Solid State for Devices Physics
Tutorial Problems (Questions Only)

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1 Basic Review Questions

Semiconductor Materials

Question: List two elemental semiconductor materials and two compound semiconductor materials.

Lattice Structures

Question: Sketch three lattice structures: (a) simple cubic, (b) body-centered cubic, and (c) face-centered cubic.

Volume Density of Atoms

Question: Describe the procedure for finding the volume density of atoms in a crystal.

Miller Indices

Question: Describe the procedure for obtaining the Miller indices that describe a plane in a crystal.

Impurities in Crystals

Question: What is meant by a substitutional impurity in a crystal? What is meant by an interstitial impurity?

Wave–Particle Duality

Question: State the wave–particle duality principle and state the relationship between momentum and wavelength.

Quantized Energy Levels

Question: What is meant by quantized energy levels? Can an electron in a potential well have an arbitrary energy?

2 Schrödinger Equation Review

Schrödinger Equation: Basic Form

Question: Write down the time-dependent Schrödinger equation. What physical quantity does the wavefunction $\Psi(x,t)$ describe?

Separation of Variables

Question: Explain why we can write $\Psi(x,t) = \psi(x)\phi(t)$ when the potential is time-independent. What form does $\phi(t)$ take?

Stationary States

Question: What does it mean for a wavefunction to be a *stationary state*? Why is the probability density $|\Psi(x,t)|^2$ time-independent in this case?

Infinite Square Well

Question: For a particle in a 1D infinite square well of width a:

> What is the general form of the wavefunction inside the well? State the boundary conditions at $x = 0$ and $x = a$. Write the expression for the allowed energy levels E_n.

Free Particle

Question: Write down the solution of the Schrödinger equation for a free particle of energy $E = \frac{\hbar^2 k^2}{2m}$. What is the physical meaning of the parameter k?

Finite Barrier

Question: If a particle has energy $E < V_0$ in a finite potential barrier, what form does the wavefunction take inside the barrier?

Normalisation

Question: Why must the total wavefunction satisfy

$$\int_{-\infty}^{+\infty} |\Psi(x,t)|^2 dx = 1 \ ?$$

3 Arrhenius Relationship

Arrhenius Relation for Thermal Defects

Question: A material has an atomic density $N = 8.5 \times 10^{22}\,\mathrm{cm}^{-3}$ and a vacancy formation energy $E_f = 1.2\,\mathrm{eV}$.

1. Calculate the fractional vacancy concentration f and the vacancy density n_d at $T = 1500\,\mathrm{K}$.
2. What is the general formula for the defect concentration n_d as a function of temperature T?

Estimating E_f from Two Concentrations

Question: The defect concentration in a material is measured to be $n_1 = 2.0 \times 10^{15}\,\mathrm{cm}^{-3}$ at $T_1 = 1000\,\mathrm{K}$ and $n_2 = 4.0 \times 10^{16}\,\mathrm{cm}^{-3}$ at $T_2 = 1200\,\mathrm{K}$. Estimate the defect formation energy E_f in eV.

Effect of Entropy Factor

Question: A material has $E_f = 2.5\,\mathrm{eV}$ and $N = 6.0 \times 10^{22}\,\mathrm{cm}^{-3}$. Calculate the defect concentration n_d at $T = 1000\,\mathrm{K}$. How does the concentration change if an entropy factor $S_f/k_B = 1.5$ is included?

Temperature for Given Vacancy Density

Question: Find the temperature T (in Kelvin) required to achieve a vacancy density of $n_d = 1.0 \times 10^{15}\,\mathrm{cm}^{-3}$ in a material with $N = 1.0 \times 10^{23}\,\mathrm{cm}^{-3}$ and $E_f = 1.8\,\mathrm{eV}$.

Comparing Two Materials

Question: Two materials (A and B) have the same atomic density $N = 7.0 \times 10^{22}\,\mathrm{cm}^{-3}$ and are held at $T = 1200\,\mathrm{K}$. Material A has a defect formation energy $E_f = 2.0\,\mathrm{eV}$ and Material B has $E_f = 2.8\,\mathrm{eV}$. Calculate the defect concentration in both materials and state the ratio n_A/n_B.

4 Crystal Structure

Miller Indices and Interplanar Spacing

Given: Simple cubic crystal with lattice constant $a = 0.30\,\mathrm{nm}$. A plane intersects the axes at $(x, y, z) = (2a, a, a/2)$.

(i) Find the Miller Indices (hkl) for this plane.

(ii) Find the interplanar spacing d_{hkl} for this plane.

5 Quantum Mechanics Exercises

Photon Energy and Wavelength

Problem: Calculate the energy of each photon of blue light of frequency $\nu = 6.40 \times 10^{14}\,\mathrm{Hz}$. What is the wavelength of this photon?

de Broglie Wavelength

Problem:

- Calculate the de Broglie wavelength of an electron moving at $v = 1 \times 10^5\,\mathrm{m/s}$.

- Calculate the de Broglie wavelength of a person (mass = 70 kg) walking at 1 m/s.

Heisenberg Uncertainty Principle

Problem: The uncertainty in the position of an electron is $\Delta x = 8$ Å.

- Determine the minimum uncertainty in the momentum Δp.
- Calculate the uncertainty in the kinetic energy (assume $p \approx \Delta p$).