1. A flat aluminum strip has a resistivity of $3.44\times10^{-8}\ \Omega$ m, a cross-sectional area of 2×10^{-4} mm^2, and a length of 5mm. what is the voltage drop across the strip for a current of 50 m A?

Sol:

$\rho = 3.44 * 10^{-8}\ \Omega.m$, $A = 2 * 10^{-4}\ mm^2$, $\ell = 5\ mm$, $I = 50\ mA$

$\Rightarrow R = \frac{\rho \ell}{A} = \frac{(3.44 * 10^{-8})(5 * 10^{-3})}{(2*10^{-4}) * 10^{-6}} = 0.86\ \Omega$

$\Rightarrow V = IR = (50 * 10^{-3})(0.86) = 0.043$ Volt

2. The resistance of no.18 copper wire (diameter= 1.03mm) is 6.5 ohms per 1000 ft. The concentration of free electrons in copper is 8.4×10^{28} electrons/m^3. If the current is 2A, find the followings:
(a) Drift velocity (b) Conductivity (c) Mobility (1 ft. = 0.3 m)

Sol:

$\Rightarrow d = 1.03\ mm$ $\Rightarrow r = 0.515 * 10^{-3} m$

$\Rightarrow R/\ell = 6.5\ \Omega / 1000 ft = 6.5 * 10^{-3}\ \Omega/ft = 6.5 * 10^{-3} * \frac{1}{0.3}\ \Omega/m$
$= 21.67 * 10^{-3}\ \Omega/m$

$\Rightarrow n = 8.4 * 10^{28}\ e^-/m^3$, $I = 2A$

a) $\Rightarrow I = J.A = nq\underbrace{\mu E}_{v_d}.A$
$= nq v_d A$

$\Rightarrow v_d = \frac{I}{nqA} = \frac{2}{8.4*10^{28} * 1.6 * 10^{-19} * \pi * (0.515 * 10^{-3})^2}$
$= 1.785 * 10^{-4}\ m/s$

b) $\because R = \frac{\ell}{\sigma A}$ $\Rightarrow \sigma = \frac{1}{R/\ell * A} = \frac{1}{(21.67*10^{-3})\ \pi (0.515 * 10^{-3})^2}$
$= 55.383 * 10^{6}\ S/m$

c) $\Rightarrow \sigma = nq\mu$ $\Rightarrow \mu = \frac{\sigma}{nq} = \frac{55.383 * 10^{6}}{8.4 * 10^{28} * 1.6 * 10^{-19}}$
$= 4.12 * 10^{-3}\ m^2/V.S.$
$= 41.2\ cm^2/V.S$

3. A specimen of silicon is 4cm long and has a square cross section 2x2mm. the current is due to electrons whose mobility is 1300 cm^2/v. Two volts impressed across the bar results in a current of 8mA.
   (a) Calculate the concentration n of free electrons.
   (b) The drift velocity.

Sol: $\ell = 4cm$, $A = 2*2\ mm^2$, $\mu_n = 1300\ cm^2/V.S.$

$V = 2\ Volt$, $I = 8mA$

a) $\because R = \frac{V}{I} \Rightarrow R = \frac{2}{8*10^{-3}} = 250\ \Omega$

$\because R = \frac{\ell}{\sigma A} \Rightarrow \sigma = \frac{\ell}{RA} = \frac{4*10^{-2}}{250*4*10^{\cancel{-6}}}$ $^{-4}$

$\because \sigma = nq\mu_n \qquad = 0.4*10^{2}\ S/m$

$\Rightarrow n = \frac{\sigma}{q\mu_n} = \frac{0.4}{1.6*10^{-19}*1300*10^{-4}} = 1.923*10^{21}\ \bar{e}/m^3$

$= 1.923*10^{15}\ \bar{e}/cm^3$

b) $\because V_d = \mu E$, $E = \frac{V}{\ell}$

$\Rightarrow V_d = (1300)(10^{-4})\left(\frac{2}{4*10^{-2}}\right) = 6.5\ m/s$

4. Show that the resistivity of intrinsic germanium at 300°k is 45 ohm.cm, and also find the resistivity of intrinsic silicon at 300°k.

Sol:

for germanium (at 300°K): $\mu_p = 1900\ cm^2/V.s$, $\mu_n = 3900\ cm^2/V.s$

$n_i = 2.4 * 10^{13}\ cm^{-3}$

$\Rightarrow \sigma = n q \mu_n + p q \mu_p$

$\because n = p = n_i$ (for intrinsic semiconductor)

$\Rightarrow \sigma = n_i q (\mu_n + \mu_p)$

$= (2.4 * 10^{13})(1.6 * 10^{-19})(3900 + 1900)$

$= 0.02227\ S/cm$

$\Rightarrow \rho = \frac{1}{\sigma} = 44.89 \simeq 45\ \Omega.cm$

for silicon (at 300°K): $\mu_p = 475\ cm^2/V.s$, $\mu_n = 1500\ cm^2/V.s$

$n_i = 1.45 * 10^{10}\ cm^{-3}$

$\Rightarrow \sigma = n_i q (\mu_n + \mu_p)$

$= (1.45 * 10^{10})(1.6 * 10^{-19})(1500 + 475)$

$= 4.582 * 10^{-6}\ S/cm$

$\Rightarrow \rho = 2.18 * 10^{5}\ \Omega.cm$

5. (a) Determine the concentration of free electrons and holes in a sample of germanium at 300°k which has a concentration of donor atoms equal to 2x10^{14} atoms/cm^3 and a concentration of acceptor atoms equal to 3x10^{14} atoms/cm^3. Is this p or n type germanium? In other words, is the conductivity due primarily to holes or to electrons? (n_i for Ge at 300°k = 2.5x10^{13} atoms/cm^3).
(b) Repeat part a for equal donor and acceptor concentration of 10^{15} atoms/cm^3 Is this p or n type germanium?
(c) Repeat part a for a donor concentration of 10^{16} atoms/cm^3 and an acceptor concentration 10^{14} atoms/cm^3.

a) $N_D = 2 * 10^{14}$ atom / cm^3 , $N_A = 3 * 10^{14}$ atoms/cm^3

$\because N_A > N_D \Rightarrow$ P-type germanium

from mass action law:

$\Rightarrow np = n_i^2$, $N_D + P = N_A + n$ (charge neutrality)

$$\Rightarrow P = \frac{n_i^2}{n}$$

$$\Rightarrow N_D + \frac{n_i^2}{n} = N_A + n$$

$$\Rightarrow n^2 + n N_A = n N_D + n_i^2$$

$$\Rightarrow n^2 - n(N_D - N_A) - n_i^2 = 0$$

$$\Rightarrow n = \frac{N_D - N_A \pm \sqrt{(N_D - N_A)^2 + 4n_i^2}}{2}$$

(we will only take + sol. since $n = n_i$ at $N_D = N_A$)

$$\Rightarrow n = \frac{-10^{14} + (1.118 * 10^{14})}{2}$$

$$= 5.9016 * 10^{12} \text{ cm}^{-3}$$

$$\Rightarrow P = \frac{n_i^2}{n} = \frac{(2.5 * 10^{13})^2}{5.9016 * 10^{12}} = 1.059 * 10^{14} \text{ cm}^{-3}$$

b) $N_A = N_D = 10^{15}$

$\because N_A = N_D \Rightarrow$ not n nor p-type $\Rightarrow$ Intrinsic Germanium

$\Rightarrow n = p = n_i = 2.5 * 10^{13}\ cm^{-3}$

c) $N_D = 10^{16}$ atom / cm^3

$N_A = 10^{14}$ atom / cm^3

$\Rightarrow N_D >> N_A \Rightarrow$ n-type Germanium

$\Rightarrow np = n_i^2 \quad , \quad N_D + P = N_A + n$

$\Rightarrow P = \frac{n_i^2}{n}$

$\Rightarrow n^2 - n(N_D - N_A) - n_i^2 = 0$

$$\Rightarrow n = \frac{(N_D - N_A) + \sqrt{(N_D - N_A)^2 + 4n_i^2}}{2}$$

$$= \frac{9.9 * 10^{15} + \sqrt{(9.9 * 10^{15})^2 + 4(2.5 * 10^{13})^2}}{2}$$

$$= 9.9 * 10^{15}$$

$$\Rightarrow P = \frac{n_i^2}{n} = 6.313 * 10^{10}\ cm^{-3}$$

Another sol:

$\because N_D >> N_A \Rightarrow n >> P$

$\Rightarrow n \simeq N_D \Rightarrow n = 10^{16}\ cm^{-3}$

$$\Rightarrow P = \frac{n_i^2}{n} = \frac{(2.5 * 10^{13})^2}{10^{16}}$$

$$= 6.25 * 10^{10}\ cm^{-3}$$