

2014(A)

ELECTRICAL & ELECTRONIC MATERIALS

Time: 3 hours

Full Marks: 70.

QUESTION 1.(Compulsory) Answer any 7

[7×2=14]

- I. Raw material for Silicon: Lime; Coke; Sand; Iron _____ Ans= Sand;
- II. How is 98% pure polycrystalline Silicon Obtained---Oxidation; Reduction; Sublimation; Evaporation. _____ Ans=Reduction;
- III. How is 98% pure polycrystalline Silicon purified: Convert to Oxide; Convert to TriChloroSilane; Melt it; Sublimate it. _____ Ans= Convert to TriChloroSilane.
- IV. How is Electronic Grade Trichlorosilane obtained: By multiple Distillation; By Decomposing it; By Oxidizing; By Reduction; _____ Ans=By multiple Distillation.
- V. Helium belongs to: First Period, Size=0.31A°; Second Period, Size =0.38A°;Third Period, Size = 0.71A°; Fourth Period, Size= 0.88A°; _____ Ans=First Period, 0.31A°
- VI. Hydrogen Lyman Series is due to: Transition to Ground State; Transition to First Excited State; Transition to Second Excited State; Transition to Third Excited State. _____ Ans= Transition to Ground State.
- VII. **Ionle Bonding is: Directional; Non-directional; Ductile; Fluctuating Dipoles; _____ Ans= non-directional.**
- VIII. **Metallic Bonding is: Directional; Brittle; Ductile; Fluctuating Dipoles; _____ Ans=Ductile.**
- IX. Bohr Postulates are:Electrons are in non-radiative Orbits; Electrons are in Stationary Orbits; Electrons are in Orbits where Angular Momentum = Integral Multiple of \hbar ; All Three; _____ Ans=All Three.
- X. Bohr Radius is: 10A°, 5A°, 1A°, 0.529A°. _____ Ans= 0.529A°

QUESTION 2.

- i. Draw the E-k diagram of electron in free space. [3.5]
- Give the energy band diagram of Metal, Insulator and Semi-conductor. [7]
- What are E_g , E_c , E_v , E_f , Work-Function W_f and surface-potential barrier Φ_{surbar} of a metal? [3.5]

Answer to Question 2.

- i. E-k diagram is given in Figure 1.

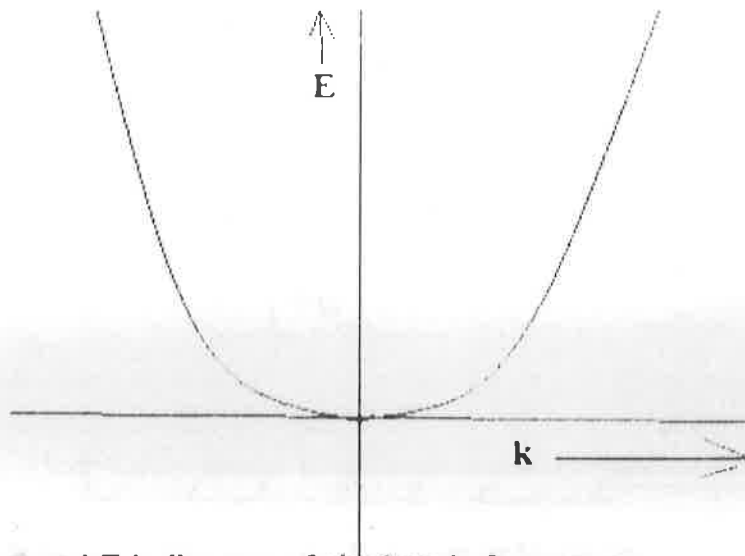


Figure 1. E-k diagram of electron in free space.

ii. Energy Band Diagram of Metal, Insulator and Semi-conductor in Figure 2.

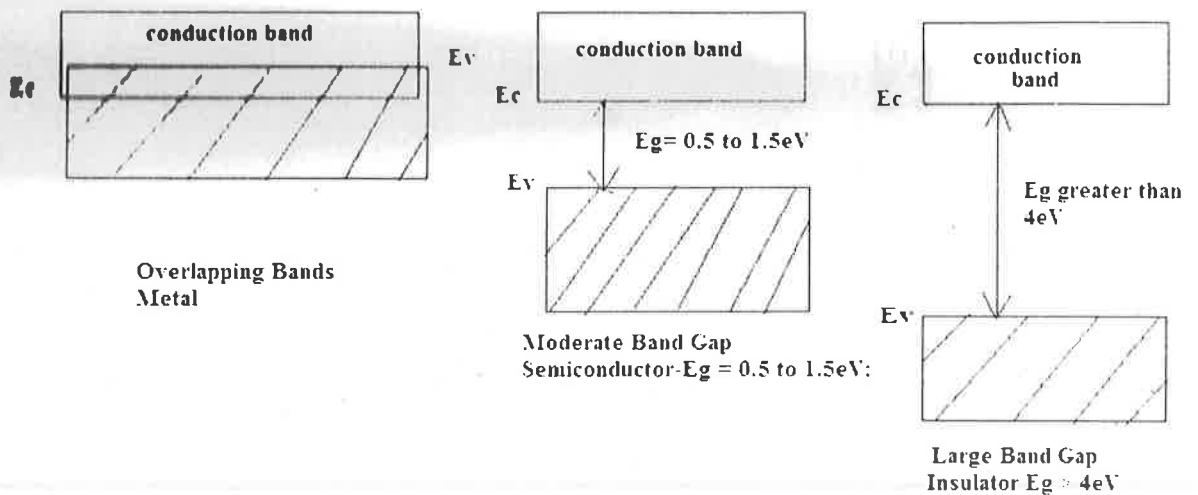


Figure 2. Energy Band Diagram of Metal, Semi-conductor and Insulator.

iii. What are E_G , E_C , E_V , E_F , Work-Function W_F and surface-potential barrier Φ_{surbar} of a metal? [3.5]

$E_G = E_C - E_V = \text{Band Gap}$; $E_C = \text{Bottom Edge of the Conduction Band}$. $E_V = \text{Upper Edge of the Valence Band}$. $E_F = \text{Fermi-Energy Level} - \text{Highest energy level of conduction electrons in conduction band at } 0\text{K}$. $W_F = \text{Work Function} = \text{minimum energy required by conduction electron to overcome the surface barrier potential and enter the Vacuum}$. This is called Thermo-ionic Emission. $\Phi_{\text{SUR}} = \text{Surface Barrier Potential}$. These symbols are positioned in the Metal's Band Diagram in Figure 3.

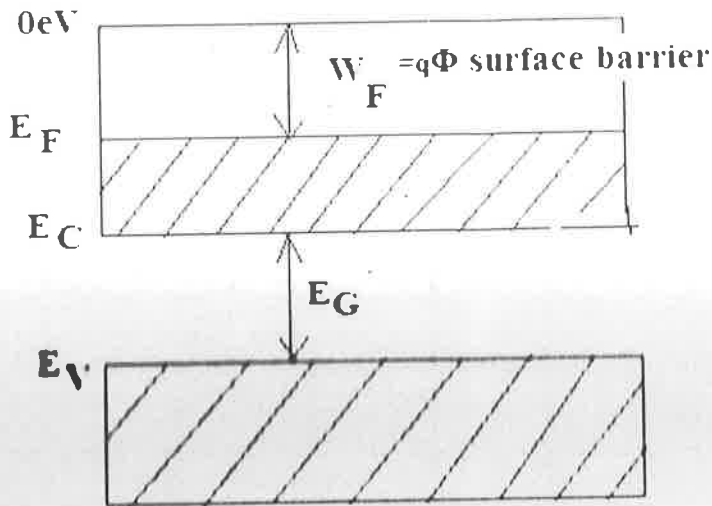


Figure 3. Energy Band Diagram of Metal and the definitions of E_F , E_C , E_V , E_G , $W_F = q\Phi_{sur}$

QUESTION 3.

- i. State the Fermi-Dirac Statistics. [7]
- ii. Draw the Fermi-Dirac Distribution curve at 0 Kelvin and at 300K. [3.5]
- iii. Define 0 Kelvin and 300K. [3.5]

Answer to Question 3.

- i. The Fermi-Dirac Statistics gives the Probability of occupancy of an Energy Level 'E' at temperature T Kelvin for Fermions. The Probability Distribution is as follows:

$$P(E) = \frac{1}{1 + \text{Exp}\left(\frac{E - E_F}{kT}\right)}$$

- ii. The Fermi Distribution is rectangular at Zero Kelvin and is askewed at Temperature T Kelvin. As Temperature rises, curve gets more and more askewed as shown in Figure 4.
- iii. At absolute 0K Thermal Energy is Zero, lattice vibrations are zero and lattice scattering is zero and the material can exhibit Superconductivity. In a metal, electrons occupy the lowest energy states and the highest energy state of electron in partially filled conduction band is Fermi-Energy (E_F) at 0 Kelvin as shown in Left Graph in Figure 4. But at higher temperature conducting electrons are not confined to Fermi-Energy (E_F) but they are jumping to higher energy states as shown in Right-side Graph in Figure 4. If the conducting metal is kept in vacuum then at higher temperature electrons may jump out of the metal into vacuum forming a Space

Charge Cloud surrounding the Metal as shown in Figure 5. This is called Thermionic Emission. This phenomena is utilized in Vacuum Tube.

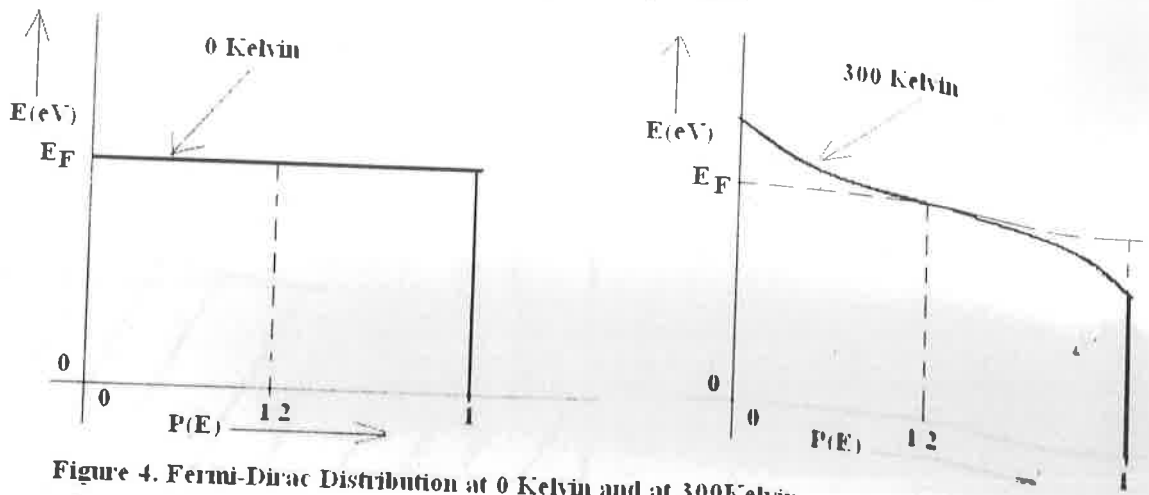


Figure 4. Fermi-Dirac Distribution at 0 Kelvin and at 300 Kelvin.

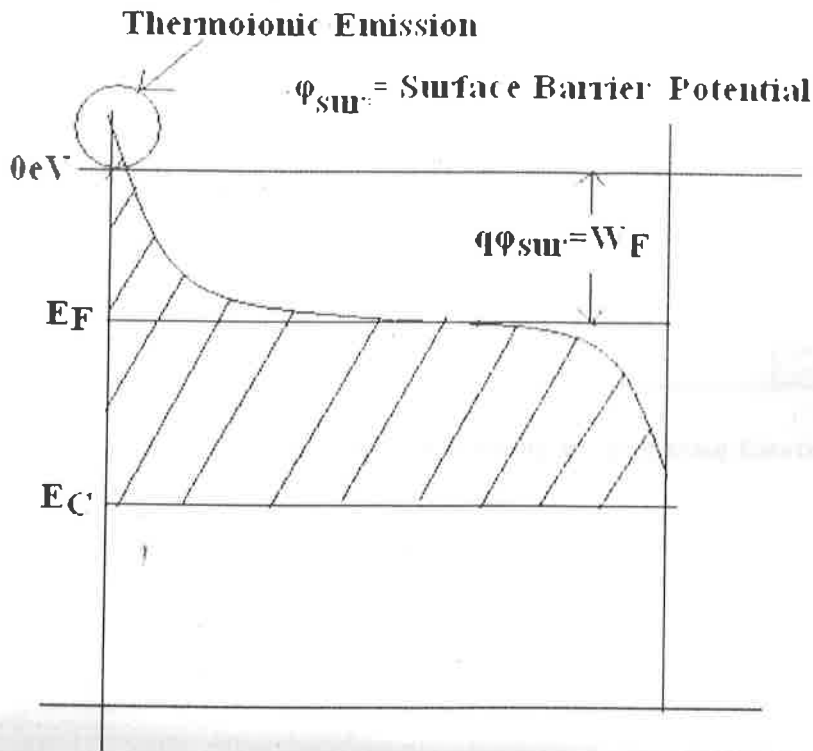


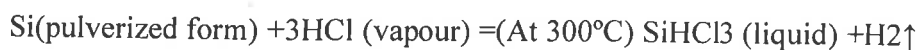
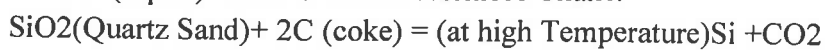
Figure 5. Awkewed Fermi-Dirac Distribution at 1200K for a Cathode Material of Work Function of 1eV leads to Thermionic Emission which is utilized in the functioning of Vacuum Tubes(Diode, Triode and Pentodes).

QUESTION 4.

Describe the step for preparing Electronic Grade Poly-crystal Silicon from sand.[14]

Answer to Question 4.

1. Quartz Sand (SiO_2) plus Coke are put in a container with submerged electrode Arc Furnace. Electric energy is consumed at the rate of 13 kWhr per kg and SiO_2 is reduced to Silicon by Coke. This silicon is of 98% purity. The solid silicon is pulverized and kept in an oven where Hydrogen Chloride vapour is passed at 300°C. Silicon is converted into $SiHCl_3$ (liquid) which is called Trichloro Silane.



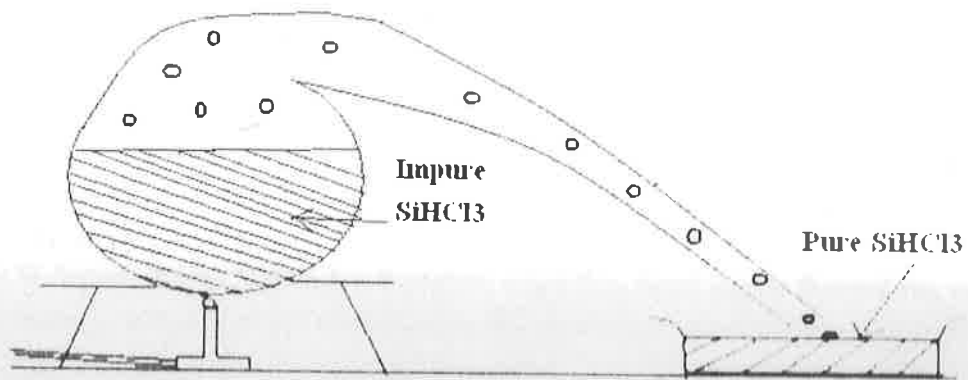


Figure 6. Multiple Distillation Set-up for preparing Electronic Grade Tri Chlor Silane

SiHCl_3 (liquid) has B.P 31.8°C . Whereas most impurities are less volatile. Therefore by multiple distillation electronic grade TriChloroSilane is obtained which eventually is used in SIEMEN'S REACTOR.

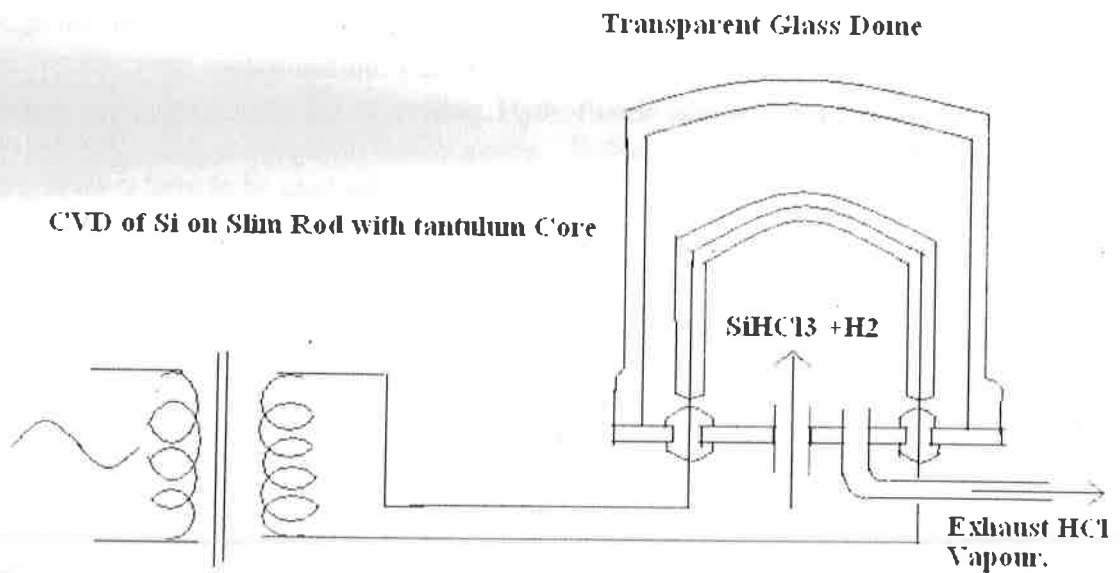


Figure 7. Siemen's Reactor for Chemical Vapour Deposition of Electronic Grade Si on Tantalum Wire Core which is heated at 1000°C .

In Siemen's reactor:



(Hydrogen reduction)

(a form of CVD of Silicon on slim rod of Silicon on Tantalum wire)

Slim rod contains Tantalum Wire surrounded by Silicon as shown in Figure 7. Slim rod can be formed by CVD on hot Tantalum wires.

(When Si deposited by CVD on hot Tantalum wires then there can be thermal runaway due to negative temperature coefficient of resistance (t.c.r) of surrounding silicon deposit dominating over positive t.c.r of the Tantalum wires. The thermal runaway has to be prevented by controlling the current.)

The resulting fattened slim rod has considerable metal contamination at the core of the rod. This can be removed by dissolving the central metallic core with Nitric acid. Nitric/Hydrofluoric acid mixture is then pumped through the hollow core. This cleaning method widens the hollow core by removing silicon and metal contamination (1mm/hr). First nitric acid is used to dissolve the metallic core. Next Hydrofluoric acid is passed through the hollowed core to dissolve the inner layer of silicon and in the process removing the metal contamination. **The fattened, purified rod of silicon thus obtained will be used as the feedstock for crystal pulling. Hydrofluoric acid is very corrosive and it can effect our bones even. Therefore Teflon gloves, Teflon Aprons, Teflon tweezers and Teflon beakers have to be used while working with HF acid.**

QUESTION 5.

- i. Density of States $[N(E)]$ is defined as number of permissible states per unit volume per unit energy level:

$$N(E) = \frac{\sqrt{2}m_e^{3/2}E^{1/2}}{\pi^2\left(\frac{h}{2\pi}\right)^3};$$

Show that mean energy of electron in conduction band is $(3/5)E_F$.

- ii. Determine $P(E_F + kT)$ in Fermi-Dirac Statistics. Determine Temperature T at which $P(E_F + 0.5\text{eV}) = 1\%$.

Answer to Question 5.

- i. Mean Energy of Electron in Conduction Band = (Total Energy in Conduction Band / Total number of electrons in Conduction Band.)
It is calculated as follows:

$$\bar{E} = \frac{\int_0^{E_F} E \times N(E) dE}{\int_0^{E_F} N(E) dE} = \frac{\frac{2E_F^{5/2}}{5}}{\frac{2E_F^{3/2}}{3}} = \frac{3}{5} E_F ;$$

ii. Probability of Occupancy at $E = E_F + kT$ is as follows:

$$P(E_F + kT) = \frac{1}{1 + \text{Exp}\left[\frac{E - E_F}{kT}\right]} = \frac{1}{1 + e} = 0.268941 = 27\%$$

The Temperature at which the Probability of Occupancy is 1% is determined in the following manner:

$$P(E_F + 0.5\text{eV}) = 1\% = 0.01 = \frac{1}{1 + \text{Exp}\left[\frac{0.5 \times 1.6 \times 10^{-19}}{1.3806503 \times 10^{-23} \times T}\right]}$$

Simplifying the above equation we get the following:

$$\text{Exp}\left[\frac{0.5 \times 1.6 \times 10^{-19}}{1.3806503 \times 10^{-23} \times T}\right] = \text{Exp}\left[\frac{5802.25}{T}\right] = 99;$$

Solving the above equation we get $T = 1262.7\text{Kelvin}$.

QUESTION 6.

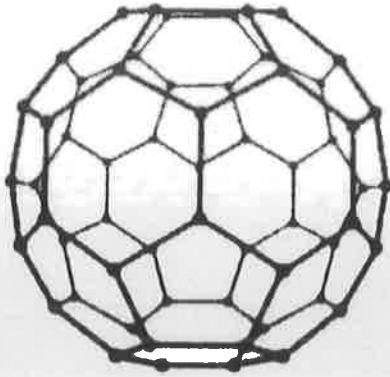
(a) Name the 0-D, 1-D, 2-D and 3-D allotropes of Carbon. [7]

(b) Draw simple sketches of them. [7]

Answers to Question 6.

- (a) C-60 Fullerene is 0-D allotrope; Carbon-nano tube (CNT) is 1-D allotrope of Carbon; Graphene is 2-D allotrope of Carbon; Graphite and Diamond are 3-D allotrope of Carbon.
- (b) Crystal Structure of the four allotropes:

(a)



(b)



(c)

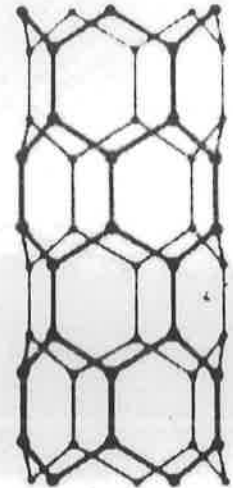


Figure 8. (a)The C₆₀ fullerene molecule, where there are 12 pentagons necessary to produce the spherical configuration. Carbon Nano-tube of arm chair type (b) and of zigzag type(c).It is not necessary to introduce pentagons for producing nano-tubes as they have zero curvature.[Pachos (2009)]

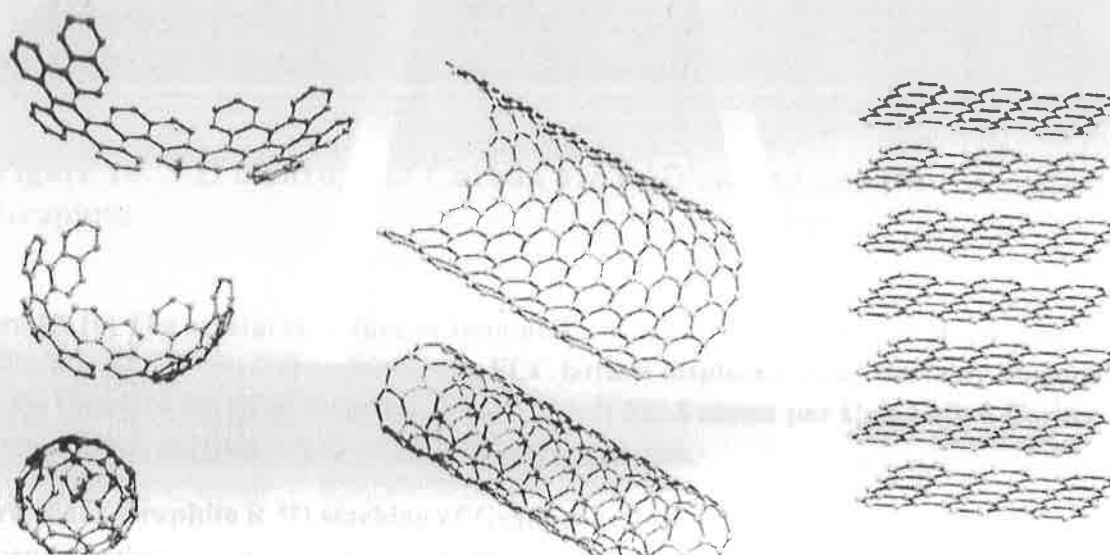
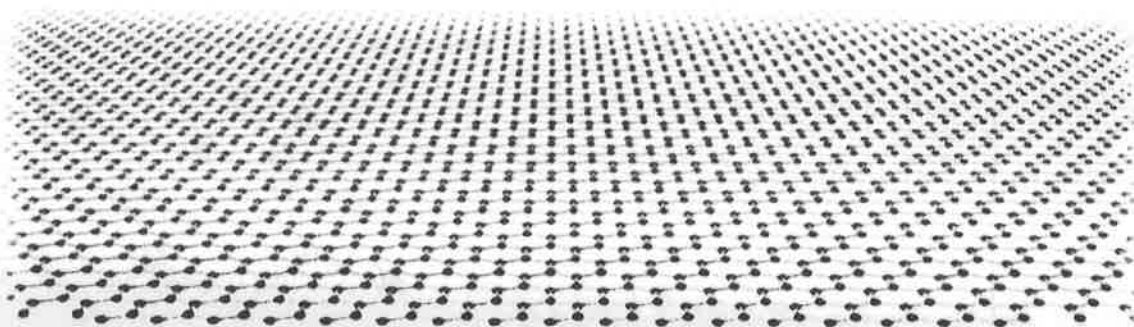


Figure 9. Graphene-mother of all graphitic forms. Graphene is a 2D building material for carbon materials of all other dimensionalities. It can be wrapped into a 0D buckyball, 1D nanotube or stacked into a 3D graphite.

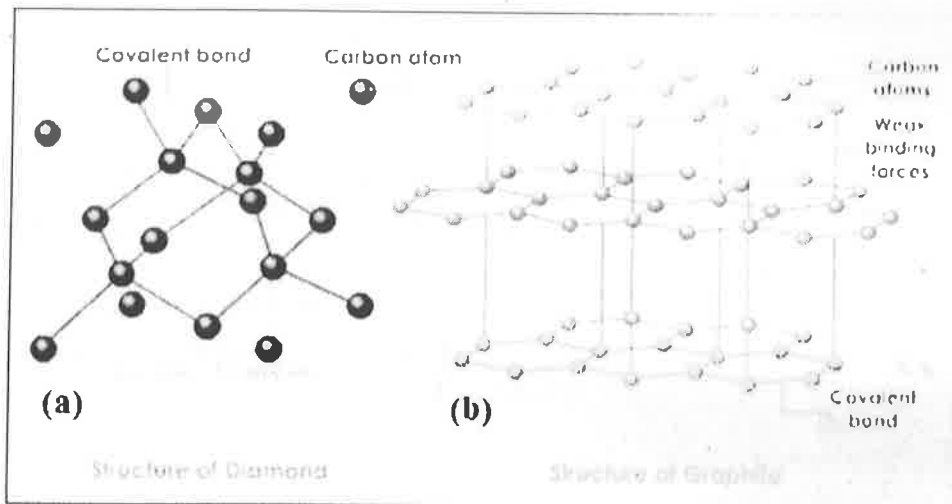


Figure 10. 3-D allotropes of Carbon are (a)Diamond and (b) Graphite.

Figure 10. (a) The crystal structure of Diamond – 3D allotrope of Carbon. It is a cubic Lattice. It contains two inter-penetrating FCC lattices displaced along the body diagonal by $\frac{1}{4}$ of the length of the cross diagonal of the Cube. It has 8 atoms per Unit Cell: 8 Corner atoms+ 6 Face Centered Atoms+4 Body Centered Atoms.

Figure 10.(b) Graphite is 3D stacking of Graphenes. It is soft and slippery used as lubricant and pencil leads.

QUESTION 7.

- (a) Draw the Reactance diagram of a piezo-electric Crystal. [7]
- (b) In AT cut piezo-electric crystal, $R_S = 5$, $L_S = 12\text{mH}$, $C_S = 0.0145\text{pF}$ and $C_P = 4.35\text{pF}$. Calculate series resonance frequency, parallel resonance frequency and Q-factor of the crystal. [7]

Answers to Question 7.

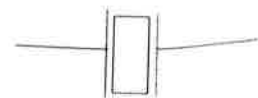
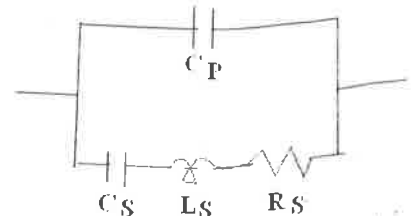
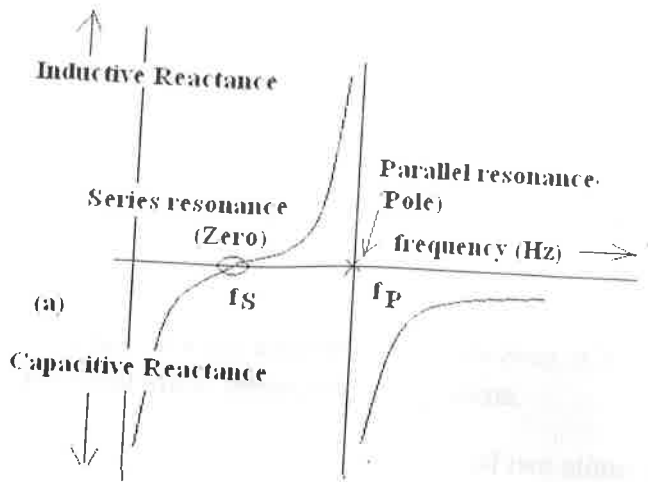


Figure 11.(a) Pole-Zero Diagram of Quartz Crystal or the Reactance Diagram of the Electrical Equivalent of the Mechanically Vibrating Quartz Crystal

(b) Electrical Equivalent Circuit of the Mechanically Vibrating Quartz Crystal

L_s, C_s, R_s are the electrical equivalent of inertia, stiffness and damping of the Mechanically Vibrating Quartz Crystal.

C_p is the interelectrode Capacitance.

(c) A rectangular precisely cut Quartz Crystal sandwiched between two metallic electrodes.

- (a)
 (b) Series Resonance (f_s), Parallel Resonance (f_p) and Quality Factor (Q) are calculated by the following formulae:

$$f_s = \frac{1}{2\pi\sqrt{L_s C_s}} = 12.0655 \text{ MHz.}$$

$$f_p = \frac{1}{2\pi\sqrt{L_s \frac{C_s C_p}{C_s + C_p}}} = 12.0856 \text{ MHz.}$$

$$Q = \frac{\omega_s L_s}{R_s} = \frac{1}{R_s} \times \sqrt{\frac{L_s}{C_s}} = 101,044$$

Answer to Question 2.

After detailed investigation it was found that in ferro-magnetic materials, spin angular momentum rather than orbital is the main contributor to Ferro-magnetism. The orbital angular momentum have a role to play but when there are uncompensated spins as in the case of transition elements the orbitals have negligible role to play.

Ferromagnetism occurs because of coupling of uncompensated spins in parallel direction. This coupling occurs directly and is called DIRECT EXCHANGE COUPLING or through intermediate anions usually Oxygen molecule through SUPER EXCHANGE.

In crystals this results in a net magnetic moments even at 300K. This is purely a Pauli-Exclusion Phenomena and Coulombic Interaction phenomena.

As shown in Figure (12)., uncompensated spins of two atoms in an overlapping electron clouds have preference for parallel alignment (which contributes to net magnetic moment) rather than anti-parallel alignment (which is zero magnetic moment). Parallel alignment corresponds to lower energy level E_2 because of less columbic repulsion and anti-parallel alignment corresponds to higher energy level E_1 because of stronger columbic repulsion due to closer spatial proximity. So obviously the lower energy state is preferred hence there is spontaneous magnetization in elements with uncompensated spin electrons. This is the case for Transition Elements hence Fe,Co and Ni are the strongest ferromagnetic materials.

$$\Delta E = E_1 - E_2 = \text{exchange energy} \quad 7.7$$

At room temperature:

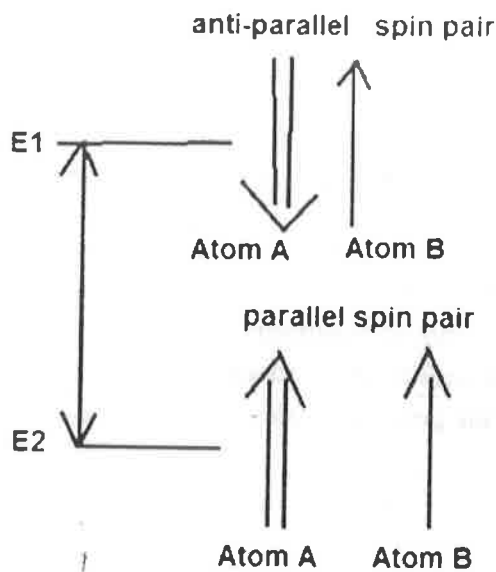
$$\Delta E \gg k_B 300K$$

Hence spontaneous magnetization is high up to Curie Temperature. At Curie Temperature exchange coupling is disrupted by thermal fluctuations and material becomes paramagnetic.

In Table 1. the Curie Temperatures of important Ferro-magnets are listed.

Table 1. Curie Temperatures of typical Ferromagnetic materials.

Materials	Curie Temperature (K)
Fe	1043
Co	1388
Ni	627
Gd	293



Pauli Exclusion Principle allows anti-parallel spins to be in close spatial proximity but leading to stronger Coulombic Repulsion hence corresponds to higher energy state E1.

Pauli Exclusion Principle does not allow close spatial proximity between parallel spin electrons. In fact parallel spin experience Pauli Exclusion Spatial Repulsion but in the process it experiences less Coulombic Repulsion hence it corresponds to lower Energy Level E2.

$E1 - E2 = \text{Exchange Energy}$

Figure 12 Illustration of Exchange Energy due to overlapping orbitals of two adjacent Atoms A and B.

QUESTION 9.

What is Band-Gap Engineering? Explain it with a practical example of application. [14]

Answer to Question 9.

The manipulation of Band Structure required for different kinds of applications is Band-gap Engineering. There are three techniques of Band-gap Engineering:

- i. Alloying;
- ii. Use of Heterojunctions and
- iii. Built-in strain via mismatched epitaxy.

The Aim of Band-gap Engineering is to tailor/customize the band-gap according to the wavelength at which we want to operate.

The second objective is to tailor the lattice constant according to our matching or our mismatching requirements.

Handwritten text at the top of the page, possibly a title or header.

Handwritten text in the upper middle section of the page.

Handwritten text in the middle section of the page.

Handwritten text in the lower middle section of the page.

Handwritten text in the lower section of the page.



Handwritten text on the right side of the page, possibly a list or detailed notes.

The wide miscibility range allows alloys to be grown with Band structures adjusted and finally tuned for specific applications.

One practical example of Band-Gap Engineering is fabrication of LEDs of different colours.

For the manufacture of coloured LEDs we have to use GaAs(1-x)P_x ternary alloy. This has a problem. Below x = 0.45 it is a direct band-gap material but at higher proportion of Phosphorous it becomes in-direct and its performance becomes very poor. By doping with Nitrogen it can be restored to Direct Band-gap material and utilized for LED manufacturing. Table 3.1 tabulates the different ternary alloys used for manufacturing the spectrum coloured LEDs.

Table 2..The Ternary Alloys (GaAs (1-x) P x) used in the manufacture of the whole range of spectrum coloured LED. Here $E_g = 1.424 + 1.15x + 0.176x^2$.

Colour	Wavelegth(μ m)	Band-Gap(eV)	'x'	Substrate
Red	0.64	1.9	0.4	GaAs
Orange	0.62	2	0.5	GaP
Yellow	0.58	2.15	0.58	GaP
Green	0.55	2.25	0.656	GaP
Blue	0.475	2.6	0.9	SiC

Seeh.
 (Sardar Tarlok Singh)
 Lecturer, Govt
 Polytechnic
 Gujranwala
 Pst-7

M- 9852150941

