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 = $\dfrac{4}{(5.65\times10^{-8}\text{ cm})^3}$ = 2.2×10^{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:

   $E_n = -m_0\, q^4 / (8\varepsilon_o^2 nh^2) = 13.5$ 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