ECE615 - Semiconductor Devices I
Winter 2021
Homework 2
Due at the 8:30 am Thursday January 28th

Question 1 [9 marks]:

a) If we apply a forward bias of 1.5V across an ideal pn-junction diode, what is the magnitude of Fermi Level Splitting? Give your answer in Joules.[1 mark]

b) Using a diagram or otherwise, explain what we mean by a quasi-neutral region in a pn junction?[2 mark]

c) In lectures we have described carrier density using notation such as \( n_p \). Describe what each of the following symbols mean: (1) full-sized \( n \), (2) subscript \( p \), (3) subscript 0.[1 mark]

d) Consider an ideal silicon pn-junction diode (one which can be described by the Schokley Equation / Ideal-Diode Equation). The mobility of electrons and holes as a function of temperature are given by Equations (1) and (2), and a relationship between intrinsic carrier concentration and temperature is given by Equation (3). For such a diode, derive an equation and plot a graph of reverse saturation current density vs temperature between \( T = 300K \) and \( T = 1000K \). For the purposes of this question you can assume that carrier lifetime, band gap, effective density of valence and conduction band states, and doping concentration are not temperature-dependent. [5 marks]

\[
\mu_n(T) = \mu_n T^{-2.4} \tag{1}
\]

\[
\mu_p(T) = \mu_p T^{-2.2} \tag{2}
\]

\[
n_i(T) = \sqrt{N_C N_V} \exp\left(\frac{-E_g}{2k_B T}\right) \tag{3}
\]

Where:

- \( \mu_n \) is the electron mobility.
- \( \mu_{n0} \) is the electron mobility prefactor.
- \( \mu_p \) is the hole mobility.
- \( \mu_{p0} \) is the hole mobility prefactor.
- \( T \) is temperature.
- \( n_i \) is the intrinsic carrier concentration.
- \( N_C \) is the effective density of conduction band states.
- \( N_V \) is the effective density of valence band states.
- \( E_g \) is the band gap of the semiconductor.
- \( k_B \) is the Boltzmann Constant.

You will need:

- Boltzmann Constant: \( k_B = 1.38 \times 10^{-23} \) J/K.
- Fundamental unit of charge \( e = 1.60 \times 10^{-19} \) C.
- Band gap in silicon: \( E_g = 1.1 \) eV.
- Mobility prefactor of electrons in this silicon: \( \mu_{n0} = 7 \times 10^8 \) cm^2/Vs.
- Mobility prefactor of holes in this silicon: \( \mu_{p0} = 4 \times 10^7 \) cm^2/Vs.
• Lifetime of electrons in this silicon: \( \tau_n = 1 \mu s \).
• Lifetime of holes in this silicon: \( \tau_p = 1 \mu s \).
• Effective density of conduction band states: \( N_C = 2.8 \times 10^{19} \text{ cm}^{-3} \).
• Effective density of valence band states: \( N_V = 1.8 \times 10^{19} \text{ cm}^{-3} \).
• Donor atom density: \( N_D = 1.0 \times 10^{17} \text{ cm}^{-3} \).
• Acceptor atom density: \( N_A = 1.0 \times 10^{18} \text{ cm}^{-3} \).

Question 2 [5 marks]:

a) What do we mean by high level injection?[1 marks]

b) Figure 1 below shows a non-ideal pn-junction diode measured as a function of voltage. This diode exhibits the same ideality factor for all voltages. This data is available to download here. If this data was measured at 293K determine the ideality factor for this diode.[4 marks]

\[ U(E_t) = \frac{\sigma_n \sigma_p v_{th} N_i (pn - n_i^2)}{\sigma_n [n + n_i \exp \left( \frac{E_t - E_i}{k_B T} \right)] + \sigma_p [p + n_i \exp \left( \frac{E_i - E_t}{k_B T} \right)]} \]  

(4)

Where:
• \( \sigma_n \) is the electron capture cross section.
• \( \sigma_p \) is the hole capture cross section.
• $v_{th}$ is the carrier thermal velocity.
• $N_t$ is the trap site density.
• $p$ is hole density.
• $n$ is electron density.
• $n_i$ is the intrinsic carrier concentration.
• $E_t$ is the trap energy.
• $E_i$ is the Fermi Energy for the intrinsic (undoped) semiconductor.
• $k_B$ is the Boltzmann Constant.
• $T$ is Temperature.

**Question 3 [8 marks]:**

a) Explain briefly the process by which thermal instability causes breakdown. [2 marks]
b) Explain briefly how tunneling can cause breakdown and what is required of our pn junction for this to occur. [2 marks]
c) Explain briefly what is meant by avalanche breakdown. [2 marks]
d) Figure 2 shows a simple circuit designed to drive a diode in reverse bias. If the diode has a breakdown voltage of $V_{BD} = 30V$, a maximum power rating of $P_{max} = 150$ mW and we apply $V = 45V$ across the circuit, what value of limiting resistor do we need to ensure that we do not damage the diode. [2 marks]

![Figure 2 Circuit diagram of limiting resistor (R) in series with pn-junction diode held in reverse bias.](image)