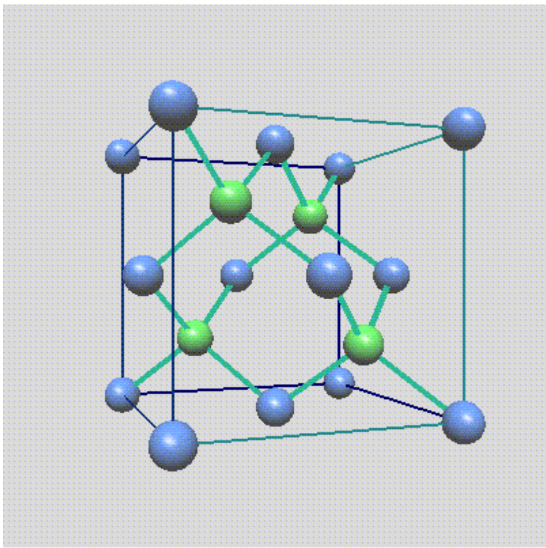


Figure 2: GaAs Crystal Lattice

Section C: Microfabrication

1. Describe the steps required in manufacturing of semiconductor devices. [6 marks]

2. With help from relevant diagrams, describe the materials that make up the semiconductor layer structures of simple diode, BJT and MOSFET transistors. [6 marks]

Section D: Diode Characteristics

1. When the n-type semiconductor is joined with the p-type semiconductor, a PN junction is formed.

   a. Describe how the electric field in the PN junction influence the movement of the charges in the diode. [4 marks]

b. Calculate the built-in potential in the diode junction made of unspecified PN materials (e.g. *p-doped part*: doping level (N_p) = 1.5 x 10^{15} cm^{-3} and *n-doped part*: doping level (N_n) = 7.5 x 10^{16} cm^{-3}). [2 marks]

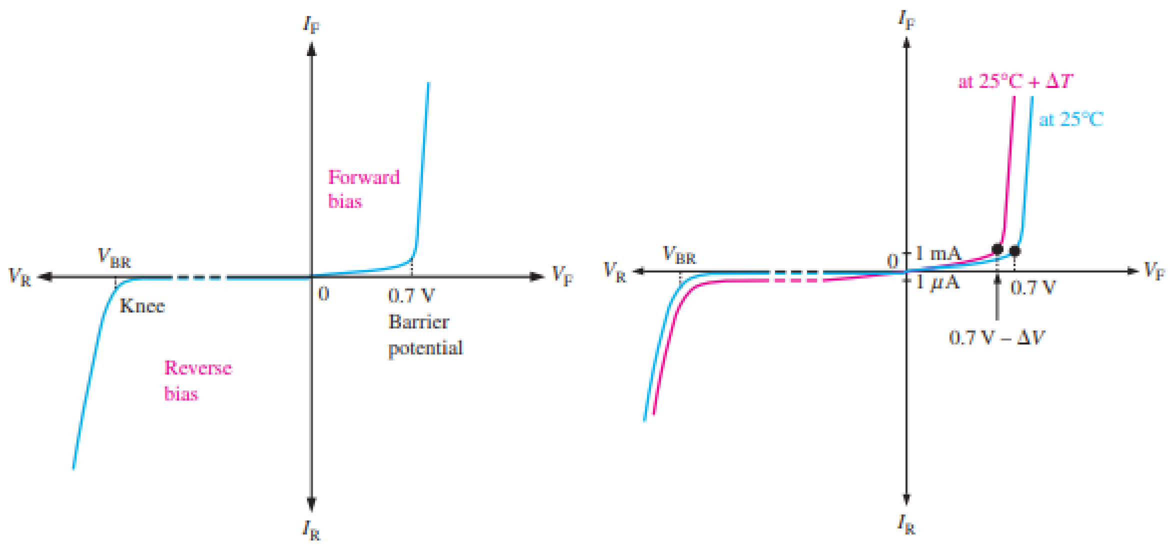
Note: the amount of atoms of the intrinsic semiconductor (n_i) is 1 x 10^{10} cm^{-3} and $V_T = 0.025$ V.

2. Describe with an aid of diagram the characteristics of the semiconductor materials of a diode when it is forward biased and reverse biased. [4 marks]

3. The process of applying the external voltage to a PN junction semiconductor diode is called biasing.

    a. Describe the characteristics of diode by referring to the diode's V-I curve plot. [4 marks]

    b. Briefly explain how temperature influences characteristics of the diode. [4 marks]



4. Forward biasing means putting a voltage across a diode that allows current to flow easily, while reverse biasing means putting a voltage across a diode in the opposite direction

    a. To forward bias a diode, to which region must the positive terminal of a voltage source be connected? [4 marks]

    b. Explain why a series resistor is necessary when a diode is forward-biased. [2 marks]

    c. By referring to its datasheet, determine the forward bias voltage of 1N4148 diode (see Appendix 1). [2 marks]

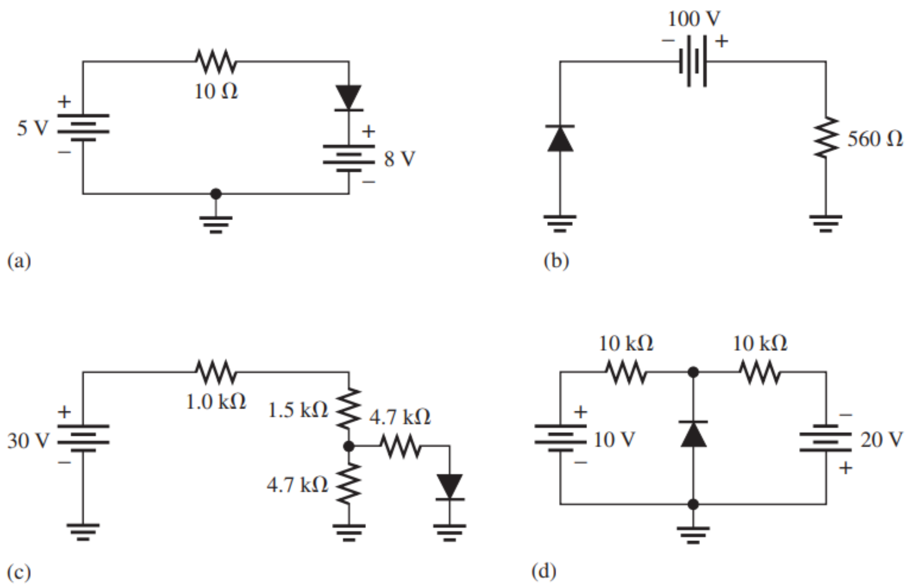
5. Sketch and describe the feasibility of several potential models of diode. [6 marks]

6. For the diode circuits given in the figures below, determine:

a. Whether each silicon diode is forward-biased or reversed-biased. [4 marks]

b. The voltage across each diode, assuming the practical and ideal models. [2 marks]

c. The voltage across each diode, using the complete diode model with $r'_d = 10\ \Omega$ and $r'_R = 100\ \text{M}\Omega$. [4 marks]



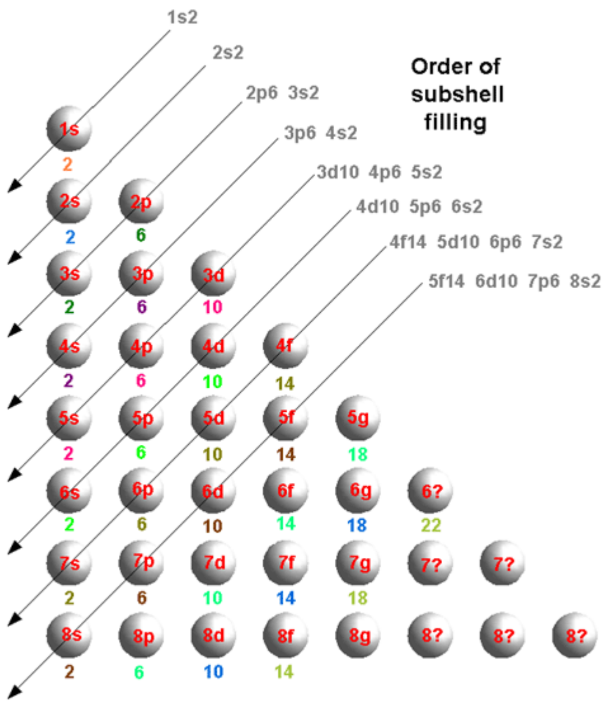
7. The V-I curve of a diode is typically a graph showing the current flow (on the y-axis) at different forward voltages (on the x-axis). This graph provides engineers with a visual record of the operating characteristics of the component.

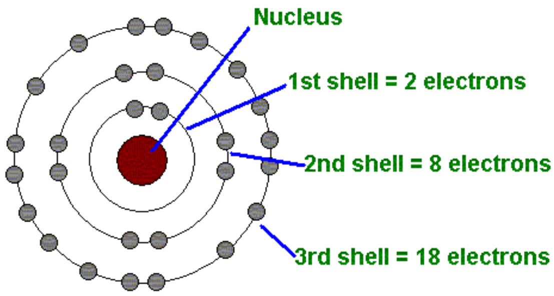
   a. Compare the V-I curves of germanium diode with silicon diode. [2 marks]

   b. Sketch a load line of the diode assuming that an input voltage source of 25 V and 2 kΩ limiting resistor. From the sketch determine approximately the V and I values for condition of operation of the diode circuit. [6 marks]

Appendix – Key Formula

Maximum number of electrons in any shell: $N_e = 2n^2$





Conductivity of Material Formulae:

Conductivity, $\sigma = n\ e\ \mu$ $^{cm-3}$

Where:

n = number of conduction electrons/cm^3 (depending on the material).
e = electron charge, 1.6×10^{-19}.
μ = mobility of electrons (depending on the material).

Resistivity of Material Formulae:

Resistance, $R = \rho L/A = L/\sigma A$

Where:

ρ = resistivity coefficient of the material.
σ = conductivity coefficient of the material.
L = length of the wire.
A = cross sectional of the wire.