**ECSE-2210 Microelectronics Technology**
**Homework 1 – Solution**

1. a) In the simple cubic lattice the nearest-neighbor distance is *a***,** where *a* is the side length of the cube, and the atomic radius *r* is therefore *a*/2. Moreover, there is one atom per unit cell. Thus:
   *Occupied volume* = $(4/3)\,\pi\, r^3 = (4/3)\,\pi\,(a/2)^3 = \pi a^3/6$
   *Total cell volume* = $a^3$
   *Ratio = Occupied volume/Total volume* = $\pi/6$

   b) In the body centered cubic lattice the atom is in the center and any one of the cube corner atoms are nearest neighbors. Thus 1/2 the nearest distance is $r = \sqrt{3}\,a/4$. Also, there are two atoms per unit cell.

   *Diagonal* = $4r = \sqrt{3}\,a$

   *Occupied volume* = $2(\frac{4}{3}\pi r^3) = \frac{8}{3}\pi(\sqrt{3}\,a/4)^3 = \frac{\sqrt{3}}{8}\pi a^3$

   *Total cell volume* = $a^3$

   *Ratio = Occupied volume/Total volume* = $\frac{\sqrt{3}}{8}\pi$

   c) For a face centered cubic lattice, the closest atoms lie in a cube face. Also, there are four atoms per unit cell in the fcc lattice.

   *Face diagonal* = $4r = \sqrt{2}\,a$; $r = \sqrt{2}\,a/4$

   *Occupied volume* = $4(\frac{4}{3}\pi r^3) = \frac{16}{3}\pi(2\,a/4)^3 = \frac{\sqrt{2}}{6}\pi a^3$

   *Total cell volume* = $a^3$

   *Ratio = Occupied volume/Total volume* = $\frac{\sqrt{2}}{6}\pi$

   d) As emphasized in figure 1.4, the atom in the upper front corner of the unit cell and the atom along the cube diagonal of the cube is equal to $\sqrt{3}$ times a cube side length, the center-to-center distance between nearest-neighbor atoms in the diamond lattice is $\sqrt{3}\,a/4$, and the atomic radius $r = \sqrt{3}\,a/8$. Moreover, there are eight atoms per unit cell in the diamond lattice. Thus

   *Occupied volume* = $8(\frac{4}{3}\pi r^3) = \frac{32}{3}\pi(\sqrt{3}\,a/8)^3 = \frac{\sqrt{3}}{16}\pi a^3$

   *Total cell volume* = $a^3$

   *Ratio = Occupied volume/Total volume* = $\frac{\sqrt{3}}{16}\pi$

2. There are 4 Ga and 4 As atoms per unit cell of GaAs

   Number of Ga atoms = $\dfrac{4}{(5.65\times10^{-8}\text{ cm})^3}$ = $2.2\times10^{22}$ atoms/cm$^{-3}$

   Number of As atoms = same as above

   Each Ga atom weighs $\dfrac{69.7}{6.02\times10^{23}}$ g

   Each As atom weighs $\dfrac{74.9}{6.02\times10^{23}}$ g

   Therefore, the density of GaAs is 5.3 g/cm$^3$

3. For the hydrogen atom in vacuum:

   $E_n = -m_0 q^4 / (8\varepsilon_0^2 n h^2) = 13.5$ eV (if $n = 1$)

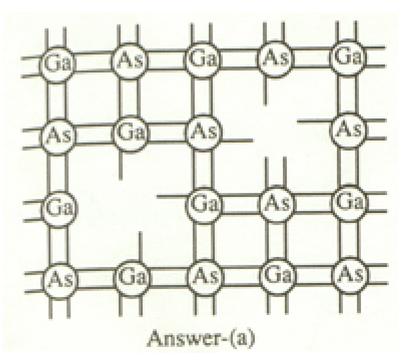
   In Si, $m_0 \rightarrow 1.1\ m_0$

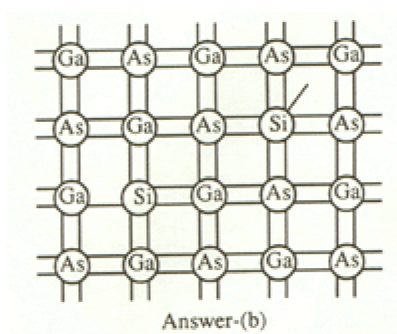
   $\varepsilon_{Si} \rightarrow 11.8\varepsilon_0$

   Therefore, the energy required to free up an electron equals $\dfrac{13.5\times1.1}{11.8^2}$ eV = 0.1 eV

4. a) The removal of the column III Ga atom with three valence electrons leaves five dangling bonds in the vicinity of the vacancy. The removal of the column V As atom with five valence electrons leaves three dangling bonds in the vicinity of the vacancy.

   b) When a Si atom with four valence electrons is inserted into the missing Ga site, there is one extra electron that does not fit snugly into the bonding pattern. Conversely, when Si atom is inserted into the missing As., there is one too few bonds to complete the bonding scheme. There is a hole in the bonding scheme.

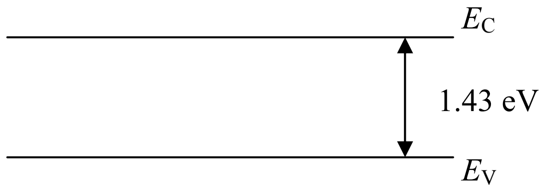


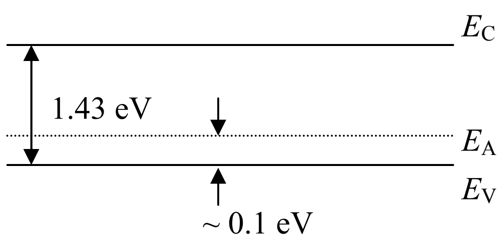

   c) n-type … The extra electron noted in part (b) is readily released yielding an increase in the electron concentration.

   d) p-type … The missing bond noted in part (b) is readily filled at room temperature yielding an increase in the hole concentration.

e) The energy required to break one of the bonds is indicated as energy required to lift one electron from the valence band to the conduction band.




f) Si As site → p-type




Si on site → n-type