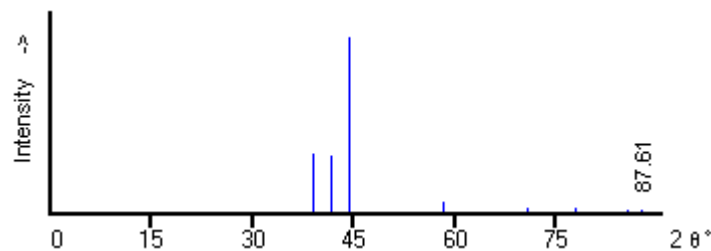


الزمن: 3 ساعة ..... اجب عن الاسئله الاتيه

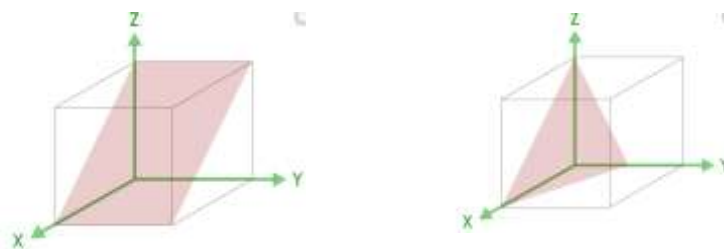
1. Give short analytical note about the the thermodynamics of crystal growth & Nucleation & Crystal growth theories.
- 2.

- Give short description for X-ray technique and define bremsstrahlung?
- state the compound name in the following chart where  $\lambda = 1.54 \text{ \AA}$ , and the data given in the table?



element	d1 Å	d2 Å	d3 Å
H <sub>2</sub>	2.3	2.1	2
Na	3.3	3.1	3
Li	2.6	2.4	2.3
Br	2.4	2.2	2.1

3.
  - Give short note about hydrothermal growth.
  - Draw the (100) and (110) planes of a body centered cubic (bcc) lattice to *THE CORRECT scale (Give dimensions)*. You can assume that the length of the cell is 1. The bcc structure consists of atoms at each corner of a cubic lattice and an atom sitting at the cube center. Draw in where the atom positions are in the planes.
4.
  - Determine the Miller indices (hkl) of the shaded planes below. Show your work on each step to determine the plane.



5. Interplanar spacing for crystal systems with cubic symmetry can be expressed by the relation:

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

where hkl is the Miller indices and a is the lattice parameter. Using a Bragg Diffractometer, we would like to determine if our Aluminum film for interconnection to our MOSFET has (111) crystal orientation for good electromigration reliability. Our diffractometer uses Cu K $\alpha$  radiation of wavelength 1.54 Å. Check to see if we actually have (111) Aluminum films if we measure  $\theta \sim 22.4^\circ$  for a first order diffraction peak. We also know that the lattice parameter of aluminum is 3.5Å.

1-

$$G = H - TS \quad (1.2)$$

where  $H$  is the enthalpy,  $S$  is the entropy and  $T$  is the temperature.

The formation of a crystal can be considered as a controlled change of phase to the solid state. The driving force for crystallization comes from the lowering of the free energy of the system during this phase transformation. The free energy change associated with such a transition is

$$\Delta G = \Delta H - T\Delta S \quad (1.3)$$

where  $\Delta H = H_L - H_S$

$$\Delta S = S_L - S_S$$

$$\Delta G = G_L - G_S$$

At equilibrium  $\Delta G = 0$

$$\therefore \Delta H = T_e \Delta S$$

where  $T_e$  is the equilibrium temperature.

$$\therefore \Delta G = \Delta H \cdot \Delta T / T_e \quad (1.4)$$

where  $\Delta T = T_e - T$

$\Delta G$  is positive when  $T_e > T$  and it depends on the latent heat of transition.

The free energy change can also be represented as the product of the entropy change and super cooling  $\Delta T$ .

$$\Delta G = \Delta S \cdot \Delta T$$

Though this representation is convenient for melt growth, one may depend on concentrations rather than supercooling for solution growth and vapour growth.

Thus the equation modifies to

$$\begin{aligned}\Delta G &\sim RT \ln (C/C_0) \\ \Delta G &\sim RT \ln (P/P_0)\end{aligned}\tag{1.5}$$

In general

$$\Delta G \sim RT \ln S\tag{1.6}$$

where  $S$  is the supersaturation ratio. Equation (1.4) and (1.6) explain how the free energy changes depend on the parameters like supercooling and supersaturation which are decisive in the process of crystallization. The rate of growth of a crystal can be regarded as a monotonically increasing function of  $\Delta G$ , if the other parameters remain the same.

### 1.3 Nucleation

Nucleation process is the conglomeration of atoms or molecules to form the first sub-microscopic speck or nucleus of the solid crystal. Nucleation can be either homogeneous or heterogeneous. Considering the total free energy for a group of atoms, a theory for the formation of a nucleus was put forward by Volmer and Weber [2].

## 1.4 Crystal growth theories

The successive growth of the critical nuclei of microscopic size leads to the formation of a crystal. In order to understand the mechanism and the kinetics of growth, several theories have been developed, which includes surface energy theory, diffusion theory, etc., but have been found to be unsatisfactory. Later Kossel and others analysed the atomic inhomogeneity of a crystal surface and explained the role of step and kink sites on the growth process. However, this was also not enough to provide a complete explanation for the continuous growth of a crystal surface. The

### 1.4.1 Surface energy theory

The surface energy theories are based on the thermodynamical treatment of equilibrium states put forward by Gibbs [1]. He compared the growth of crystals with the formation of water droplets in mist and defined the equilibrium form as one with minimum total surface energy for a given volume. The thermodynamical treatment suggested by Gibbs was later extended by a number of researchers. Curie [8] calculated the shapes and end forms of crystals in equilibrium with solution or vapour, consistent with Gibbs criterion. Wulff [9] gave an extension to Curie's ideas and deduced relations connecting the growth rate of different faces and the corresponding surface free energies. Marc and Ritzel [10] further developed the concepts of Wulff, stating that different faces have different solubilities. They

### 1.4.4 Screw dislocation theory

The discrepancy between the observed growth rate and the theoretical prediction based on two dimensional nucleation theory points to the fact that there is some other mechanisms responsible for the continuous growth of a crystal surface. Frank [22] proposed that dislocations having a screw component can act as a continuous source of steps on the surface of the crystal which eliminates the need for surface nucleation. A screw dislocation emerging at a point on the crystal surface provides a step on the surface with a height equal to 'a', the projection of the Burgers vector of the dislocation. Since the step provided by the screw dislocation

2.

- The supersaturation can be kept constant by :
  1. Isothermal evaporation of the solvent
  2. lowering the temperature
  3. adding solute
  4. adding another solvent

•

For an ice crystal growing from water vapour, we can write the growth velocity normal to the surface in terms of the Hertz–Knudsen formula [34]

$$\begin{aligned}v_n &= \alpha \frac{c_{\text{sat}}}{c_{\text{solid}}} \sqrt{\frac{kT}{2\pi m}} \sigma_{\text{surf}} \\ &= \alpha v_{\text{kin}} \sigma_{\text{surf}},\end{aligned}\tag{1}$$

where the latter defines the velocity  $v_{\text{kin}}$ . In this expression  $kT$  is Boltzmann's constant times temperature,  $m$  is the mass of a water molecule,  $c_{\text{solid}} = \rho_{\text{ice}}/m$  is the number density for ice,  $\sigma_{\text{surf}} = (c_{\text{surf}} - c_{\text{sat}})/c_{\text{sat}}$  is the supersaturation just above the growing surface,  $c_{\text{surf}}$  is the water vapour number density at the surface, and  $c_{\text{sat}}(T)$  is the equilibrium number density above a flat ice surface. The parameter  $\alpha$  is known as the *condensation coefficient*, and it embodies the surface physics that governs how water molecules are incorporated into the ice lattice, collectively known as the *attachment kinetics*. The attachment kinetics can be nontrivial, so in general  $\alpha$  will depend on  $T$ ,  $\sigma_{\text{surf}}$ , the surface structure and geometry, surface chemistry, etc. If molecules striking the surface are instantly incorporated into it, then  $\alpha = 1$ ; otherwise we must have  $\alpha \leq 1$ . The appearance of crystal facets indicates that the growth is limited by attachment kinetics, so we must have  $\alpha < 1$  on faceted surfaces. For a molecularly rough surface, or for a liquid surface, we expect  $\alpha \approx 1$  [35].

3.

- Hydrothermal growth

Hydrothermal growth is growth technique we can use if the solubility of the solute in water is not high. Since the solubility increases with increasing temperature. This calls for employment of high pressure containers. For example, sapphire, quartz

The basic components of an X-ray tube are shown in Figure 7-4. The tube is operated in a vacuum, thus allowing independent control of the number and speed of acceleration of the electrons striking the anode. The anode is made of either tungsten or molybdenum. The cathode is composed of two parts: the filament made of tungsten, and a focusing cup. The filament is a helical coil about 0.2 mm in diameter. When current flows through the coil and the wire heats up; this energizes the electrons. If the heat is high enough, then the electrons escape from the metal. These electrons are then accelerated towards the anode by applying a high-voltage potential across the anode and cathode.

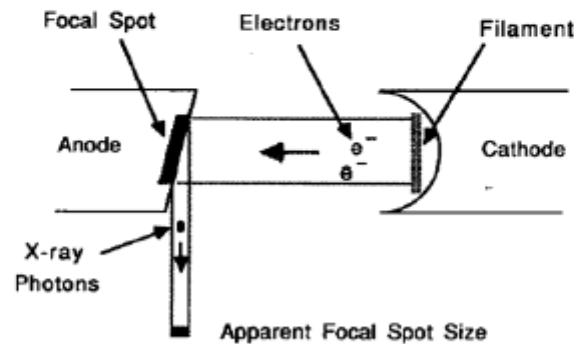
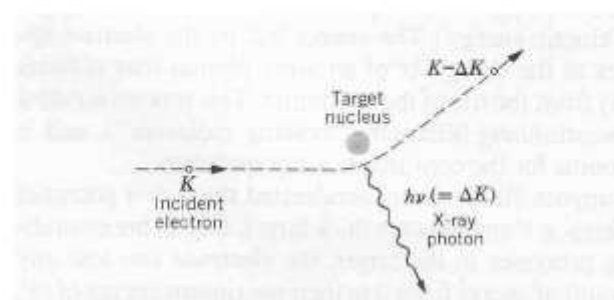


Figure 7-4 Basic components of an X-ray source

Potential energy  $eV$  have been converted to electromagnetic wave as follow :

$$\frac{h}{c\lambda_{\min}} = eV$$

The mechanism for bremsstrahlung is as follows:-



**Bremsstrahlung** (“Braking radiation”): An energetic electron which undergoes a sudden acceleration caused by interaction with a high-Z nucleus has a high probability of emitting a “bremsstrahlung” photon with an energy in the range from 0 to the full kinetic energy of the electron. This is the process that occurred in Röntgen’s discovery experiment when electrons accelerated in the discharge struck the glass wall of the tube.

3.

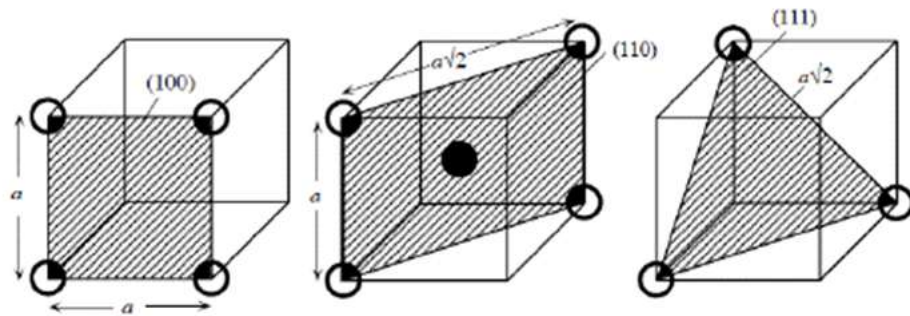
- **By substitute in Bragg law**

$$n\lambda = 2d \cdot \sin \theta$$

By  $\theta_1, \theta_2, \theta_3$

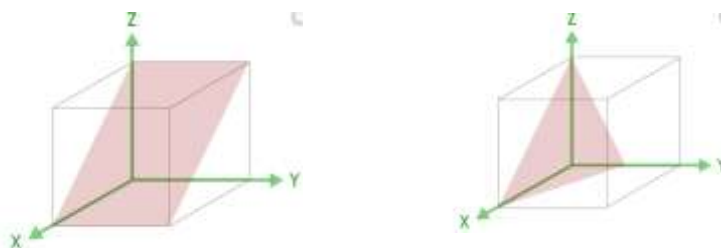
To obtain lattice constants  $d_1, d_2$  and  $d_3$  and comparing the data by table data we will obtain hydrogen chart name.

- 



(100), (110), (111) planes in the BCC crystal

4.



101

121

**5.**

$$d_1 = 3.5 / (3^{0.5})$$

$$= 2.02 \text{ \AA}$$

$$2d \sin(\theta) = n\lambda \quad \Rightarrow d_2 = -1.93$$

$$\Rightarrow d_1 \neq d_2$$

$\Rightarrow$  we actually have not 111 aluminum film