University of Sheffield

Department of Electronic and Electrical Engineering

EEE207 Semiconductors for Electronics and Devices

Problem Sheet 1

1. A bar of intrinsic germanium at 300 K has 2.5×10^{19} electrons per cubic metre in the conduction band. Find the net current density when an electric field of 500V m^{-1} is applied to the bar. Assume $\mu_h = 0.19 m^2 V^{-1} s^{-1}$ and $\mu_e = 0.39 m^2 V^{-1} s^{-1}$.

2. The resistivity of intrinsic silicon at 27°C is 3000Ω m. Assuming $\mu_e = 0.17 m^2 V^{-1} s^{-1}$ and $\mu_h = 0.035 m^2 V^{-1} s^{-1}$, calculate the intrinsic carrier density n_i at this temperature.

3. A current density of $10^3 A\ m^{-2}$ flows through an n-type germanium crystal of resistivity 0.05Ω m. Calculate the time taken for electrons to travel 5×10^{-5}m, if the mobility is $\mu_e = 0.39 m^2 V^{-1} s^{-1}$.

4. Compare the drift velocity of an electron moving in a field of 10000V m^{-1} in pure germanium, with the final velocity of an electron that has moved through a distance 10mm in the same field in a vacuum. The free electron mass is 9.11×10^{-31}kg, and the mobility $\mu_e = 0.39 m^2 V^{-1} s^{-1}$ in germanium.

5. A rod of p-type germanium 6mm long, 1mm wide and 0.5mm thick has an electrical resistance of 120Ω. What is the impurity concentration? What proportion of the conductivity is due to electrons in the conduction band? (Take $\mu_h = 0.19 m^2 V^{-1} s^{-1}$, $\mu_e = 0.39 m^2 V^{-1} s^{-1}$, and $n_i = 2.5 \times 10^{19} m^{-3}$.)

6. Given that the mobilities of charge carriers in germanium vary with temperature over a certain range according to $\mu_e \propto T^{-1.6}$ and $\mu_h \propto T^{-2.3}$, the mobilities at 290K are $\mu_e = 0.38 m^2 V^{-1} s^{-1}$ and $\mu_h = 0.18 m^2 V^{-1} s^{-1}$, the energy gap is $E_g = 0.67$eV, and that over this temperature range the intrinsic carrier density is given by

$$n_i = 5 \times 10^{21}\ (T/K)^{3/2} \exp(-E_g/2kT)\ m^{-3}$$

(where (T/K) signifies absolute temperature measured in kelvin), show that the electrical conductivity of pure germanium as a function of temperature is of the form

$$\sigma = \left[C_1\left(\frac{290}{T}\right)^{0.1} + C_2\left(\frac{290}{T}\right)^{0.8}\right]\exp\left(\frac{-C_3}{T}\right).$$

Hence, estimate the conductivity of germanium at its melting point (958°C).

7. Show that a semiconductor has minimum conductivity at a given temperature when

$$n = n_i\sqrt{\frac{\mu_h}{\mu_e}} \quad \text{and} \quad p = n_i\sqrt{\frac{\mu_e}{\mu_h}}.$$

Find the numerical values of the intrinsic and minimum conductivities for germanium at a temperature such that $n_i = 2.5 \times 10^{19}\text{m}^{-3}$, $\mu_e = 0.38\text{m}^2\ \text{V}^{-1}\ \text{s}^{-1}$ and $\mu_h = 0.19\text{m}^2\ \text{V}^{-1}\ \text{s}^{-1}$.

For what value of n or p (other than $n = p = n_i$) does the crystal have a conductivity equal to the intrinsic conductivity?

8. Calculate the fraction of electrons in the conduction band at room temperature for (*a*) pure Germanium ($E_g = 0.72\text{eV}$), (*b*) pure Silicon ($E_g = 1.10\text{eV}$) and (*c*) pure diamond ($E_g = 5.6\text{eV}$), and comment on the results.

9. Pure silicon has resistivity 2000Ω m at room temperature, and the density of conduction electrons is $1.4 \times 10^{16}\text{m}^{-3}$. Calculate the resistivities of two other, doped, samples containing acceptor concentrations of 10^{21}m^{-3} and 10^{23}m^{-3} respectively. Assume that the hole mobility remains the same as in pure silicon and that it is equal to 0.26 times the electron mobility.

10. The variation of the resistivity of intrinsic germanium with temperature is found to be as follows:

T/K:	384	458	556	714
ρ/(Ω m):	0.028	0.0061	0.0013	0.00027

Assuming that for an intrinsic semiconductor the density of carriers is approximately proportional to $\exp(-E_g/2kT)$ where E_g is the band gap energy and T is absolute temperature, determine the value of E_g in eV. It may be assumed, as a rough approximation, that the hole and electron mobilities vary as $T^{-3/2}$ and that E_g does not vary with temperature.

Numerical Answers

1. 1.16kA m^{-2}
2. $1.02 \times 10^{16}\text{m}^{-3}$
3. 2.5μs
4. $3.9 \times 10^3\text{m s}^{-1}$ in Ge; $5.93 \times 10^6\text{m s}^{-1}$ in vacuum. Note the effect of the crystal lattice in Ge.
5. $3.29 \times 10^{21}\text{m}^{-3}$; 1 in 8.4×10^3
6. $6.5 \times 10^4\text{S m}^{-1}$
7. 2.28S m^{-1}, 2.15S m^{-1}, $1.25 \times 10^{19}\text{m}^{-3}$, $5 \times 10^{19}\text{m}^{-3}$
8. 10^{-6}, $10^{-9.3}$, 10^{-47}
9. 0.135Ω m and 0.00135Ω m
10. 0.8eV