Tutorial 1

Exercise 1: Defining Semiconductors

In terms of electrical conductivity, describe where semiconductors sit relative to conductors and insulators. Explain how their conductivity responds to changes in temperature compared to metals.

Exercise 2: Categorizing Types

Contrast **Intrinsic** and **Extrinsic** semiconductors. Within extrinsic materials, explain the structural difference between an **n-type** and a **p-type** semiconductor, specifically mentioning the role of "dopants."

Exercise 3: Semiconductor Alloys

Define what a semiconductor alloy is and provide one example. Why would a manufacturer choose an alloy over a pure element like Silicon?

Exercise 4: Electron-Hole Dynamics

Describe the process of **Generation** (formation) and **Recombination** of electron-hole pairs. What external factor typically triggers the formation of these pairs in a dark environment?

Exercise 5: Energy Band Theory

Elucidate the concept of the **Energy Band Gap (Eg)**. Use this concept to explain why a diamond is an insulator while Silicon is a semiconductor.

Exercise 6: Describing Semiconductors

A Silicon (Si) sample at 300 K has an intrinsic carrier concentration ni≈1.5×1010 cm−3. Given the electron mobility $\mu_n = 1350cm^2/(\mathrm{V}\cdot s^{-1})$ and hole mobility $\mu_p = 450cm^2/(\mathrm{V}\cdot s^{-1})$, calculate the electrical conductivity σ of pure Silicon: $\sigma = n_i e(\mu_n + \mu_p)$

Exercise 7: Types of Semiconductors (Doping)

An n-type Silicon sample is doped with Phosphorus such that the donor concentration $N_D = 1016cm^{-3}$. If the intrinsic carrier concentration is $n_i = 1.5 \times 10^{16} cm^{-3}$, determine the minority carrier (hole) concentration p_0. Given the Mass action law: $n_0 \times p_0 = n_i^2$ and we assume that $n_0 \approx N_D$ at complete ionization

Exercise 8: Semiconductor Alloys

The bandgap Eg of the ternary alloy $Al_xGa_{1-x}As$ at 300 K can be estimated using the Virtual Crystal Approximation for low x values. Calculate the bandgap for an alloy with 20% Aluminum ($x = 0.2$), given $Eg(GaAs) = 1.42\,eV$ and $Eg(AlAs) = 2.16\,eV$, $Eg(x) = xEg(AlAs) + (1-x)Eg(GaAs)$

Pr. Omar ELOUTASSI o.eloutassi@umi.ac.ma

Exercise 9: Formation and Recombination

In a steady-state condition, light is shining on a semiconductor, creating excess electron-hole pairs (EHPs) at a generation rate $G = 10^{20} cm^{-3} s^{-1}$. If the minority carrier lifetime is $\tau = 10\ \mu$ s, what is the steady-state excess carrier concentration Δn? :$\Delta n = G \times \tau$

Exercise 10: Energy Bands in Solids

The intrinsic carrier concentration ni depends on temperature T and the bandgap Eg. If the temperature of a Silicon sample increases from $300\ K$ to $350\ K$, how does the exponential term in the n_i formula change? (Assume $Eg = 1.12$eV and $K_B = 8.617 \times 10^{-5}\ eV/K$).and $ni \propto exp\left(\frac{-Eg}{2K_BT}\right)$

Exercise 11: Optoelectronic Sensor

An advanced materials laboratory is designing a high-sensitivity light sensor for a deep-space probe. To optimize the sensor for a specific deep-red wavelength (approx. 785 nm), the team uses a ternary alloy, $Al_xGa_{1-x}As$, doped with Selenium (a donor impurity).

1. **Bandgap Engineering:** Determine the Aluminum mole fraction (x) required for the alloy to have a bandgap (Eg) corresponding to a 785 nm photon. (Use (eV)=1240/$\lambda(nm)$ and the alloy formula $Eg(x) = xEg(AlAs) + (1 - x)Eg(GaAs)$, where Eg(GaAs)=1.42 eV and Eg(AlAs)=2.16 eV).
2. **Doping & Conductivity:** The chosen alloy is then doped to create an n-type semiconductor with a donor concentration $N_D = 2 \times 10^{16}\ cm^{-3}$. If the intrinsic carrier concentration n_i at the operating temperature is $10^6\ cm^{-3}$, calculate the minority carrier concentration (p_0).
3. **Steady-State Dynamics:** In a dark environment, the sensor is suddenly exposed to a laser, creating excess electron-hole pairs at a generation rate $G = 5 \times 10^{18} cm^{-3} s^{n-1}$. If the minority carrier lifetime is $\tau = 2\ \mu\ s$, calculate the steady-state excess hole concentration Δp and the total hole concentration (p_{total} during illumination.
4. **Temperature Response:** If the probe moves closer to a star and the temperature increases, explain, using energy band theory, how this will affect the sensor's "dark current" (conductivity without light).