COVENANT UNIVERSITY
NIGERIA

TUTORIAL KIT
OMEGA SEMESTER

PROGRAMME: PHYSICS

COURSE: PHY 222

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PHY 222: Semiconductor Technology

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1. What do you understand by Miller indices of a crystal plane? Show that in a cubic crystal the spacing between two consecutive parallel planes of Miller indices (hkℓ) is given by

$$d_{hk\ell} = \frac{a}{\sqrt{h^2 + k^2 + \ell^2}}.$$

Ans:

The labelling of lattice planes by their corresponding reciprocal lattice vectors is called 'Miller indices'.

Here a = b = c

$$d_{hk\ell} = a\left(h^2 + k^2 + l^2\right)^{-1/2} = \frac{a}{\left(h^2 + k^2 + \ell^2\right)^{1/2}}$$

2. What are miller indices? What are their significances? Draw a (100), (110), and a (111) plane inside a cubic unit cell.

3. Obtain the Miller indices of a plane which intercepts at a, b/2, 3c in a simple Cubic unit cell. Draw a neat diagram showing the plane.(Where a, b, c are lattice parameters)

Ans:

(i) The intercepts made by the plane along three crystallographic axes(x, y and z axes).

X	Y	Z
a	b/2	3c
pa	qb	rc

with $p = 1$, $q = \frac{1}{2}$, $r = 3$.

(ii) The intercepts as multiples of unit cell dimensions along the axes:

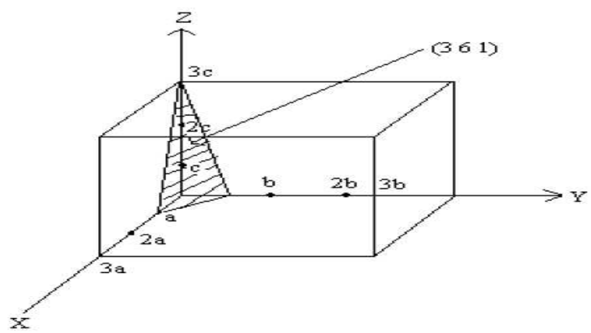
$$\frac{a}{a} \quad \frac{b/2}{b} \quad \frac{3c}{c}$$

i.e. 1 $\quad \frac{1}{2} \quad$ 3

(iii) The reciprocal of these numbers: $\quad 1 \quad 2 \quad \frac{1}{3}$

(iv) Smallest set of integral numbers of the above reciprocals: $\quad 3 \times 1 \quad 3 \times 2 \quad 3 \times \frac{1}{3}$

3 $\quad$ 6 $\quad$ 1



Thus the Miller indices of the plane is (3 6 1.) as shown in the figure.

4. Explain the following terms as applied to crystals:
   i. Crystal lattice
   ii. Unit cell
   iii. Premitive cell
   iv. Packing factor
   v. Atomic radius

5.

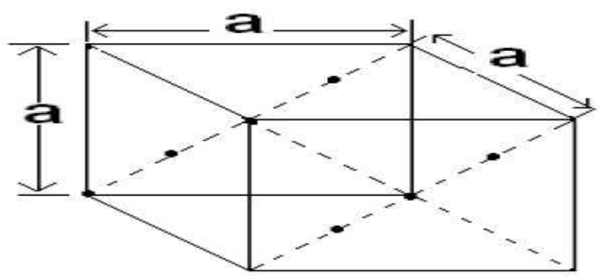
Show that the atomic packing factor for FCC and HCP metals are the same. Draw (112) and (120) planes in a fee structure.

Ans:

In FCC structure the number of atoms per unit cell are 4 an atomic radius $r = \frac{a\sqrt{2}}{4}$

$$r = \frac{a\sqrt{2}}{4}; \quad \text{APF} = \frac{\text{Volume of atoms per unit cell}}{\text{Volume of unit cell}}$$

$$= \frac{4 \times \frac{4\pi r^3}{3}}{a \times a \times a} = \frac{16\pi \frac{a\sqrt{2}}{4}^3}{3 \times 64 a^3} = \frac{\pi}{3\sqrt{2}} = 0.74$$



FCC

In HCP unit cell, the corner atoms are touching the centre atom on top and bottom faces Therefore $a = 2r$ or $r = a/2$

$$APF = \frac{\text{Volume of atoms per unit cell}}{\text{Volume of unit cell}}$$

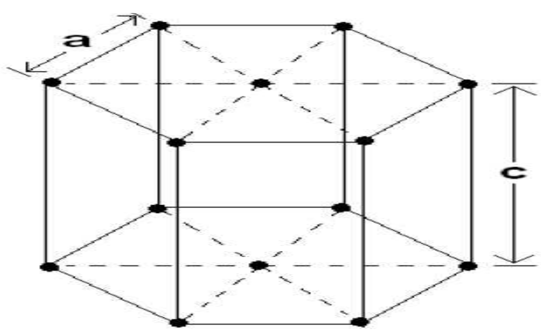
Volume of the hexagon = 33.8767

$$= \frac{6 \times \frac{4\pi r^3}{3}}{3a \sin 60 \times c} = \frac{6 \times \frac{4\pi a^3}{2^3}}{3a^2 \sin 60 \times c} = \frac{\pi a}{3 \sin 60 \times c}$$

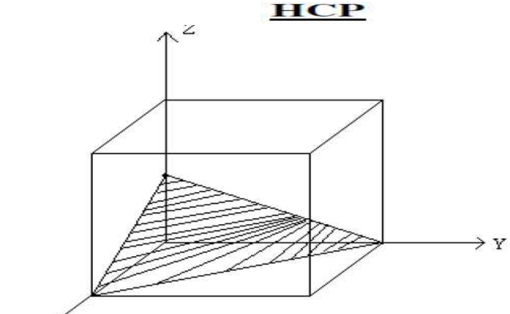
Taking c/a ratio for HCP structure = 1.633

$$APF = \frac{\pi}{3 \times 0.866 \times 1.633} = 0.74$$

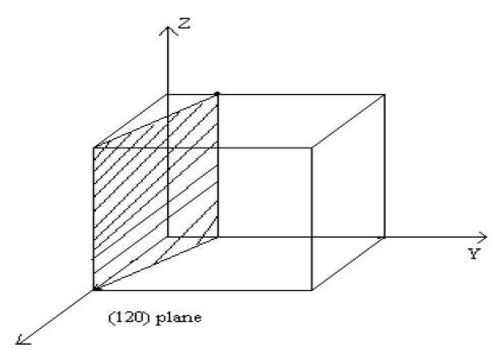
Thus it is seen that the atomic packing factor for HCP is the same as for an FCC structure.



HCP



(112) plane



(120) plane

6. What is a semiconductor? Discuss salient properties of common semiconducting materials. What are their uses? Where are they used? Give examples.

7.

Find the maximum radius of the interstitial sphere that can just fit into the void between the body centred atoms of bcc structure.

Ans: In Body centered cubic structure, the atoms touch each other along the diagonal of the cube. Usually, the length of the cell edge is represented by *a*. The direction from a corner of a cube to the farthest corner is called body diagonal (*bd*). The face diagonal (*fd*) is a line drawn from one vertex to the opposite corner of the same face. If the edge is *a*, then we have:

$$fd^2 = a^2 + a^2 = 2\,a^2$$
$$bd^2 = fd^2 + a^2$$
$$= a^2 + a^2 + a^2$$
$$= 3\,a^2$$

Atoms along the body diagonal (*bd*) touch each other. Thus, the body diagonal has a length that is four times the radius of the atom, *R*.

$bd = 4\,R$

The relationship between *a* and *R* can be worked out by the Pythagorean theorem:

$(4R)^2 = 3\,a^2$

Thus,

$4R = \sqrt{3}a$

or

$R = \sqrt{3}a/4$

8. Name various types of cubic class of crystalline structure. Explain their characteristics. Give the values of parameters which distinguish them from each other.

9.

Calcium has a face-centred cubic structure with an ionic radius of 1.06 Ǻ. Calculate the interplanar separation for (111) planes.

Ans: $d = a / \sqrt{(h^2 + k^2 + l^2)}$

Here, $a = 1.06 * 10^{-10}m$

And $h = k = l = 1$

Therefore, $d_{111} = 1.06 * 10^{-10}m / \sqrt{(1^2 + 1^2 + 1^2)}$

$= 1.06 * 10^{-10}m / \sqrt{3}$

$= 0.612 * 10^{-10}m$

10. Write short accounts on the following processes:

i. Oxidation in processing of electronic materials
ii. Epitaxial growth (CVD)
iii. Ion implantation

11.

How are p-type and n-type semiconductor obtained?

Ans: A **P-type semiconductor** is obtained by carrying out a process of doping, that is adding a certain type of atoms to the semiconductor in order to increase the number of free charge carriers (in this case positive). The purpose of **P-type doping** is to create an abundance of holes.

When the doping material is added, it takes away (accepts) weakly-bound outer electrons from the semiconductor atoms. This type of doping agent is also known as *acceptor material* and the semiconductor atoms that have lost an electron are known as *holes*

An **N-type semiconductor** is obtained by carrying out a process of doping, that is, by adding an impurity of valence-five elements to a valence-four semiconductor in order to increase the number of free charge carriers (in this case negative). The purpose of **N-type doping** is to produce an abundance of mobile or "carrier" electrons in the material.

Semiconductor doping is the process that changes an intrinsic semiconductor to an extrinsic semiconductor. During doping, impurity atoms are introduced to an intrinsic semiconductor. Impurity atoms are atoms of a different element than the atoms of the intrinsic semiconductor. Impurity atoms act as either donors or acceptors to the intrinsic semiconductor, changing the electron and hole concentrations of the semiconductor.

12. Compare and differentiate the properties of common semiconducting materials and common dielectric materials.

13.

Differentiate between chemical vapour deposition and lithography.

Ans: Chemical vapor deposition (CVD) is a chemical process used to produce high-purity, high-performance solid materials. The process is often used in the semiconductor industry to produce thin films. In a typical CVD process, the wafer (substrate) is exposed to one or more volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit. Frequently, volatile by-products are also produced, which are removed by gas flow through the reaction chamber.

Whereas Photolithography, which is one of the kinds of lithography is a process used in microfabrication to selectively remove parts of a thin film (or the bulk of a substrate). It uses light to transfer a geometric pattern from a photomask to a light-sensitive chemical (photoresist), on the substrate. A series of chemical treatments then engraves the exposure pattern into the material underneath the photoresist. In a complex integrated circuit (for example, modern CMOS), a wafer will go through the photolithographic cycle up to 50 times.

14. Differentiate "ion implantation and metallization" processes in the fabrication of integrated circuits (ICS).

15.

What are the metallurgical factors which affect the quality of a welded joint?

Ans: The **quality of a weld** is dependent on the combination of materials used for the base material and the filler material. Not all metals are suitable for welding, and not all filler metals work well with acceptable base materials. Most often, the major criterion used for judging the quality of a weld is its strength and the strength of the material around it. Many distinct factors influence this, including the welding method, the amount and concentration of energy input, the base material, the filler material, the flux material, the design of the joint, and the interactions between all these factors.

16. What is doping? In what importance respect does the conductivity of a conductor differ from that of an intrinsic semiconductor?

17. Write short note on Lithography and its applications.

Ans: The word **lithography** comes from the Greek lithos, meaning stones, and graphia, meaning to write. It means quite literally writing on stones. In the case of semiconductor lithography our stones are silicon wafers and our patterns are written with a light sensitive polymer called a photoresist. To build the complex structures that make up a transistor and the many wires that connect the millions of transistors of a circuit, lithography and etch pattern transfer steps are repeated at least 10 times, but more typically are done 20 to 30 times to make one circuit. Each pattern being printed on the wafer is aligned to the previously formed patterns and slowly the conductors, insulators, and selectively doped regions are built up to fabricate the final device.

18. In the context of processing of electronic material, explain oxidation, diffusion and metallization.

19. Explain the various steps required in the fabrication of an integrated circuit. What are the important functions of oxide layer in an integrated circuit?

Ans: The fabrication of integrated circuits consists basically of the following process steps:

- **Lithography:** The process for pattern definition by applying thin uniform layer of viscous liquid (photo-resist) on the wafer surface. The photo-resist is hardened by baking and than selectively removed by projection of light through a reticle containing mask formation.
- **Etching:** Selectively removing unwanted material from the surface of the wafer. The pattern of the photo-resist is transferred to the wafer by means of etching agents.
- **Deposition:** Films of the various materials are applied on the wafer. For this purpose mostly two kinds of processes are used, physical vapour deposition (PVD) and chemical vapour deposition (CVD).
- **Chemical Polishing:** A planarization technique by applying chemical slurry with etchant agents to the wafer surface.
- **Oxidation:** In the oxidation process oxygen (dry oxidation) or H_2O (wet oxidation) molecules convert silicon layers on top of the wafer to silicon dioxide.
- **Ion Implantation:** Most widely used technique to introduce dopant impurities into semiconductor. The ionized particles are accelerated through an electrical field and targeted at the semiconductor wafer.
- **Diffusion:** A diffusion step following ion implantation is used to anneal bombardment-induced lattice defects.

The functions of the oxide layer are to:

1. mask against diffusion or ion-implant
2. passivate the surface electrically and chemically
3. isolate one device from another
4. act as a component in MOS devices

20. What is meant by crystal imperfections? List and explain 4 types of defects.