1. (5%) How you can differentiate a semiconductor from other solids?

A semiconductor can be differentiated from other solid on following basis;

1. Crystal structure
2. Bonding mechanism
3. Bandgap
4. Electrical properties

2. (10%) If \( \mathbf{r} = 4\mathbf{a} + 3\mathbf{b} \). Where do you think the shaded unit cell can be translated within figure-1 below?
3. (5%) Why is the effective mass term used in solid instead of rest mass.

   All the quantum mechanic effects are lumped into it.

4. (10%) In an intrinsic semiconductor, is it possible to achieve
   
a. No. of holes > No. of electrons or No
   
b. No. of holes < No. of electrons No

   Explain why or why not?

   Under the equilibrium conditions, in an intrinsic semiconductor the number of holes is always equal to the number of electrons.

5. (15%) An \( n \)-type extrinsic Si was made by doping \( 5 \times 10^{14} \) As atom per cm\(^3\). If all the As atoms are replaced with P. What type of semiconductor it would be? Also draw the bonding and energy band diagrams for the new material if the doping level is the same.

   - It would still be an \( n \)-type material.
   - Bonding diagram

   ![Bonding Diagram](image)

   - Energy band diagram

   \[ E_G = 1.12 \text{ eV} \]
6. (15%) Calculate the resistance and the sheet resistance for a piece of a semiconductor with the following parameters;
\[ L = 3W, \ T = 5\mu m \text{ and } N_A = 2 \times 10^{15}/cm^3. \]

\[ \begin{align*}
\sigma_p &= 0.1466 \text{ (}\Omega\text{.cm)}^{-1} \\
\rho_p &= 6.823 \\Omega\text{.cm} \\
R_p &= 40.938 \text{ K}\Omega \\
R_{Sp} &= 13.646 \text{ K}\Omega/\text{Sq.}
\end{align*} \]

7. (15%) What would be \( R \) and \( R_s \) in the previous question if \( N_A \) is replaced with \( N_D \). Would you please comment what type of semiconductor it could be?

\[ \begin{align*}
\sigma_n &= 0.4304 \text{ (}\Omega\text{.cm)}^{-1} \\
\rho_n &= 2.232 \\Omega\text{.cm} \\
R_n &= 13.938 \text{ K}\Omega \\
R_{Sn} &= 4.646 \text{ K}\Omega/\text{Sq.}
\end{align*} \]

8. (10%) Explain why a semiconductor has negative temperature coefficient?

Because as temperature increases, resistively decreases as schematically shown in figure below. Whereas in conductors, it increases with an increase in temperature.
9. (5% each, 20% total) Calculate $D_n$, $D_p$, $L_n$ and $L_p$ at 100°C for a carrier concentrations of $N_D = N_A = 2 \times 10^{16}$ cm$^{-3}$. Take $\tau_p = 3$ ns and $\tau_n = 0.5 \tau_p$.

At 100°C, electrons and holes mobilities are estimated as

- $\mu_n = 680$ cm$^2$/Vs
- $\mu_p = 272$ cm$^2$/Vs
- $kT/q$ is calculated as 0.0359 V.

Therefore;

- $D_n = 24.06$ cm$^2$/s
- $D_p = 9.625$ cm$^2$/s
- $L_n = 0.19 \times 10^{-3}$ cm = 1.9 μm
- $L_p = 0.169 \times 10^{-3}$ cm = 1.69 μm

10. (1% each, 35% total) Complete the table below for a group of Si samples at room temperature.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>$p$ (cm$^3$)</th>
<th>$n$ (cm$^3$)</th>
<th>$E_F-E_i$ (eV)</th>
<th>$N_D-N_A$ (cm$^3$)</th>
<th>Type of Semiconductor</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>$N_V$</td>
<td>$n_i^2/N_V$</td>
<td>-0.56</td>
<td>$(n_i^2/N_V) - N_V$</td>
<td>Degenerated, $n$-type</td>
</tr>
<tr>
<td>b.</td>
<td>$n_i^2/N_C$</td>
<td>$N_C$</td>
<td>0.56</td>
<td>$(n_i^2/N_C) - N_C$</td>
<td>Degenerated, $n$-type</td>
</tr>
<tr>
<td>c.</td>
<td>$10^{10}$</td>
<td>$10^{10}$</td>
<td>0</td>
<td>$N_D = N_A$</td>
<td>Intrinsic</td>
</tr>
<tr>
<td>d.</td>
<td>$10^{10}$</td>
<td>$10^{10}$</td>
<td>0</td>
<td>0</td>
<td>Intrinsic</td>
</tr>
<tr>
<td>e.</td>
<td>5000</td>
<td>$2 \times 10^{16}$</td>
<td>0.375</td>
<td>$2 \times 10^{16}$</td>
<td>$n$-type</td>
</tr>
<tr>
<td>f.</td>
<td>$2.422 \times 10^{18}$</td>
<td>41.298</td>
<td>-0.5</td>
<td>-2.42 $\times 10^{18}$</td>
<td>$p$-type</td>
</tr>
<tr>
<td>g.</td>
<td>$2.456 \times 10^{19}$</td>
<td>4.072</td>
<td>-0.56</td>
<td>-2.456 $\times 10^{19}$</td>
<td>Degenerated, $p$-type</td>
</tr>
<tr>
<td>h.</td>
<td>89.392</td>
<td>$-1.119 \times 10^{18}$</td>
<td>$E_D = 0.08$ eV below $E_c$</td>
<td>$1.119 \times 10^{18}$</td>
<td>$n$-type</td>
</tr>
</tbody>
</table>

Note: Underlined values are the given values.

**WISH YOU BEST OF LUCK**