TFE 4152 Design of Integrated Circuits

Exercise 1

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Problem 1

A pn-junction has a donor concentration of $N_D = 10^{25}\frac{electrons}{m^3}$ and an acceptor concentration of $N_A = 5 \cdot 10^{22}\frac{holes}{m^3}$ at a temperature of $289K$. Assume that $n_i = 1.1 \cdot 10^{16}\frac{carriers}{m^3}$ at room temperature. What is the built-in junction potential Φ_0?

The built-in voltage of an open-circuit pn junction is:

$$\Phi_0 = V_T \ln\left(\frac{N_A N_D}{N_i^2}\right) \tag{1}$$

$$V_T = \frac{kT}{q} \tag{2}$$

Where T is the temperature in degrees Kelvin ($\cong 300^o K$) at room temperature, k is the Boltzmann's constant $1.38 \cdot 10^{-23} JK^{-1}$, and q is hte charge of an electron ($1.602 \cdot 10^{-19}C$). At room temperature, $V_T \approx 26mV$

In this problem $N_A = 5 \cdot 10^{22}\frac{holes}{m^3}$, $N_D = 10^{25}\frac{electrons}{m^3}$, $n_i = 1.1 \cdot 10^{16}\frac{carriers}{m^3}$ and $T = 289K$. By using equation 1 and 2 we get:

$$V_T = \frac{1.38 \cdot 10^{-23} JK^{-1} \cdot 289K}{1.602 \cdot 10^{-19}C} = 0.025V \tag{3}$$

and

$$\Phi_0 = 0.025V \ln\left(\frac{5 \cdot 10^{22}\frac{holes}{m^3} \cdot 10^{25}\frac{electrons}{m^3}}{(1.1 \cdot 10^{16}\frac{carriers}{m^3})^2}\right) = 0.899V \tag{4}$$

The built-in junction potential $\Phi_0 = 899mV$

Problem 2

A piece of Silicon is doped with arsenic at a concentration of $4 \cdot 10^2 5 \frac{atoms}{m^3}$

a) Is the material n-type or p-type?

This material is called n-type dopants since the free carriers resulting from their use have negative vharge.

b) The temperature is $300K$ and the intrinsic carrier concentration n_i at this temperature is $1.1 \cdot 10^1 6 \frac{carriers}{m^3}$. Estimate the carrier concentrations.

Since we have an n-type impurity used, the total number of negative carriers or electrons is almost the same as the doping concentration, and is much greater than the number of free electrons in intrinsic silicon. In other words,

$$n_n = N_D$$

where n_n denotes the free-electron concentration in n-type material and N_D is the doping concentration. We can therefore estimate that the carrier concentration will be approximately $4 \cdot 10^{25} \frac{atoms}{m^3}$

c) Estimate the electron and hole concentrations in the same material at a temperature of $322K$.

The number of carriers approximately doubles for every 11^oC increase in temperature.

Therefore we will get that the electron and hole concentrationw in the same material at a temperature of $322K$ is equal total to

$$4 \cdot 10^{25} \frac{atoms}{m^3} \cdot 2^2 = 1.6 \cdot 10^{25} \frac{atoms}{m^3}$$

d) How does a change in temperature change the conductivity σ of:

1. Intrinsic silicon?

An increased tempeature will increase the conductivity, while a decreased temperature will have the opposite result.

2. Extrinsic (heavily doped) silicon?

   With the extrinsic silicon the the carrier concentration will increace linear at low temperatures, and then increase exponentialy at high temperatures as the ammount of holes/electrons is given by:

$$p_n = \frac{n_i^2}{N_D}$$
$$n_p = \frac{n_i^2}{N_A}$$

   The higher the carrier concentration, the higher the conductivity will be.

Problem 3

The pn-junction in Figure 1 was fabricated using a $100\mu m$ x $100\mu m$ mask. The pnjunction is backward biased with a 5 V voltage source, as is shown in the Figure 1. Due to thermal generation, $3.2 \cdot 10^7$ new electron-hole pairs are generated each second in the depletion region of the diode.

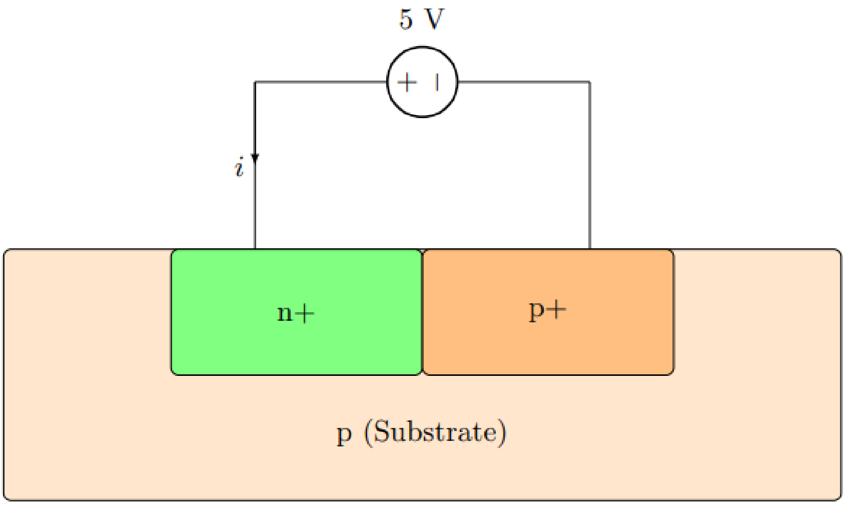

Figure 1: A pn-junction in a p-type substrate is reverse biased with a 5 V voltage source.

a) How much reverse leakage current will flow in the diode? (HINT: The charge of an electron is $q = 1.6 \cdot 10^{-19} C$)

We wan use the formula

$$I = q \cdot n \cdot A$$

Where I is the current, q is the charge of electron, n is the number of electropn-hole pairs generated per second and A is the cross-sectional area of the diode. Given that $3.2 \cdot 10^7$ new electron-hole pairs are generated each second in the depletion region of the diode, this equals to

$$I = 1.6 \cdot 10^{-19} C \cdot 3.2 \cdot 10^7 s^{-1} \cdot 100\mu m \cdot 100\mu m = 5.12 \cdot 10^{-20} A$$

b) Does this current depend on the reverse bias voltage? Why?

This current does not depend on the reverse bias voltage as the current is determined by the the thermal generation, which is primarily affected by the temperature.

c) Does this current increase or decrease if the temperature increases? Why?

As answered in problem 3b) the current is affected by the increase or decrease of the temperature, this is because the number of carriers approximately doubles for every $11^{o}C$ increase in temperature. This means that a increased temperature will result in an increased thermal generation.

d) Next to this diode, another similar diode was fabricated using a $200\mu m$ x $200\mu m$ mask. How much is the reverse leakage current in this diode, if the temperature and the bias voltage are the same as with the $200\mu m$ x $200\mu m$ diode?

Using the same equation as in problem 3a) we get

$$I = 1.6 \cdot 10^{-19}C \cdot 3.2 \cdot 10^{7}s^{-1} \cdot 200\mu m \cdot 200\mu m = 2.048 \cdot 10^{-19}A$$

Problem 4

This problem will simulate a diode using AIM-spice. All simulations should be performed at room temperature (27^o).

a) Describe the circuit of Figure 1 in AIM-Spice using the diode model 'DBSBdiode.mod' found on blackboard. The model files found on blackboard models a $100\mu m$ x $100\mu m$ diode

Appendix