Chapter 2

2-2) The specific density of tungsten is 18.8 g/cm^3,and its atomic weight is 184.0. Assume that there are two free electrons per atom. Calculate the concentration of free electrons.

Answer

$d = 18.8 g/cm^3 = 18.8*10^3 kg/m^3$

$A = 184.0$

$\nu = 2$

$$n = \frac{A_0 d \nu *10^3}{A} = \frac{6.023*10^{23}*18.8*10^3*2*10^3}{184.0} = 1.23*10^{29} electron/m^3$$

2-3)
(a) Compute the conductivity of copper for which $\mu = 34.8 cm^2/Vs$ and d=8.9 g/cm^3.
(b) If an electrical field is applied across such a copper bar with an intensity 10V/cm, find the average velocity of the free electrons.

Answer

(a)

$\mu = 34.8 cm^2/Vs = 34.8*10^{-4} m^2/Vs$

$d = 8.9 g/cm^3 = 8.9*10^3 kg/m^3$

$\nu = 1 electron/atom$

$A = 63.54$

$$n = \frac{A_0 d \nu *10^3}{A} = \frac{6.023*10^{23}*8.9*10^3*1*10^3}{63.54} = 8.4*10^{28} electron/m^3$$

$\sigma = nq\mu = 8.4*10^{28}*1.6*10^{-19}*34.8*10^{-4} = 4.697*10^7 (\Omega m)^{-1}$

(b)

$E = 10V/cm = 10^3 V/m$

$v = \mu E = 10^3*34.8*10^{-4} = 3.48 m/s$

2-4) Compute the mobility of free electrons in aluminum for which the density is 2.70 g/cm^3 and the resistivity is $3.44*10-6\Omega cm$. Assume that aluminum has three valance electrons /atom.

Answer

$d = 2.7 g/cm^3 = 2.7*10^3 kg/m^3$

$\rho = 3.44*10^{-6} \Omega cm = 3.44*10^{-8} \Omega m$

$$\sigma = \frac{1}{\rho} = 2.9*10^7 (\Omega m)^{-1}$$

$A = 26.98$

$$n = \frac{A_0 d \nu *10^3}{A} = \frac{6.023*10^{23}*2.7*10^3*3*10^3}{26.98} = 1.8*10^{29} electron/m^3$$

$\rho = nq\mu$

$$\mu = \frac{\sigma}{nq} = \frac{2.9*10^{7}}{1.8*10^{29}*1.6*10^{-19}} = .001 m^2/Vs$$

2-5) The resistance of No. 18 copper wire (diameter = 1.03 mm) is 6.51Ω per 1000ft. The concentration of free electrons in copper is $8.4*10^{28}\, electons/m^3$. If the current is 2 A, find the (a) drift velocity (b)mobility (c)conductivity

Answer

$d = 1.03mm$

$r = .565*10^{-3} m$

$$A = \pi r^2 = \frac{\pi d^2}{4} = 8.66*10^{-7} m^2$$

$R = 6.51\Omega$

$L = 1000ft = 1000*.305 = 305m$

$n = 8.4*10^{28}\, electrons/m^3$

$I = 2A$

$$\sigma = \frac{L}{RA} = \frac{305}{6.51*8.66*10^{-7}} = 5.41*10^{7}(\Omega m)^{-1}$$

$$\mu = \frac{\sigma}{nq} = \frac{5.41*10^{7}}{8.4*10^{28}*1.6*10^{-19}} = .004 m^2/Vs$$

$$v = \mu E = \mu\frac{V}{L} = \mu\frac{IR}{L} = .004*\frac{2*6.51}{305} = 1.72*10^{-4} m/s$$

2-7)

(a) Find the concentration of holes and of electrons in a p-type germanium at 300K if the conductivity is $100(\Omega m)^{-1}$

(b)Repeat part a for n-type silicon if the conductivity is $0.1(\Omega m)^{-1}$

Answer

a)

$n_i = 2.5*10^{13}\, electrons/cm^3$

$\mu_p = 1800 cm^2/Vs$

$\sigma = pq\mu_p$

$$p = \frac{\sigma}{q\mu_p} = \frac{100}{1.6*10^{-19}*1800} = 3.47*10^{17}\, holes/cm^3$$

$$n = \frac{n_i^2}{P} = \frac{(2.5*10^{13})^2}{3.47*10^{17}} = 1.8*10^{9}\, electrons/cm^3$$

b)

$n_i = 1.5*10^{10}\, electrons/cm^3$

$\mu_n = 1300 cm^2/Vs$

$\sigma = nq\mu_n$

$$n = \frac{\sigma}{q\mu_n} = \frac{0.1}{1.6*10^{-19}*1300} = 4.8*10^{14} electrons/cm^3$$

$$p = \frac{n_i^2}{n} = \frac{(1.5*10^{10})^2}{4.8*10^{14}} = 4.68*10^5 holes/cm^3$$

2-8)

a) Show that the resistivity of intrinsic germanium at 300K is $45\Omega m$ **.**

b) If a donor-type impurity is added to the extent of 1 atom per 10^8 germanium atoms prove that the resistivity drops to $3.7\Omega cm$

Answer

a)

$n_i = 2.5*10^{13}\, electrons/cm^3$

$\mu_p = 1800 cm^2/Vs$

$\mu_n = 3800 cm^2/Vs$

$$\sigma = n_i q(\mu_p + \mu_n) = 2.5*10^{13}*1.6*10^{-19}*(1800+3800)$$

$$= 0.0224(\Omega cm)^{-1}$$

$$\rho = \frac{1}{\sigma} = 44.64\Omega cm \cong 45\Omega cm$$

b)

$n - type$

$d = 5.32 g/cm^3$

$A = 72.6$

$$N = \frac{A_0 d}{A} = \frac{6.023*10^{23}*5.32}{72.6} = 4.41*10^{22} atom/cm^3$$

$$n \cong N_D = \frac{4.41*10^{22}}{10^8} = 4.41*10^{14} \quad ,as\ for\ each\ 10^8\ Ge\ atom\ there\ are\ one\ donor\ atom$$

$$\sigma = nq\mu_n = 4.41*10^{14}*1.6*10^{-19}*3800 = 0.268(\Omega m)^{-1}$$

$$\rho = \frac{1}{\sigma} = 3.72\Omega m$$

2-9)
a) Find the resistivity of intrinsic silicon at 300K.
b) If a donor-type impurity is added to the extent of 1 atom per 10^8 silicon atoms, find the resistivity.

Answer

a)

$n_i = 1.5*10^{10}\, electrons\,/cm^3$

$\mu_p = 500 cm^2\,/Vs$

$\mu_n = 1300 cm^2\,/Vs$

$\sigma = n_i q(\mu_p + \mu_n) = 1.5*10^{10}*1.6*10^{-19}*(1300+500)$

$= 4.32*10^{-6}\,(\Omega cm)^{-1}$

$\rho = \dfrac{1}{\sigma} = 2.3*10^5\,\Omega cm$

b)

$n - type$

$d = 2.33 g\,/cm^3$

$A = 28.1$

$N = \dfrac{A_0 d}{A} = \dfrac{6.023*10^{23}*2.33}{28.1} = 4.99*10^{22}\, atom\,/cm^3$

$n \cong N_D = \dfrac{4.99*10^{22}}{10^8} = 4.99*10^{14}$ $\quad$ *,as for each* 10^8 *Ge atom there are one donor atom*

$\sigma = nq\mu_n = 4.99*10^{14}*1.6*10^{-19}*1300 = 0.104(\Omega m)^{-1}$

$\rho = \dfrac{1}{\sigma} = 9.634\,\Omega m$

2-10) Consider intrinsic germanium at room temperature (300K). By what percentage does the conductivity increase per degree rise in temperature?

Answer

$\sigma_{301} = \sigma_0 e^{-\frac{Eg}{2kT_{301}}}$

$\sigma_{300} = \sigma_0 e^{-\frac{Eg}{kT_{300}}}$

$\dfrac{\sigma_{301}}{\sigma_{300}} = \dfrac{\sigma_0 e^{-\frac{Eg}{2kT_{301}}}}{\sigma_0 e^{-\frac{Eg}{2kT_{300}}}} = e^{-\frac{Eg}{2kT_{301}}+\frac{Eg}{2kT_{300}}} = e^{-\frac{Eg}{2k}\left(\frac{1}{301}-\frac{1}{300}\right)}$

$= e^{-\frac{.67}{2*8.62*10^{-5}}\left(\frac{1}{301}-\frac{1}{300}\right)} = 1.044$

$Where\ Eg = .67 eV \quad , K = 8.62*10^{-5} eV\ /K$

$\sigma_{301} = 1.044*\sigma_{300}$

conductivity increase= $\dfrac{\sigma_{301}-\sigma_{300}}{\sigma_{300}} = \dfrac{1.044*\sigma_{300}-\sigma_{300}}{\sigma_{300}}*100 = 4.4\%$

2-11) Repeat Prob. 2-10 for intrinsic silicon.

Answer

$$\sigma_{301} = \sigma_0 e^{-\frac{Eg}{2kT_{301}}}$$

$$\sigma_{300} = \sigma_0 e^{-\frac{Eg}{kT_{300}}}$$

$$\frac{\sigma_{301}}{\sigma_{300}} = \frac{\sigma_0 e^{-\frac{Eg}{2kT_{301}}}}{\sigma_0 e^{-\frac{Eg}{2kT_{300}}}} = e^{-\frac{Eg}{2kT_{301}}+\frac{Eg}{2kT_{300}}} = e^{-\frac{Eg}{2k}\left(\frac{1}{301}-\frac{1}{300}\right)}$$

$$= e^{-\frac{1.1}{2*8.62*10^{-5}}\left(\frac{1}{301}-\frac{1}{300}\right)} = 1.073$$

$$Where\ Eg = 1.1eV \qquad , K = 8.62*10^{-5} eV\ /K$$

$$\sigma_{301} = 1.073 * \sigma_{300}$$

$$\text{conductivity increase} = \frac{\sigma_{301}-\sigma_{300}}{\sigma_{300}} = \frac{1.073*\sigma_{300}-\sigma_{300}}{\sigma_{300}} * 100 = 7.3\%$$