POSTAL Study Package 2019

Electrical Engineering

Conventional Practice Sets

Electrical Materials

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1 CHAPTER
Crystal Structure

Q.1 Discuss about primary bonding and secondary bonding.

Solution:

Primary bonds are of three types:

(i) Ionic (ii) Covalent (iii) Metallic

(i) Ionic: It is developed between two atoms where one atom has low ionisation energy and the other has high electron affinity. The atoms exchange electrons to become oppositely charged ions and consequently develop a strong electrostatic force.

Therefore, ionic bond is an electrostatic force of attraction between two oppositely charged ions formed by the process of electron transfer between the related atoms.

Example:

$Li - 1s^2\ 2s^1$ 1 excess electron

$Na - 1s^2\ 2s^2\ 2P^6\ 3s^1$ 1 excess electron

(ii) Covalent bonds: When two similar atoms share equal electrons, the bond between them is known as a covalent bonds. As these electrons circulate between the atoms, they spend more time between the atoms than elsewhere which produces an electric force.

These bonds are strong and directional in nature.

These are of three types:

(a) Sigma bond (b) Pi-bond (c) Hybrid bond

(iii) Metallic bonds: In a metal, free electrons are present in a very large number and they behave like electron gas. The interaction between electron gas and the positive metal ions leads to a strong cohesive force and give rise to metallic bond. The presence of such free electrons in a metal account nicely. For the high electrical and thermal conductivities, heat capacity surface lustre and other unique properties. Also these electrons never move inside a metal or in any solid with total freedom. All of them are influenced, to some extent by the other particles present inside and when their presence is taken into consideration.

Secondary Bonds:

As compared to primary bonds, secondary bonds are weak. The driving force arises due to the attraction of electric dipoles contained in atoms or molecules.

(i) Van der-Waals Bonds:

Atoms, molecules or ions of all substances exert attractive force on each other when they are brought closer bond so developed is known as van der-waals bond. The forces that act are proportional to r^{-7} where r is seperation between the atoms or molecules.

(ii) Hydrogen bond:

Certain compounds, notably water, have much higher boiling and melting points than would be expected.

Example : Non-metallic hydrides H_2Te, H_2Se and H_2S.

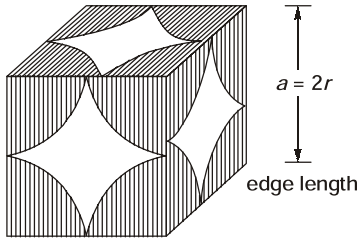
Have the respective boiling points of –2°, –42° and –60° while H_2O with a still smaller molecular weight has a boiling point of 100°C.

Q.2 What are the main types of cubic crystral structure? Define atomic packing factor of all the cubic crystal structure materials.

Solution:

There are three types of cubic crystal structures:

- **Simple Cubic Crystal structure (SCC):**
  In this structure, there is one Lattice point at each of the eight corners of the unit cell. It has a coordination number of six.

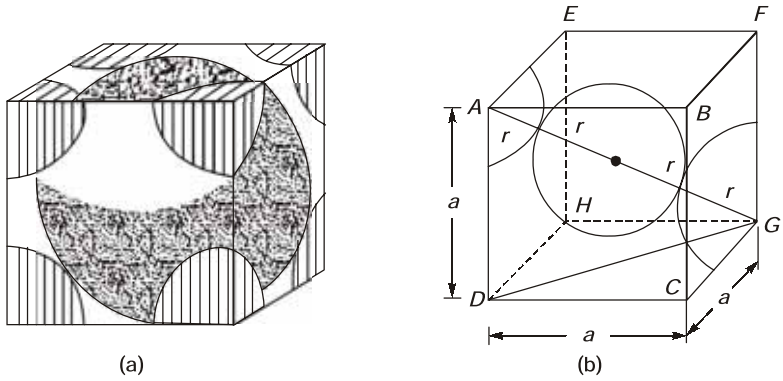


  Atomic Packing Factor (APF) of the crystal structure is defined as the ratio of total volume of the atoms per unit cell to the volume of the unit cell. It is also known as packing efficiency (η)

  Here, $$\text{APF} = \frac{1\times(\pi/6)a^3}{a^3} = \frac{\pi}{6} = 0.524$$

  $\therefore$ % APF = 52.4% filled

- **Body Centrad Cubic structure (BCC):**
  In this structure, in a unit cell there are eight corners and another atom is at the body centred. It has a co-ordination number of eight.



(a) (b)

Body centered cubic structure

  From the figure, $$r = \frac{a\sqrt{3}}{4}$$

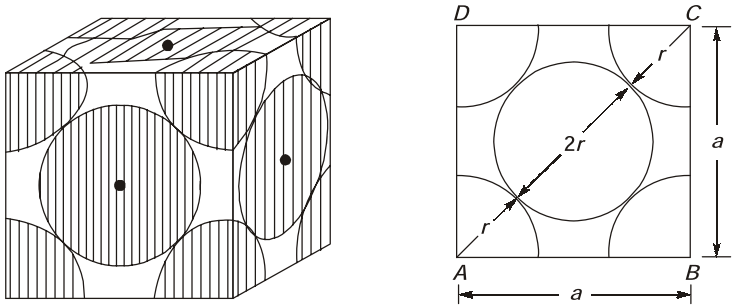
  Number of atom per unit cell and for BCC, $N = 2$

  Now, $$(\text{APF})_{\text{BCC}} = \frac{\text{N}\times\text{Volume of each sphere}}{\text{Total volume of each cell}}$$

$$= \frac{2\times\frac{4}{3}\pi\left(\frac{a\sqrt{3}}{4}\right)^3}{a^3} = \frac{\frac{2\times\pi\sqrt{3}}{16}a^3}{a^3} = \frac{\pi\sqrt{3}}{8} = 0.68$$

  $\therefore$ % APF = 68% filled

- **Face Centred Cubic structure (FCC):**
  In this structure, one atom lies at each corner of the cube in addition to one atom at the centre of each face. The co-ordination number of FCC structure is (4 + 4 + 4 = 12).



(a) (b)

(Face centered cubic structure)

From the figure,

$$\text{Radius of FCC} = r = \frac{a\sqrt{2}}{4}$$

Number of atom per unit cell and for FCC, $N = 4$

Now,

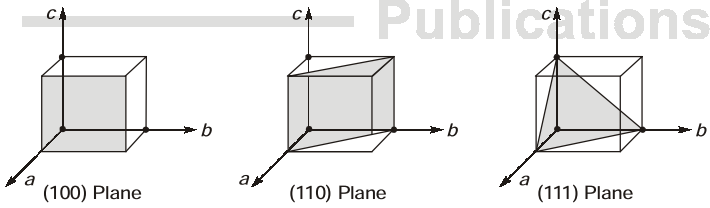
$$(\text{APF})_{\text{FCC}} = \frac{N \times \text{Volume of each sphere}}{\text{Total volume of each cell}}$$

$$= \frac{4 \times \frac{4}{3}\pi \times \left(\frac{a\sqrt{2}}{4}\right)^3}{a^3} = \frac{\frac{4}{3} \times \frac{\sqrt{2}\pi a^3}{2^4}}{a^3} = \frac{\sqrt{2}\pi}{6} = \frac{\pi}{3\sqrt{2}} = 0.74$$

$\therefore$ % APF = 74 % filled

Q.3 Draw sketches illustrating a (100) plane, a (110) plane, and a (111) plane in a cubic unit cell. How many equivalent (100) planes are there in a cubic crystal? A material has a face-centred cubic structure with an ionic radius of 1.06 Å. Calculate the inter planar separation for (111) planes.

Solution:



There are six equivalent (100) planes in a cubic crystal.

$\Rightarrow$ In a face-centred cubic structure.

$$\boxed{a\sqrt{2} = 4r}$$

where, a = side of cube

r = ionic radius

Given: $r = 1.06$ Å,

$$a = \frac{4r}{\sqrt{2}} = \frac{4 \times 1.06}{\sqrt{2}} = 2.998 \text{ Å}$$

Inter planar separation for (111) planes is

$$d = \frac{a}{\sqrt{3}} = \frac{2.998}{\sqrt{3}} = 1.731 \text{ Å}$$

Q.4 Discuss the difference in covalent bonding in carbon as:
(i) diamond (ii) graphite

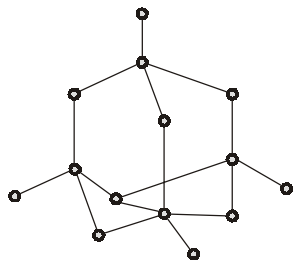
Solution:

(i) Covalent bonding of Carbon in diamond:

In diamond, every carbon atom bonds with four other adjoining atoms in a continuous network. No electrons are left unbonded. This results in very strong bonds between carbon atoms and is responsible for the great hardness of diamonds and their clear colourless appearance. Their great density bends light more than other crystals do making their appearance so spectacular.

Valance electrons of carbon atoms in diamonds are bonded to 4 electrons in ***Tetrahedral arrangement***. The covalent bond is very strong, this makes diamonds have high melting points, the covalent bond in three dimensional structure causes diamond to become the hardest material.

The bonding of electrons, diamonds have deme shaped structures. Deme is one of the strongest structures. Diamond forces more carbon atoms into a smaller densor package. Since there are no free electrons to wander through the structure, diamonds are excellent insulators. The brilliance and fire of cut diamonds is due to a very high index of refraction (2.42) and the strong dispersion of light, properties which are related to the structure of diamonds.



Dimaond

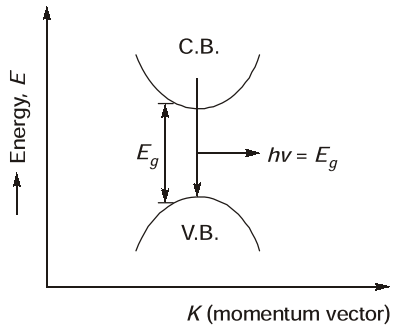
(ii) Covalent bonding of Carbon in Graphite:

In graphite, each carbon atom shares electrons with only three neighbouring carbon atoms, leaving the fourth electron relatively free to roam around from one carbon atom to another, in much the same way as metals do. The carbon atoms form a network consisting of layers of interconnected carbons able to slide against each other making in a pencil. Unlike diamond, graphite is soft, pitch black in colour, and conducts electricity due to the free roaming valence electrons.

Valence electrons of graphite are only bonded to 3 valence electrons, so the covalent bond in hexagonal ring. Graphite is softer than diamond because they are held by weak intermolecular force. Graphite sheet like array of carbon atoms joined with minimal pressure.

Q.5 What is a direct band gap and an indirect band gap semiconductor? **[5 marks : 2013]**

Solution:

Direct Band Gap Semiconductor:

In this, an electron in the conduction band can fall to an empty state in the valence band, giving off the energy difference E_g as a photon of light.