**BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI**
**MID SEMESTER EXAMINATION (closed Book)**
**2023-24 I SEM**
**PHYSICS OF ADVANCED MATERIALS PHY F414**
**TIME 180 mins 120 MARKS DATE: 13th DECEMBER**

**Instructions**

• Part A is a closed book section, with 40 marks and a duration of 1 hour. You will be required to write short answers as relevant.
• Part B is an open book section, with 80 marks and a duration of 2 hours. You are allowed to refer to handwritten and photocopied notes, as well as books.
• You will find all the relevant data in a separate sheet, which you can use as and when required.

## Section A (short answer type)

### Write in sequence

1. Using block diagrams, show the fabrication steps of a bipolar junction transistor (BJT). **[3]**

2. Calculate the number of vacancies for copper at 1000 $^oC$. Given: activation energy for vacancy formation as 0.9 eV/atom, atomic weight of Cu as 63.5 g/mol and density as 8.4 $g/cm^3$. **[2]**

3. A 100 mm diameter GaAs wafer is uniformly implemented with 100 KeV impurity ions (+e charge on each ion) for five minutes with a constant ion beam current of 10 μA. Calculate ion dose per unit area and the peak current. Given $\Delta R_p$ = 20 nm. **[3]**

4. Plot the temperature dependence of resistivity for a metal and the temperature dependence of the conductivity of a semiconductor and normal ionic conductor. **[2]**

5. Consider a unit cell of $BaTiO_3$ with origin at Ba atom. Find the atomic packing factor. You may take ionic radii from the Table provided. **[3]**

6. How will you differentiate between a normal ionic and a semiconductor? Suggest two methods. **[2]**

7. What are the most essential three conditions for epitaxial growth? **[3]**

8. What is the importance of primary flat and secondary flat in a Si wafer? **[2]**

9. Using which phenomena a molecular beam can be produced? Explain in brief. **[2]**

10. What are the basic mechanisms by which an ion loses energy when it enters a solid during ion implantation process? Plot the energy loss as a function of energy of incident ion. **[2]**

**11.** Assume that 10 kg pure Silicon is used. What is the amount of boron that must be added to get the boron concentration of 9 x $10^{18}$/$cm^3$ when half of the crystal is grown? Given:$k_0$ = 0.8, density of liquid Si = 2.33 g/$cm^3$ boron atomic weight = 10.8 g/mol. **[5]**

**12.** Plot Nyquist (Z′-Z′′) plots for (i) a metal (ii) a semiconductor, and (iii) an ionic conductor. **[2]**

**13.** Justify why, despite the significant difference in the ionic radii, the cation and anion vacancies form together. **[3]**

**14.** Explain using the concept of chemical potential the electrochemical stability window. **[3]**

**15.** What are the magnetic moment (orbital and spin) of Cu and Fe atoms in the units of Bohor Magneton. **[3]**

## Part B (Open Book)

Q1. In an ion implantation experiment, calculate the damage density for Si if it is bombarded by boron. Given information: A 100 keV Boron is implanted into Si substrate. The projected range is 1500A. Spacing between Si planes is about 2.5 A. Initial nuclear energy loss is 12 eV/A. The energy required to displace a single silicon atom from its mean position is 15 eV. Assume that each displaced Si atom moves 25 A in the perpendicular direction to the ion beam. Also, calculate % damage if the Silicon density is $5.02 \times 10^{28}$ /m$^3$. **[14]**

Q2: Consider an alloy that initially has a uniform carbon concentration of 0.25 wt% and is to be treated at 950 $^oC$. If the concentration of carbon at the surface is brought to and maintained at 1.20 wt%, how long will it take to achieve a carbon content of 0.80 wt% at a position of 0.5 mm below the surface? The diffusion constant at this temperature is $1.6 \times 10^{-11}$ m$^2$/s. **[12]**

Q3 Schematically sketch a Molecular beam epitaxy setup which must have the relevant in situ measurement facilities, along with basic requirements, for the following characterization (i) mass to charge ratio (ii) to see atoms on the metallic and nonmetallic surface (iii) particle size calculation and inner crystal structure determination (iv) exclusive surface structure determination (v) suitable vacuum system and gauges (vi) Phosphorous doping facility. **[14]**

Q4 Why is lithium important for energy storage applications? What is the second-best choice? Calculate the theoretical capacity of $LiCoO_2$, Lithium, and $LiFePO_4$ electrodes. **[12]**

Q5: Construct a hypothetical phase diagram for metals A and B between 0 $^oC$ temperature and 700 $^oC$ given the following information:

(i) The melting temperature of A is 480 $^oC$
(ii) Maximum solubility of B in A is 4 wt% of B which occurs at 420 $^oC$.
(iii) The solubility of B in A at room temperature is 0 wt % of B
(iv) One eutectic occurs at 420 $^oC$ and 18 wt% B
(v) A second eutectic occurs at 475 $^oC$ and at 42 wt% B
(vi) The intermetallic compound AB exists at a composition of 30 wt% B and melts congruently at 525 $^oC$.
(vii) The melting temperature of B is 600 $^oC$.
(viii) The maximum solubility of A in B is 87 wt% of B, which occurs at 475 $^oC$.
(ix) The solubility of A in B at room temperature is 97 wt% of B.

**[16]**

Q6 The first four peaks of a neutron diffraction pattern (You may consider the diffraction angles (2θ as 26, 30.1, 42.8, and 50.2 degrees) for an FCC crystal structure are obtained using neutron radiation having a wavelength of 0.109 nm. (a) Index (i.e., give h,k, and l indices for) each of these peaks (b) Determine the inter planar spacing for each of the peaks and (c) Lattice parameter from each peak . [**12]**

**Table 5.1 Tabulation of Error Function Values**

| $z$ | $erf(z)$ | $z$ | $erf(z)$ | $z$ | $erf(z)$ |
|---|---|---|---|---|---|
| 0 | 0 | 0.55 | 0.5633 | 1.3 | 0.9340 |
| 0.025 | 0.0282 | 0.60 | 0.6039 | 1.4 | 0.9523 |
| 0.05 | 0.0564 | 0.65 | 0.6420 | 1.5 | 0.9661 |
| 0.10 | 0.1125 | 0.70 | 0.6778 | 1.6 | 0.9763 |
| 0.15 | 0.1680 | 0.75 | 0.7112 | 1.7 | 0.9838 |
| 0.20 | 0.2227 | 0.80 | 0.7421 | 1.8 | 0.9891 |
| 0.25 | 0.2763 | 0.85 | 0.7707 | 1.9 | 0.9928 |
| 0.30 | 0.3286 | 0.90 | 0.7970 | 2.0 | 0.9953 |
| 0.35 | 0.3794 | 0.95 | 0.8209 | 2.2 | 0.9981 |
| 0.40 | 0.4284 | 1.0 | 0.8427 | 2.4 | 0.9993 |
| 0.45 | 0.4755 | 1.1 | 0.8802 | 2.6 | 0.9998 |
| 0.50 | 0.5205 | 1.2 | 0.9103 | 2.8 | 0.9999 |

## Characteristics of Selected Elements

| Element | Symbol | Atomic Number | Atomic Weight (amu) | Density of Solid, 20°C (g/cm³) | Crystal Structure, 20°C | Atomic Radius (nm) | Ionic Radius (nm) | Most Common Valence | Melting Point (°C) |
|---|---|---|---|---|---|---|---|---|---|
| Aluminum | Al | 13 | 26.98 | 2.71 | FCC | 0.143 | 0.053 | 3+ | 660.4 |
| Argon | Ar | 18 | 39.95 | — | — | — | — | Inert | −189.2 |
| Barium | Ba | 56 | 137.33 | 3.5 | BCC | 0.217 | 0.136 | 2+ | 725 |
| Beryllium | Be | 4 | 9.012 | 1.85 | HCP | 0.114 | 0.035 | 2+ | 1278 |
| Boron | B | 5 | 10.81 | 2.34 | Rhomb. | — | 0.023 | 3+ | 2300 |
| Bromine | Br | 35 | 79.90 | — | — | — | 0.196 | 1− | −7.2 |
| Cadmium | Cd | 48 | 112.41 | 8.65 | HCP | 0.149 | 0.095 | 2+ | 321 |
| Calcium | Ca | 20 | 40.08 | 1.55 | FCC | 0.197 | 0.100 | 2+ | 839 |
| Carbon | C | 6 | 12.011 | 2.25 | Hex. | 0.071 | −0.016 | 4+ | (sublimes at 3367) |
| Cesium | Cs | 55 | 132.91 | 1.87 | BCC | 0.265 | 0.170 | 1+ | 28.4 |
| Chlorine | Cl | 17 | 35.45 | — | — | — | 0.181 | 1− | −101 |
| Chromium | Cr | 24 | 52.00 | 7.19 | BCC | 0.125 | 0.063 | 3+ | 1875 |
| Cobalt | Co | 27 | 58.93 | 8.9 | HCP | 0.125 | 0.072 | 2+ | 1495 |
| Copper | Cu | 29 | 63.55 | 8.94 | FCC | 0.128 | 0.096 | 1+ | 1085 |
| Fluorine | F | 9 | 19.00 | — | — | — | 0.133 | 1− | −220 |
| Gallium | Ga | 31 | 69.72 | 5.90 | Ortho. | 0.122 | 0.062 | 3+ | 29.8 |
| Germanium | Ge | 32 | 72.64 | 5.32 | Dia. cubic | 0.122 | 0.053 | 4+ | 937 |
| Gold | Au | 79 | 196.97 | 19.32 | FCC | 0.144 | 0.137 | 1+ | 1064 |
| Helium | He | 2 | 4.003 | — | — | — | — | Inert | −272 (at 26 atm) |
| Hydrogen | H | 1 | 1.008 | — | — | — | 0.154 | 1+ | −259 |
| Iodine | I | 53 | 126.91 | 4.93 | Ortho. | 0.136 | 0.220 | 1− | 114 |
| Iron | Fe | 26 | 55.85 | 7.87 | BCC | 0.124 | 0.077 | 2+ | 1538 |
| Lead | Pb | 82 | 207.2 | 11.35 | FCC | 0.175 | 0.120 | 2+ | 327 |
| Lithium | Li | 3 | 6.94 | 0.534 | BCC | 0.152 | 0.068 | 1+ | 181 |
| Magnesium | Mg | 12 | 24.31 | 1.74 | HCP | 0.160 | 0.072 | 2+ | 649 |
| Manganese | Mn | 25 | 54.94 | 7.44 | Cubic | 0.112 | 0.067 | 2+ | 1244 |
| Mercury | Hg | 80 | 200.59 | — | — | — | 0.110 | 2+ | −38.8 |
| Molybdenum | Mo | 42 | 95.94 | 10.22 | BCC | 0.136 | 0.070 | 4+ | 2617 |
| Neon | Ne | 10 | 20.18 | — | — | — | — | Inert | −248.7 |
| Nickel | Ni | 28 | 58.69 | 8.90 | FCC | 0.125 | 0.069 | 2+ | 1455 |
| Niobium | Nb | 41 | 92.91 | 8.57 | BCC | 0.143 | 0.069 | 5+ | 2468 |
| Nitrogen | N | 7 | 14.007 | — | — | — | 0.01–0.02 | 5+ | −209.9 |
| Oxygen | O | 8 | 16.00 | — | — | — | 0.140 | 2− | −218.4 |
| Phosphorus | P | 15 | 30.97 | 1.82 | Ortho. | 0.109 | 0.035 | 5+ | 44.1 |
| Platinum | Pt | 78 | 195.08 | 21.45 | FCC | 0.139 | 0.080 | 2+ | 1772 |
| Potassium | K | 19 | 39.10 | 0.862 | BCC | 0.231 | 0.138 | 1+ | 63 |
| Silicon | Si | 14 | 28.09 | 2.33 | Dia. cubic | 0.118 | 0.040 | 4+ | 1410 |
| Silver | Ag | 47 | 107.87 | 10.49 | FCC | 0.144 | 0.126 | 1+ | 962 |
| Sodium | Na | 11 | 22.99 | 0.971 | BCC | 0.186 | 0.102 | 1+ | 98 |
| Sulfur | S | 16 | 32.06 | 2.07 | Ortho. | 0.106 | 0.184 | 2− | 113 |
| Tin | Sn | 50 | 118.71 | 7.27 | Tetra. | 0.151 | 0.071 | 4+ | 232 |
| Titanium | Ti | 22 | 47.87 | 4.51 | HCP | 0.145 | 0.068 | 4+ | 1668 |
| Tungsten | W | 74 | 183.84 | 19.3 | BCC | 0.137 | 0.070 | 4+ | 3410 |
| Vanadium | V | 23 | 50.94 | 6.1 | BCC | 0.132 | 0.059 | 5+ | 1890 |
| Zinc | Zn | 30 | 65.41 | 7.13 | HCP | 0.133 | 0.074 | 2+ | 420 |
| Zirconium | Zr | 40 | 91.22 | 6.51 | HCP | 0.159 | 0.079 | 4+ | 1852 |