For the multiple choice questions, if you select the wrong answer, then you will get -2 marks. In addition to selecting the right answer, you should write one sentence justification to get +2 marks. Answers must be written in the space provided below the questions.

1. A Silicon sample doped with $10^{15}/\text{cm}^3$ Phosphorous atoms is kept at 0°K. The donor level $E_D$ for Phosphorous is 0.044 eV below the conduction band. Which of the following is/are true
   a) The Fermi level position will be at $E_i$ 
   b) The Fermi level position will be between $E_i$ and $E_D$
   c) The Fermi level position will be between $E_D$ and $E_C$ 
   d) None of the above.

   All donor energy levels are filled with electrons, and the conduction band is empty. Consistent with $f(E)$ at 0°K.

2. A Silicon sample doped with with $10^{15}/\text{cm}^3$ Phosphorous atoms and $10^{15}/\text{cm}^3$ Boron atoms is kept at 0°K. The donor level $E_D$ for Phosphorous is 0.044 eV below the conduction band, and the acceptor level $E_A$ for Boron is 0.045 eV above valence band. Which of the following is/are true
   a) The Fermi level position will be at $E_i$ 
   b) The Fermi level position will be between $E_i$ and $E_D$
   c) The Fermi level position will be between $E_D$ and $E_C$ 
   d) The Fermi level position will be between $E_A$ and $E_i$ 
   e) The Fermi level position will be between $E_A$ and $E_C$ 
   f) None of the above.

   Electrons from donors can fill the acceptor energy level, with $E_F = E_i$, consistent with $f(E)$ at 0°K.

3. For silicon doped with $10^{15}/\text{cm}^3$ Phosphorous atoms, if we heat the sample from room temperature to 1000°K, which of the following is/are true.
   a) The resistivity increases monotonically 
   b) The resistivity decreases monotonically 
   c) First the resistivity increases for certain temperature and then it decreases.
   d) First the resistivity decreases for certain temperature and then it increases.
   e) None of the above.

   Initially $n_i < N_d$, resistivity increases due to mobility degradation, but when $n_i > N_d$ at high temperature, exponential increase in $n_i$ decreases the resistivity.

4. When an electric field of 1V/cm is applied across an n-type phosphorus doped silicon slab at room temperature, a current density of 50mA/cm² is measured. What is the resistivity of silicon? If the electron mobility is 1500cm²/V·sec, then what is the phosphorus doping density?

   $J = \sigma E \Rightarrow \sigma = \frac{1}{6} \Rightarrow \frac{E}{J} = \frac{1}{5 \times 10^{-3}} = 200 \text{ cm}$

   $\sigma = \frac{n e \mu_n}{2}$, $n = N_d^+ + N_d^-$

   $N_d = \frac{1}{n e \mu_n} = \frac{1}{20 \times 1.6 \times 10^{-3} \times 1500} = 2.09 \times 10^8 / \text{cm}^3$ 

   2 marks
5. A p-n junction has p-type doping of $10^{19}/\text{cm}^3$ and n-type doping of $10^{15}/\text{cm}^3$. What is the built-in potential? Sketch the band diagram under thermal equilibrium.

\[ V_{\text{bi}} = \frac{kT}{q} \ln \frac{10^{19}}{1.4 \times 10^{10}} + \frac{kT}{q} \ln \frac{10^{15}}{1.4 \times 10^{10}} \]

\[ = 0.06 \times 8 + 0.06 \times 5 = 0.48 + 0.3 = 0.78 \text{V} \]

Most of the potential drop is across the lightly doped n region.

Depletion width essentially extends into lightly-doped n region.

6. In one of the technology scaling experiment, the generalized scaling theory was followed. The technology was scaled down from node A to node B, such that the dimensional scaling factor $k = 1.43$ and the voltage scaling factor $\alpha = 1.2$. If the technology A has a circuit delay of 10pS. What would be the delay for technology B? If the technology A has a power dissipation of 10mW. What would be the power for technology B?

\[ \text{Delay scaling} \rightarrow CV \rightarrow \frac{10}{k} \cdot \frac{\alpha}{k} = \frac{1}{\alpha k} \]

\[ \therefore \text{Node B delay} = \frac{10}{1.2 \times 1.43} = 5.83 \text{ pS} \]

\[ \text{Power scaling} \rightarrow VI \rightarrow \frac{\alpha}{K} \cdot \frac{\alpha^2}{K} = \frac{\alpha^3}{K^2} \]

\[ \therefore \text{Node B power} = \frac{10 \times (1.2)^3}{(1.43)^2} = 8.45 \text{ mW} \]