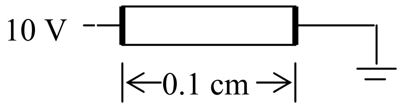
ECSE-2210 Microelectronics Technology
Class Activity 6 – Solution

1. Short Answer Questions.

   (a) What is the electric field inside the Si bar shown below? What is its direction?



The electric field is given by $\mathcal{E} = -\,\mathrm{d}V/\mathrm{d}x$; for uniform electric filed case this equation simplifies to $\mathcal{E} = -\,V/l$; the negative sign indicates that the direction of the electric field is opposite to the positive voltage direction (i.e. $\mathcal{E}$ field direction is from +V to –V)

The electric field is $\mathcal{E} = 10$ V/0.1 cm = 100 V/cm and points from left to right.

(b) How long does it take on average for an electron to drift 1 μm in pure Si with an applied electric field of 100 V/cm?

Drift velocity is the average velocity of electron when subjected to some electric field. We have $v_\mathrm{d} = \mu_\mathrm{n}\,\mathcal{E}$ for electrons. For pure or intrinsic Si, from graph in text by extending N_D or N_A to zero, we get $\mu_\mathrm{n} = 1350\ \mathrm{cm^2/(Vs)}$.

$v_\mathrm{d} = 1350 \times 100\ [\mathrm{cm^2/(Vs)} \times \mathrm{V/cm}] = 135\,000\ \mathrm{cm/s}$

$1\ \mu\mathrm{m} = 10^{-4}\ \mathrm{cm}$

So, the time it takes on average is $t = 10^{-4}/135\,000\ \mathrm{s} = 74\ \mathrm{ns}$

(c) Repeat (b) for 10^5 V/cm. Explain why you cannot use the relationship $v_\mathrm{d} = \mu\,\mathcal{E}$ here.

See graph in text. The drift velocity does not increase linearly with the $\mathcal{E}$ field for very high $\mathcal{E}$ field. In this case, the drift velocity is not proportional to the electric field we cannot use the relationship $v_\mathrm{d} = \mu\,\mathcal{E}$

The drift velocity can be read from the curve in figure 3.4. $v_\mathrm{d} \approx 10^7$ cm/s

The time is $t = 10^{-4}/10^7\ \mathrm{s} = 10\ \mathrm{ps}$

(d) An average hole drift velocity of 10^3 cm/s results when 2 V are applied across a 1-cm long semiconductor bar. What is the hole mobility inside the bar?

When 2V is applied across cm length of Si, the E field inside is $\mathcal{E} = -\,V/l = -\,2$ V / 1 cm $\mathcal{E} = -\,2$ V/cm (Sign just indicates the direction)

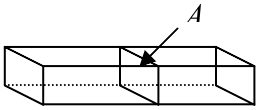
$v_\mathrm{d} = \mu\,\mathcal{E}$: 1000 cm/s = μ 2 V/cm; therefore $\mu = 500\ \mathrm{cm^2/Vs}$

(e) For a given semiconductor the carrier mobilities in the intrinsic material are (choose one: higher than, lower than, the same as) those in heavily doped material. Explain why?
There are two scattering mechanisms that reduce the mobility of carriers. They are the collision with impurity atoms and lattice scattering. In intrinsic material the ionized impurity scattering is negligible (as there are no impurity atoms).
Therefore, the mobility is higher.

(f) Name two dominant carrier scattering mechanisms in don-degenerately doped semiconductor of device quality.

1. Lattice scattering involving collisions with thermally agitated lattice atoms
2. Ionized impurities scattering (i.e. donor site and/or acceptor site)

(f) In the diagram below, 100 million electrons cross the marked area *A* from left to right every 1 microsecond. What is the value of the current in A, and its direction?



The current is the charge crossing the area *A* per unit time. If 100 electrons are crossing then the total charge is given by 100 million × q
Current = $(100 \times 10^{6} \times 1.6 \times 10^{-19}\ \text{C})/10^{-6}\ \text{s} = 16\ \mu\text{A}$.
The current direction is from right to left.

2. Show that the units of $1/(q\mu n)$ are Ω cm.

$1/[\text{C} \times \text{cm}^2/(\text{Vs} \times \text{cm}^{-3})] = 1/[\text{A}/(\text{V} \times \text{cm}^{-1})] = \Omega\ \text{cm}$

3. A lightly doped ($< 10^{14}\text{cm}^{-3}$) Si sample is heated up from room temperature to 100 °C. $N_D >> n_i$ at both room temperature and at 100 °C. Is the resistivity of the sample expected to increase or decrease? Explain.

See figure 3.7
Since $N_D >> n_i$, both at room temperature and at 100 °C, $n \approx N_D$; and $p = n_i^2/n$ (too small compared to n)

$$\rho = 1/(q\,\mu_n n)$$

Here, n does not change between room temperature and 100 °C. The mobility μ_n will decrease as temperature increases and so ρ will increase.

4. Determine the resistivity of Si doped with 2×10^{16} cm^{-3} of phosphorous and 1×10^{16} cm^{-3} of boron.

Phosphorous is a donor: $N_D = 2 \times 10^{16}\ \text{cm}^{-3}$
Boron is an acceptor: $N_A = 1 \times 10^{16}\ \text{cm}^{-3}$
So, $n = N_D - N_A = 2 \times 10^{16} - 1 \times 10^{16} = 1 \times 10^{16}\ \text{cm}^{-3}$. Since, $N_D - N_A >> n_i$

$p = n_i^2/n = 10^4$ cm^{-3}
(Note that $n \neq N_D$ and $p \neq N_A$)
$\rho = 1/(q\,\mu_n n + q\,\mu_p p) \approx 1/(q\,\mu_n n)$
For $N_A + N_D = 3 \times 10^{16}$ cm^{-3}, read μ from graph 3.5
Then the resistivity value can be calculated.

5. Determine the resistivity of Si doped with $N_D = 2 \times 10^{18}$ cm^{-3} and $N_A = 10^{18}$ cm^{-3}.
   $n = N_D - N_A = 1 \times 10^{18}$ cm^{-3} Since, $N_D - N_A >> n_i$
   For $N_A + N_D = 3 \times 10^{18}$ cm^{-3}, read μ from graph 3.5: The electron mobility is about 150 cm^2/(Vs).
   The resistivity is given by $\rho = 1/[1.6 \times 10^{-19}$ C $\times 10^{18}$ cm$^{-3} \times 150$ cm^2/(Vs)]
   Since electron concentration is 10^{18} cm^{-3} and the hole concentration is negligible.