NATIONAL UNIVERSITY OF SINGAPORE
Department of Electrical and Computer Engineering

EE2021 : Tutorial 1

1. There are two samples of silicon, A and B. Each of them is uniformly doped with both donor and acceptor impurities. Assume that the silicon samples are at thermal equilibrium at 300 K, that all the dopants are ionized, and that the intrinsic carrier concentration, $n_i = 1.5 \times 10^{10}$ cm^{-3}. Complete the table below by filling in the missing values of N_D, N_A and n_0.

   Is Sample A n-type, p-type or intrinsic? Is Sample B n-type, p-type or intrinsic?

   Hints: Apply the Law of Mass Action and consider compensation doping.

Silicon Sample	Donor conc. N_D (cm^{-3})	Acceptor conc. N_A (cm^{-3})	Equilibrium electron conc. n_0 (cm^{-3})	Equilibrium hole conc. p_0 (cm^{-3})
Sample A	1×10^{17}			4.5×10^{4}
Sample B		8×10^{15}		1.5×10^{10}

[Ans. Sample A : $N_A = 9.5 \times 10^{16}$ cm^{-3}, $n_0 = 5 \times 10^{15}$ cm^{-3}, n-type ; Sample B : $N_D = 8 \times 10^{15}$ cm^{-3}, $n_0 = 1.5 \times 10^{10}$ cm^{-3}, intrinsic]

2. A silicon bar is in the shape of a circular cylinder with a cross-sectional area of 10^{-4} cm^2, and a length of 0.1 cm. The silicon bar is uniformly doped with phosphorus (Group V element) at a concentration of 2×10^{16} cm^{-3}. At this doping concentration, the electron mobility is 1100 cm^2 V^{-1} s^{-1} and the hole mobility is 400 cm^2 V^{-1} s^{-1}. The silicon bar is at thermal equilibrium at T = 300 K. The intrinsic carrier concentration of silicon at this temperature, $n_i = 1.5 \times 10^{10}$ cm^{-3}.

   (a) Calculate the electron and hole concentrations in the silicon bar. Calculate also the conductivity and resistance of the silicon bar between the two ends.

   [Ans. 2×10^{16} cm^{-3}, 1.125×10^{4} cm^{-3}, 3.52 (Ω cm)$^{-1}$, 284 Ω]

   (b) Boron (Group III element) is subsequently added uniformly to the silicon bar, at a concentration of 6×10^{16} cm^{-3}. The electron and hole mobilities are now 700 cm^2 V^{-1} s^{-1} and 350 cm^2 V^{-1} s^{-1} respectively. Calculate the electron and hole concentrations in the silicon bar. Calculate also the conductivity and resistance of the silicon bar. Note that the mobilities of the electrons and holes are both reduced compared to the original mobilities.

   [Ans. 5.625×10^{3} cm^{-3}, 4×10^{16} cm^{-3}, 2.24 (Ω cm)$^{-1}$, 446 Ω]

   (c) Comment on the difference in the conductivities of the silicon bar in parts (a) and (b).

3. The concept of drift is applicable to metals (e.g., aluminium) as well as semiconductors.

The concentration of (conduction) electrons in an aluminium wire is 2×10^{23} cm^{-3}. The electrical resistivity of aluminium at 300 K is 2.5 μΩ cm.

(a) Calculate the mobility of the (conduction) electrons in the aluminium wire.

[Ans. 12.5 cm^2 V^{-1} s^{-1}]

(b) An aluminium wire is 100 cm long and has a cross-sectional area of 10^{-4} cm^2. A voltage of 1 V is applied across its two ends. Calculate the drift velocity of the electrons in the wire. Hence find the time it takes for an electron to drift from one end of the wire to the other end.

[Ans. 0.125 cm s^{-1}, 800 s]

(c) Compare the conductivity of aluminium with that of the silicon bar in Q2(a) in terms of their carrier concentrations and mobilities.

4. Figure Q.4 below shows the structure of a silicon n-p-n bipolar transistor with the regions and <u>majority</u> carrier concentrations as indicated. Starting with a silicon wafer (substrate) doped with donors at a concentration $N_D = 10^{15}$ cm^{-3}, the different regions (collector, base, emitter) are made by successively introducing dopants into selected regions by ion-implantation through the top surface. Assume, for simplicity, that uniform doping concentrations can be achieved in each of the regions.

In the figure, n and p are the electron and hole concentrations respectively, the subscript 0 indicates thermal equilibrium condition, and the subscripts E, B and C refer to the emitter, base and collector of the bipolar transistor, respectively.

Determine the doping sequence, and the type and concentration of the dopant to be added in each of the sequential steps.

What is the total concentration of dopants (i.e., $N_D + N_A$) in the emitter? Would the property of the emitter region be the same or different from a piece of silicon doped only with donors of concentration, $N_D = 10^{18}$ cm^{-3}?

[Ans. 1.42 x 10^{18} cm^{-3}]

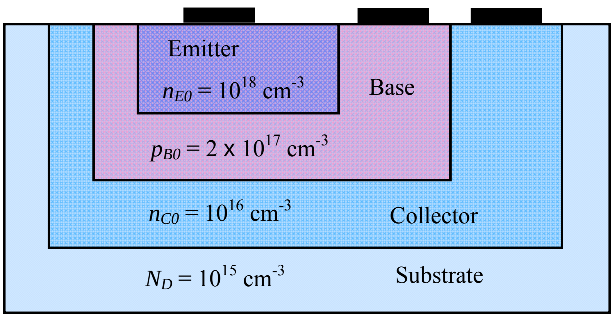

Fig. Q.4