Solutions to chapter two problems

1. we know that the thermal velocity of an electron, as a function of effective mass and temperature is:

$$V_{th} = \sqrt{\frac{3k_BT}{m_e^*}}$$ where k_B (Boltzmann's constant) = $1.38*10^{-23}\frac{J}{K}$

2. we know the mean free path between collisions will be as such

$l_{mfp} = \tau_{mfp} V_{th}$ where V_{th} (thermal velocity) = $\sqrt{\frac{3k_BT}{m_e^*}}$

and

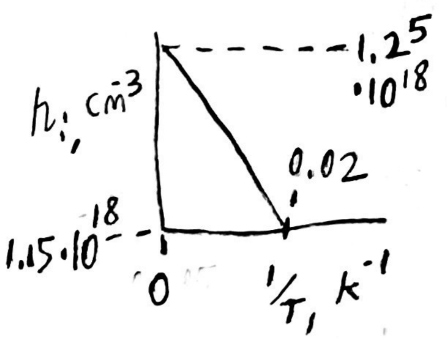
τ_{mfp} is the time between collisions as electrons scatter in media

3. The intrinsic carrier concentration may be defined as:

$$n_i = \sqrt{N_C N_V} \cdot e^{-E_G/2k_BT}$$

where N_C and N_V are the densities of carriers in the conduction and valance bands respectively and E_G is the energy gap between the bands

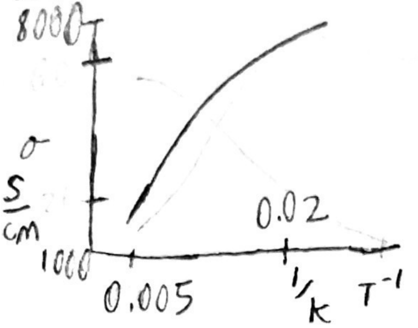
using this equation, a plot of intrinsic carrier concentration as a function of reciprocal temperature should look like this:



the vertical axis uses a logorithmic scale while the horizontal axis uses a linear scale (this particular graph applies to Germanium)

4. conductivity as a function of reciprocal temperature for the same semiconductor as presented in problem 3, given a mobility temperature dependence of $\mu = (4.9 \cdot 10^7) \cdot T^{-3/2}\ \frac{cm^2}{Vs}$ should look as follows:

both the horizontal and vertical axes are linear in this graph



conductivity

$\sigma = q \cdot n_t \cdot \mu$

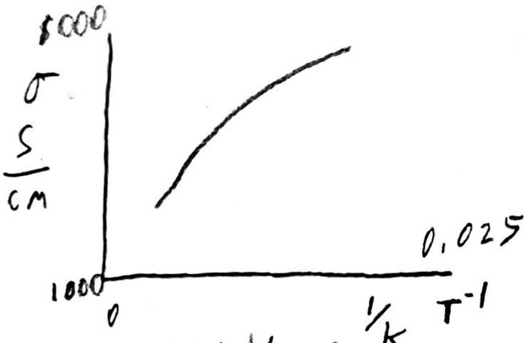
$n_t = n_i + n_d$

$n_d = N_D \cdot e^{-\frac{E_c - E_F}{n \cdot k_B \cdot T}}$

where N_D is the concentration of donors, such as phosphorous in this example, n is 2 for shallow donors, and $E_c - E_F$ represents dopant ionization/activation energy assumed to be 0.013 eV

5.

apply the same principles used in problem 4:



assuming an $N_D = 10^{15}\ cm^{-3}$ and
$E_C - E_F = 35\ meV$

6. we know that the criteria for compensation is as follows:

$$N_D^+ = N_A^-$$

$$\downarrow$$

$$N_D e^{\left(-\frac{E_c - E_D}{n \cdot k_B \cdot T}\right)} = N_A e^{-\left(\frac{E_A - E_V}{n k_B T}\right)}$$

$$\downarrow$$

plugging in the values given in the problem statement

$$(2 \cdot 10^{16}) e^{-\left(\frac{0.05}{2 \cdot (8.62e^{-5}) \cdot T}\right)} = N_A e^{-\left(\frac{0.08}{2 \cdot (8.62e^{-5}) \cdot T}\right)}$$

$$\downarrow$$

$$\frac{2 \cdot 10^{16}}{N_A} = e^{-\left(\frac{0.08}{2 \cdot (8.62e^{-5}) \cdot T}\right) + \left(\frac{0.05}{2(8.62e^{-5}) \cdot T}\right)}$$

The acceptor concentration required to achieve compensation will then be the below function of temperature

$$\boxed{N_A = (2 \cdot 10^{16}) \cdot e^{\frac{0.03}{2 \cdot (8.62 \cdot 10^{-5}) \cdot T}}}$$

7. the acceleration of an electron under an applied force is different in solids than in a vacuum. To account for this mathematically we add a coefficient next to mass in the expression relating the aforementioned force and the acceleration it is responsible for

$$F = M^* \frac{dv}{dt} = \frac{1}{\frac{1}{\hbar^2} \frac{d^2E}{dk^2}}$$

Holes operate in the valence band since the current-carrying electrons that left them behind jumped from the valence band into the conduction band. Because of this holes move more slowly than electrons and spend more time interacting with the semiconductor's crystal lattice. This grants holes effective masses larger than those of electrons.

1. (?) we know that diffusion current density is defined like so:

assuming an unchanging gradient of carrier density: $\frac{dn}{dx} = \frac{10^{14} - 10^{10}}{20 \cdot 10^{-4}}$

$$J_{diff} = q \cdot D_n \cdot \frac{dn}{dx}$$

where the diffusion coefficient is defined below:

$$D_n = \frac{K_B T \mu}{q} = \frac{(1.38 \cdot 10^{-23}) \cdot 300 \cdot 1500}{1.602 \cdot 10^{-19}} =$$

$$\downarrow$$

$$J_{diff} = \frac{(10^{14} - 10^{10}) \cdot (1.38 \cdot 10^{-23}) \cdot 300 \cdot 1500}{20 \cdot 10^{-4}} = \boxed{0.3104 \cdot 10^{0} \ \frac{A}{cm^2}}$$

this is an outrageous current density but makes sense in the context of the small scales involved in semiconductor physics

8. drift current density is given below

$$J_{drift} = \sigma E = q n \mu \cdot E \qquad E = \frac{dV}{dx} = \frac{10\text{ V}}{1 \cdot 10^{-1}\text{ cm}}$$

$$J_{drift} = (1.602 \cdot 10^{-19}) \cdot \sqrt{N_C N_V} \cdot e^{-\frac{E_G}{2 K_B T}} \cdot 1200 \cdot 100$$

↓ plug in relevant values for silicon

$$J_{drift} = 1 \cdot \sqrt{(3.2 \cdot 10^{19})(1.8 \cdot 10^{19})} \cdot e^{-\frac{1.12}{2 \cdot (8.62 \cdot 10^{-5}) \cdot 300}} \cdot 1200 \cdot 100$$

$$\downarrow$$

$$J_{drift} = 1.134 \cdot 10^{21} \frac{A}{cm^2}$$

9. the recombination of holes and electrons separated by the photoelectric effect is defined as follows:

$n(t) = n_0 e^{-t/\tau}$ where τ is the excess carrier life time

number of electron-hole pairs created

based on the problem statement

$n_0 = (1mW) * (10^{19})$

$= \boxed{1.602*10^{19} \text{ carriers generated}}$

$$\cancel{n_0} \cdot 0.5 = \cancel{n_0} e^{-t/100 \cdot 10^{-9}}$$

$\downarrow$

$$t = \ln(0.5) \cdot (-100 \cdot 10^{-9}) = \boxed{6.93 \cdot 10^{-8} \text{ seconds}}$$

10. there will be no excess carriers as the band gap of silicon is 1.12 eVs and the photon energy of 0.7 eV is insufficient to move electrons into the conduction band

11. we know that $V_{nRMS} = \sqrt{4 k_B T \cdot R \cdot \Delta f}$

where R is load resistance and Δf is band with

apply parameters given in problem statement

$\downarrow$

$$V_{nRMS} = \sqrt{4 \cdot (1.38 \cdot 10^{-23}) \cdot (300) \cdot \rho \cdot \frac{1 \cdot 10^{-1}}{1} \cdot 100 \cdot 10^{3}}$$

$\downarrow$

$$\boxed{V_{nRMS} = 3.407 \text{ V}}$$

$$\rho = \frac{1}{\sigma} = \frac{1}{q \cdot n \cdot \mu}$$

$\downarrow$

$$\rho = \frac{1}{(1.602 \cdot 10^{-19}) \cdot \sqrt{(3.2 \cdot 10^{19})(1.8 \cdot 10^{19})} \cdot e^{-\frac{1.12}{2(1.38 \cdot 10^{-23}) \cdot 300}} \cdot (4.9 \cdot 10^{7} \cdot 300^{-3/2})}$$

$\downarrow$

$$\rho = 70\,030.56 \ \Omega \text{ cm}$$