Tutorial 1 Answers

Answer 1: Semiconductor Description

Semiconductors are materials with electrical conductivity falling between that of a conductor (like copper) and an insulator (like glass).

- **Temperature Dependency:** Unlike metals (where resistance increases with heat), semiconductors have a **negative temperature coefficient**. As temperature rises, more electrons gain energy to jump into the conduction band, decreasing resistance and increasing conductivity.

Answer 2: Types of Semiconductors

- **Intrinsic:** Pure semiconductor material (e.g., pure Silicon) with no significant impurities. Charge carriers are created only by thermal excitation.
- **Extrinsic:** Semiconductors "doped" with impurities to alter electrical properties.
    - **n-type:** Created by adding **pentavalent** atoms (e.g., Phosphorus). These have five valence electrons, providing "extra" free electrons (negative charge carriers).
    - **p-type:** Created by adding **trivalent** atoms (e.g., Boron). These have three valence electrons, creating "holes" (positive charge carriers) where an electron is missing.

Answer 3: Semiconductor Alloys

A semiconductor alloy is a compound made of two or more elements (e.g., **Gallium Arsenide - GaAs** or **Silicon-Germanium - SiGe**).

- **Purpose:** Alloys allow engineers to "tune" the band gap. By varying the ratio of elements, they can customize the material to emit or absorb specific wavelengths of light (crucial for LEDs and Fiber Optics) or operate at higher frequencies than pure Silicon.

Answer 4: Formation and Recombination

- **Formation (Generation):** This occurs when an electron gains enough energy (from heat or light) to break free from its covalent bond, moving from the valence band to the conduction band. This leaves behind a "hole" (a vacant positive state).
- **Recombination:** This is the reverse process. A free electron in the conduction band loses energy and falls back into an empty state (hole) in the valence band, often releasing energy as heat or light (photons).

Answer 5: Energy Band Theory

Energy bands consist of the **Valence Band** (filled with electrons) and the **Conduction Band** (where electrons move freely). The space between them is the **Band Gap**.

- **Semiconductors (Silicon):** Have a small band gap (~1.1 eV), allowing some electrons to jump across at room temperature.

- **Insulators (Diamond):** Have a very wide band gap (>5 eV). The energy required to move an electron to the conduction band is so high that under normal conditions, no current flows.

Exercise 6

Sum of mobilities: $1350 + 450 = 1800\ \text{cm}^2/(\text{V} \cdot \text{s})$.

$$\sigma = (1.5 \times 10^{10}\ \text{cm}^{-3}) \times (1.6 \times 10^{-19}\ \text{C}) \times (1800\ \text{cm}^2/(\text{V} \cdot \text{s})).$$

$$\approx 4.32 \times 10^{-6}\ \text{S/cm}.$$

Exercise 7

$$n_0 = 10^{16}\ \text{cm}^{-3}$$

$$p_0 = \frac{n_i^2}{n_0} = \frac{(1.5 \times 10^{10})^2}{10^{16}}$$

$$= \frac{2.25 \times 10^{20}}{10^{16}}$$

$$= 2.25 \times 10^4\ \text{cm}^{-3}$$

Exercise 8

$$E_g(0.2) = 0.2(2.16) + (1 - 0.2)(1.42)$$

$$= 0.432 + (0.8 \times 1.42) = 0.432 + 1.136$$

$$\approx 1.568\ \text{eV}$$

Exercise 9:

$$\Delta n = (10^{20}\ \text{cm}^{-3}\text{s}^{-1}) \times (10^{-5}\ \text{s}) = 10^{15}\ \text{cm}^{-3}$$

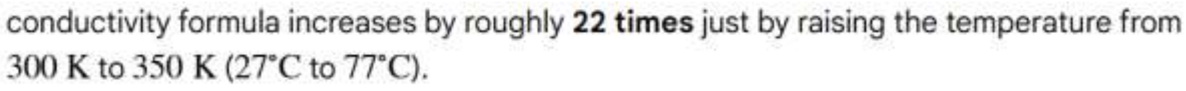
Exercise 10

$$\text{At } T_1 = 300\ \text{K: Factor} \approx \exp\left(\frac{-1.12}{2 \times 8.617 \times 10^{-5} \times 300}\right) \approx \exp(-21.66)$$

$$\text{At } T_2 = 350\ \text{K: Factor} \approx \exp\left(\frac{-1.12}{2 \times 8.617 \times 10^{-5} \times 350}\right) \approx \exp(-18.57)$$

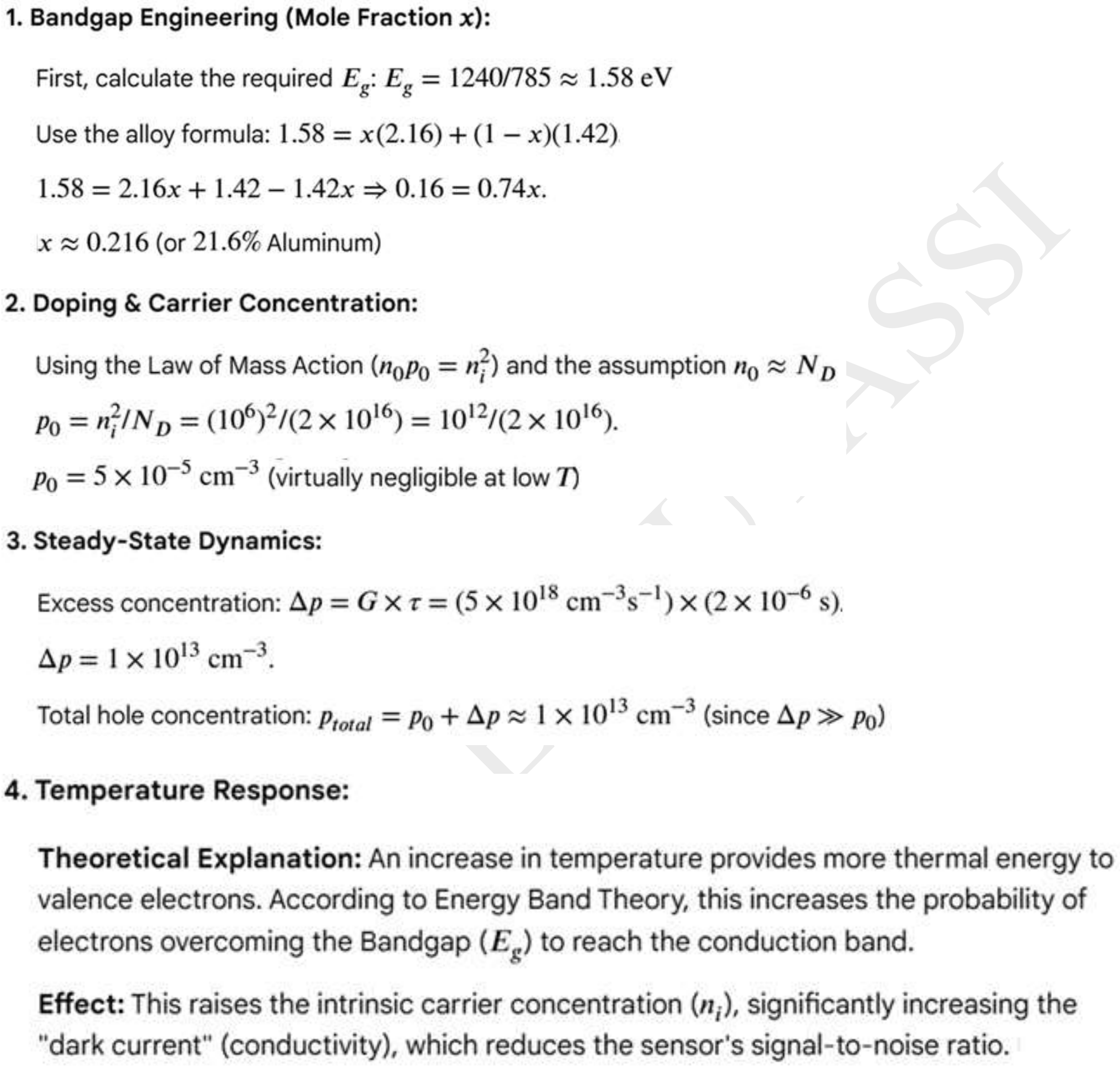
It is better to use the ratio in this case rather the differential so:

$$\text{Increase Ratio} = \frac{\exp(-18.57)}{\exp(-21.66)} = e^{3.09} \approx \mathbf{21.98} \approx \mathbf{22}$$



conductivity formula increases by roughly **22 times** just by raising the temperature from 300 K to 350 K (27°C to 77°C).

Exercise 11



1. Bandgap Engineering (Mole Fraction x):

First, calculate the required E_g: $E_g = 1240/785 \approx 1.58\ \text{eV}$

Use the alloy formula: $1.58 = x(2.16) + (1-x)(1.42)$

$1.58 = 2.16x + 1.42 - 1.42x \Rightarrow 0.16 = 0.74x$.

$x \approx 0.216$ (or 21.6% Aluminum)

2. Doping & Carrier Concentration:

Using the Law of Mass Action ($n_0 p_0 = n_i^2$) and the assumption $n_0 \approx N_D$

$p_0 = n_i^2/N_D = (10^6)^2/(2 \times 10^{16}) = 10^{12}/(2 \times 10^{16})$.

$p_0 = 5 \times 10^{-5}\ \text{cm}^{-3}$ (virtually negligible at low T)

3. Steady-State Dynamics:

Excess concentration: $\Delta p = G \times \tau = (5 \times 10^{18}\ \text{cm}^{-3}\text{s}^{-1}) \times (2 \times 10^{-6}\ \text{s})$.

$\Delta p = 1 \times 10^{13}\ \text{cm}^{-3}$.

Total hole concentration: $p_{total} = p_0 + \Delta p \approx 1 \times 10^{13}\ \text{cm}^{-3}$ (since $\Delta p \gg p_0$)

4. Temperature Response:

Theoretical Explanation: An increase in temperature provides more thermal energy to valence electrons. According to Energy Band Theory, this increases the probability of electrons overcoming the Bandgap (E_g) to reach the conduction band.

Effect: This raises the intrinsic carrier concentration (n_i), significantly increasing the "dark current" (conductivity), which reduces the sensor's signal-to-noise ratio.