EEE105 Tutorial Questions & Review Topics – W6

Fundamental Constants

Avagadro's number = $6x10^{23}$
Charge on Electron, $q = 1.602x10^{-19}$ C

Data for germanium
Hole mobility, μ_h=0.19
Electron mobilityμ_e=0.39 $m^2V^{-1}s^{-1}$
Intrinsic carrier density n_i=$2.5x10^{19}$ m^{-3}

Data for silicon
Hole mobility μ_h=0.046 $m^2V^{-1}s^{-1}$.
Electron mobility μ_e=0.12 $m^2V^{-1}s^{-1}$
Intrinsic carrier density n_i ~$1.5x10^{16}$ m^{-3}
Density =$2.3x10^3$ kgm^{-3}
Atomic weight=28.1 g/mol

1. A rod of heavily p-doped germanium is 6 mm long, l mm wide and 0.5 mm thick. It has an electrical resistance of 120 ohms along its length.

a) Assuming that all the conductivity is due to holes, determine the impurity concentration.
b) Using this value as the hole density, determine the ratio of the conductivity due to electrons and the conductivity due to holes. What magnitude of errors do we introduced by considering just the majority carrier in this case?

2. A chip of Si is 1 mm x 2 mm in area and 0.1 mm thick. The material has one in every 10^8 atoms replaced by an atom of B

(a) Is the doped material n-type or p-type. Why?
(b) What is the density of majority and minority carriers?
(c) Can one carrier be neglected?
(d) What voltage is required for a current of 2mA between the large faces?

3. A chip of Si is 1 mm x 2 mm in area and 0.1 mm thick. The material has one in every 10^{12} atoms replaced by an atom of B (i.e. the same as Q2 but now *much* lower doping)

(a) What is the density of majority and minority carriers?
(b) Can one carrier be neglected?

Solutions

1. This material is heavily p-doped so we can assume that the conductivity due to electrons is much less than that due to holes. So to start with we neglect the electrons completely. Let us then estimate the hole concentration:

$$\rho = \frac{RA}{l} = 120x0.5x10^{-6}/6x10^{-3} = 0.01\Omega\text{m}$$
$$p = \frac{1}{\rho q \mu} = \frac{1}{0.01x1.6x10^{-19}x0.19} = 3.3x10^{21}\,\text{m}^{-3}$$

In the next part of the question we will prove the assumption that in very heavily doped material we can normally neglect the conduction due to minority carriers. To calculate the relative values, let's calculate the electron concentration

$$n = \frac{n_i^2}{p} = 1.9x10^{17}\,m^{-3}$$

Then to get the relative magnitudes of the conductivities

$$\frac{\sigma_p}{\sigma_n} = \frac{qp\mu_h}{qn\mu_e} = \frac{3.3x10^{21}x0.19}{1.9x10^{17}x0.39} = 8.4x10^3$$

Thus neglecting the electron conduction in this case gives an error of one part in 8400. In practice this is not important.

2.

(a) B is an acceptor in Si as it has 3 outer electrons compared to 4 for silicon, so the Si is doped **p-type**

(b) Similarly to Q1, Sheet 1 for silicon

$$\text{Density} = \frac{(\text{Number Density})(\text{Atomic Weight})}{(\text{Avagadro's Number})}$$

$$\text{Number Density} = \text{Density x}\,\frac{\text{Avagadro's Number}}{\text{Atomic Weight}} = \frac{2.3x10^3\,x6x10^{23}}{0.0281} = 4.9x10^{28}\,Atoms/m^3$$

As we have one Si atom in every 10^8 replaced with dopant, and at room temperature each one is assumed to give us a free hole, **p = 4.9x10^{20} m^{-3}.**

n then follows using

$$n = \frac{n_i^2}{p} = \frac{\left(1.5x10^{16}\right)^2}{4.9x10^{20}} = 4.6x10^{11} m^{-3}$$

(c) p>>n and hence n can be neglected -- the answer is **yes**

(d) To calculate the voltage we need to calculate the resistance. Since the geometry is given, then provided the resistivity can be calculated, the rest should follow:

$$\rho = \frac{1}{pq\mu} = \frac{1}{4.9x10^{20}x1.6x10^{-19}x0.046} = 0.28\Omega\text{m}$$

$$R = \rho\frac{l}{A} = 0.28\frac{0.1x10^{-3}}{1x10^{-3}x2x10^{-3}} = 14.0\Omega$$

$$V = IR = 2x10^{-3}x14.0 = 0.028\text{V}$$

3.

(a) Si number density is **4.9x10^{28} m^{-3}.**

For doping one part in 10^{12} of the Si with B, the hole density p = **4.9x10^{16} m^{-3}.**

n then follows using

$$n = \frac{n_i^2}{p} = \frac{\left(1.5x10^{16}\right)^2}{4.9x10^{16}} = 4.6x10^{15} m^{-3}$$

(b) Hole density (p) is one order of magnitude higher than electron density (n). However if we think about conductivity being made up of the two components

$$\sigma_{Total} = \sigma_p + \sigma_e = qp\mu_h + qn\mu_e$$

Ratio of conductivities due to holes and electrons is important again

$$\frac{\sigma_p}{\sigma_n} = \frac{qp\mu_h}{qn\mu_e} = \frac{4.9x10^{16}x0.046}{4.6x10^{15}x0.12} = 4.1$$

Considering only one carrier in this case gives significant errors.