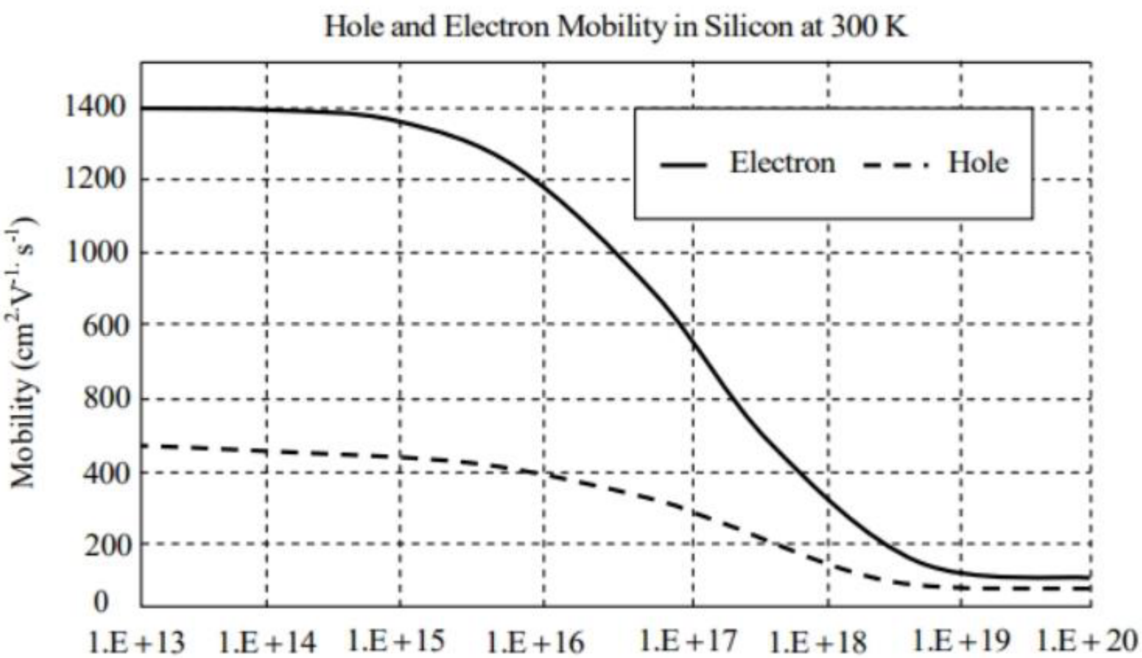
Problems on Carrier Transport

1) If an electric field of 30 V/cm is applied across the specimen, then the drift velocity of free electrons is ……………. (Given $\mu = 34.8 \times 10^{-4}$ m²/V-s)

2) A piece of silicon is doped uniformly with phosphorus with a doping concentration of 10^{16} / cm³. The expected value of mobility versus doping concentration for silicon assuming full dopant ionization is shown below. The charge of an electron is $1.6 * 10^{-19}$ C. The conductivity (in S cm^{-1}) of the silicon sample at 300 K is …………….



Doping Concentration (cm^{-3})

3) A silicon sample is uniformly doped with donor type impurities with a concentration of 10^{16} /cm³. The electron and hole mobilities in the sample are 1200 cm²/V.s and 400 cm²/V.s respectively. Assume complete ionization of impurities. The charge of an electron is 1.6×10^{-19} C. The resistivity of the sample (in Ω cm) is …………….

4) At T = 300 K, the hole mobility of a semiconductor μ_p=500 cm² /V.s and (kT/q)=26mV. The hole diffusion constant D_p in cm²/s is …………….

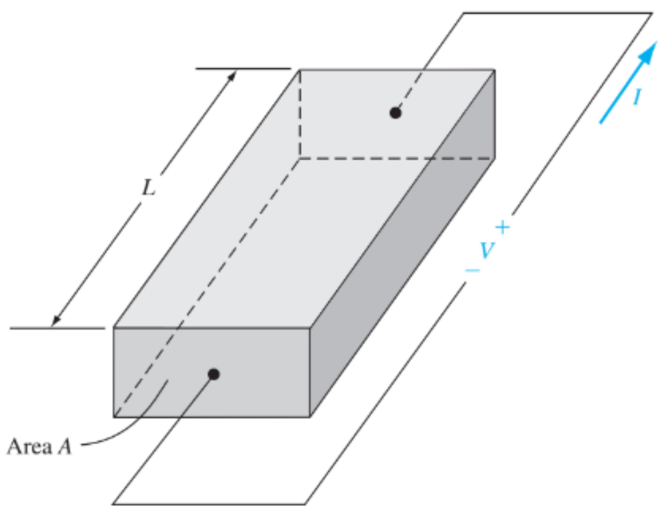
5) A small concentration of minority carriers is injected into a homogeneous semiconductor crystal at one point. An electric field of 10 V/cm is applied across the crystal and this moves the minority carriers a distance of 1 cm in 20 μ sec. The mobility (in cm²/volt-sec) will be …………….

6) The concentration of donor impurity atoms in silicon is $N_d = 10^{15}\ cm^{-3}$. Assume an electron mobility of $\mu_n = 1300\ cm^2/V\text{-}s$ and a hole mobility of $\mu_p = 450\ cm^2/V\text{-}s$. (a) Calculate the resistivity of the material. (b) What is the conductivity of the material?

7) The hole density in silicon is given by $p(x) = 10^{16}\ e^{-(x/Lp)}$, $(x \geq 0)$ where $L_p = 2 \times 10^{-4}$ cm. Assume the hole diffusion coefficient is $D_p = 8\ cm^2/s$. Determine the hole diffusion current density at (a) $x = 0$, (b) $x = 2 \times 10^{-4}$ cm, and (c) $x = 10^{-3}$ cm.

8) A silicon semiconductor resistor is in the shape of a rectangular bar with a cross-sectional area of $8.5 \times 10^{-4}\ cm^2$, a length of 0.075 cm, and is doped with a concentration of $2 \times 10^{16}\ cm^{-3}$ boron atoms. Let T = 300 K. A bias of 2 volts is applied across the length of the silicon device. Calculate the current in the resistor. (b) Repeat part (a) if the length is increased by a factor of three. (c) Determine the average drift velocity of holes in parts (a) and (b). (Consider $\mu_p = 400\ cm^2/V\text{-}s$)

9) A bar of p-type silicon, such as shown in Figure below, has a cross-sectional area, $A = 10^{-6}\ cm^2$ and a length $L = 1.2 \times 10^{-3}$ cm. For an applied voltage of 5 V, a current of 2 mA is required. What is the required (a) resistance, (b) resistivity, and (c) impurity doping concentration? (Consider $\mu_p = 410\ cm^2/V\text{-}s$)



10) Calculate the hall voltage when the magnetic field is 8 A/m, current is 4 A, width is 5m and the concentration of the carrier is $10^{20}/cm^3$.

CARRIER TRANSPORT TUTORIAL SOLUTIONS

Q1)

Concept:

The drift velocity of a free electron is given by

$\Rightarrow V = \mu . E$

- V denotes drift velocity
- μ is the mobility of free electrons
- E is the applied electric field

Calculation:

Given:- $E = 30 V/cm$, $\mu = 34.8 \times 10^{-4}\ m^2/v\text{-}s = 34.8\ cm^2/v\text{-}s$

$\Rightarrow V = (34.8 \times 30)\ cm/s$

$\Rightarrow V = 1044\ cm/s$

$\Rightarrow V = 10.44\ m/s$

Hence the drift velocity of a free electron is **10.44 m/s**

Therefore the correct answer is option 3

Q2)

$N_d = 10^{16}/cm^3$; Density of e^- $n \approxeq N_d$

$q = 1.6 \times 10^{-19} C$

$T = 300 k$

$\sigma = ?$

From the Graph,

when $N_d = 10^{16}/cm^3$, $\mu_e \approxeq 1200 cm^2/V.sec$

So,

$\sigma = q N_d \mu_e$

$\sigma = 1.6 \times 10^{-14} \times 10^{16} \times 1200\ S/cm$

$\sigma = 1920 \times 10^{-3}\ S/cm$

$\sigma = 1.92\ S/cm$

Q3)

$N_d = 10^{16}/cm^3$; Density of $\bar{e}$ $n \approx N_d$

$q = 1.6 \times 10^{-19} C$

$\sigma = q n \mu_n$

Resistivity, $\rho = \dfrac{1}{\text{conductivity}} = \dfrac{1}{\sigma}$

$$\rho = \frac{1}{q n \mu_n}$$

$$\rho = \frac{1}{1.6 \times 10^{-19} \times 10^{16} \times 1200}$$

$$\rho = 0.5208\ \Omega\text{-cm}$$

Q4)

According to Einstein's Relation,

$$\frac{D_p}{\mu_p} = \frac{KT}{q}$$

Given, $T = 300k$

and $\dfrac{KT}{q} = 26mV$

$\mu_p = 500\ cm^2/V\text{-sec}$

$$\frac{D_p}{500} = 26 \times 10^{-3}$$

$$D_p = 26 \times 10^{-3} \times 500$$

$$D_p = 13\ cm^2/sec$$

Q5)

Drift velocity of the carriers, $v = \mu E$

Given $E = 10\,V/cm$

$\mu = ?$

$v = 1cm/20\mu\,sec$

$$\mu = \frac{v}{E}$$

$$= \frac{1}{20\times10^{-6}\times 10}$$

$$\mu = 5000\ cm^2/V\text{-}sec$$

Q6)

5.1

(a) $$\rho = \frac{1}{e\mu_n N_d} = \frac{1}{(1.6\times10^{-19})(1300)(10^{15})}$$
$$= 4.808\ \Omega\text{-cm}$$

(b) $$\sigma = \frac{1}{\rho} = \frac{1}{4.8077} = 0.208\ (\Omega\text{-cm})^{-1}$$

Q7)

Ex 5.5

$$J_p = -eD_p \frac{dp}{dx}$$
$$= -eD_p \frac{d}{dx}\left[10^{16} e^{-x/L_p}\right]$$
$$= -eD_p \left(10^{16}\right)\left(\frac{-1}{L_p}\right)e^{-x/L_p}$$
$$= \frac{+eD_p\left(10^{16}\right)}{L_p} e^{-x/L_p}$$
$$= \frac{\left(1.6\times10^{-19}\right)(8)\left(10^{16}\right)}{2\times10^{-4}} e^{-x/L_p}$$
$$J_p = 64\exp\left(\frac{-x}{L_p}\right)$$

(a) For $x = 0$,

$$J_p = 64 \text{ A/cm}^2$$

(b) For $x = 2\times10^{-4}$ cm,

$$J_p = 64\exp\left(\frac{-2\times10^{-4}}{2\times10^{-4}}\right) = 23.54 \text{ A/cm}^2$$

(c) For $x = 10^{-3}$ cm,

$$J_p = 64\exp\left(\frac{-10^{-3}}{2\times10^{-4}}\right) = 0.431 \text{ A/cm}^2$$

Q8)

5.8

(a) $R = \dfrac{L}{\sigma A} = \dfrac{L}{\left(e\mu_p N_a\right)A}$

For $N_a = 2\times10^{16}$ cm^{-3}, then

$$\mu_p \cong 400 \text{ cm}^2\text{/V-s}$$

$$R = \frac{(0.075)}{\left(1.6\times10^{-19}\right)(400)\left(2\times10^{16}\right)\left(8.5\times10^{-4}\right)}$$
$$= 68.93\ \Omega$$

$$I = \frac{V}{R} = \frac{2}{68.93} = 0.0290 \text{ A}$$

or $I = 29.0$ mA

(b) $R \propto L \Rightarrow R = (68.93)(3) = 206.79\ \Omega$

$$I = \frac{V}{R} = \frac{2}{206.79} = 0.00967 \text{ A}$$

or $I = 9.67$ mA

(c) $J = ep_o \upsilon_d$

For (a), $J = \dfrac{29.0\times10^{-3}}{8.5\times10^{-4}} = 34.12 \text{ A/cm}^2$

Then $\upsilon_d = \dfrac{J}{ep_o} = \dfrac{34.12}{\left(1.6\times10^{-19}\right)\left(2\times10^{16}\right)}$

$$= 1.066\times10^4 \text{ cm/s}$$

For (b), $J = \dfrac{9.67\times10^{-3}}{8.5\times10^{-4}} = 11.38 \text{ A/cm}^2$

$$\upsilon_d = \frac{11.38}{\left(1.6\times10^{-19}\right)\left(2\times10^{16}\right)}$$
$$= 3.55\times10^3 \text{ cm/s}$$

Q9)

Ex 5.4

(a) $R = \frac{V}{I} = \frac{5}{2\times10^{-3}} = 2500\ \Omega$

(b) $\rho = \frac{RA}{L} = \frac{(2500)(10^{-6})}{1.2\times10^{-3}} = 2.083\ \Omega\text{-cm}$

(c) $\sigma = \frac{1}{\rho} = \frac{1}{2.083} = 0.480\ (\Omega\text{-cm})^{-1}$

$= e\mu_p N_a$

Then $\mu_p N_a = \frac{0.48}{1.6\times10^{-19}} = 3.00\times10^{18}$

Using Figure 5.3 and trial and error,

$N_a \cong 7.3\times10^{15}\ \text{cm}^{-3}$

(d) $\mu_p \cong 410\ \text{cm}^2/\text{V-s}$

Q10)

Calculation:

W = Thickness = 5 m, I = 4 A, B = 8 A/m, n = 100000

$\rho_c = ne$

$\rho_c = 10^{20} \times 1.6 \times 10^{-19}$

$\rho_c = 1.6 \times 10^{-4}$

$$V_{12} = V_H = \frac{8\times4}{10^{20}\times5\times1.6\times10^{-19}}$$

V_H = 0.4 V