Problem 1

Compensation criterion

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

$\downarrow$

at room temperature:

$$N_A e^{-\frac{0.068}{2(8.62\cdot10^{-5})\cdot300}} = (2\cdot10^{16}) e^{-\frac{0.025}{2(8.62\cdot10^{-5})\cdot300}}$$

$\downarrow$

$$N_A = \frac{(2\cdot10^{16}) e^{-\frac{0.025}{2(8.62\cdot10^{-5})\cdot300}}}{e^{-\frac{0.068}{2(8.62\cdot10^{-5})\cdot300}}}$$

$\downarrow$

$$\boxed{N_A = 4.593\cdot10^{16}\ cm^{-3}}$$

at $T = 200$ K

$$N_A = \frac{(2\cdot10^{16}) e^{-\frac{0.025}{2(8.62\cdot10^{-5})\cdot200}}}{e^{-\frac{0.068}{1(8.62\cdot10^{-5})\cdot200}}}$$

$\downarrow$

$$\boxed{N_A = 5\cdot10^{17}\ cm^{-3}}$$

rule of thumb for differentiating between shallow and deep impurities

shallow impurities: activation energy $< 3k_BT$

deep impurities: activation energy $> 3k_BT$

assume room temperature:

$3k_BT = 0.078$

donor activation energy $= 0.025 < 0.078$

shallow, n is 2

acceptor activation energy $= 0.068 < 0.078$

shallow, n is 2

assume $T = 200$ K

$E_c - E_D = 0.025 < 0.052$

shallow, n is 2

$E_A - E_V = 0.068 > 0.052$

deep n is 1

Problem 2

drift current density is given as

$$J_{Drift} = \sigma E = q n \mu_{dr} \cdot E$$

$$J_{Drift} = (1.602 \cdot 10^{-19})(1.99 \cdot 10^{13})(3500) \cdot 10$$

$$\boxed{J_{Drift} = 0.112 \ \frac{A}{CM^2}}$$

find electric field intensity

$$E = \frac{dV}{dX} = \frac{10}{1CM} = 10 \text{V/cm}$$

find n_i

$$n_i = \sqrt{N_C N_V} \cdot e^{-\frac{E_G}{2K_B T}}$$

$$n_i = \sqrt{10^{19} \cdot 5 \cdot 10^{18}} \, e^{-\frac{0.661}{2K_B \cdot 300}}$$

$$n_i = 1.99 \cdot 10^{13}$$

problem 3

Thermal noise RMS voltage is given as such

without light

$$V_{nRMS} = \sqrt{4(1.38\cdot10^{-23})(350K)\cdot R\cdot\Delta f}$$

$$V_{nRMS} = \sqrt{4(1.38\cdot10^{-23})\cdot(350)\cdot(89.58)\cdot(100\cdot10^{3})}$$

$$\boxed{V_{nRMS} = 1.6698\cdot10^{-7}\,V}$$

with light

$$V_{nRMS} = \sqrt{4(1.38\cdot10^{-23})(350K)\cdot(8.92\cdot10^{-3})\cdot(100\cdot10^{3})}$$

$$\boxed{V_{nRMS} = 4.149\cdot10^{-9}\,V}$$

we know that

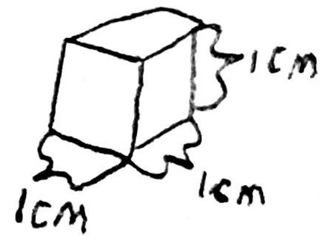
$$\sigma = q n_i \mu_{dr}$$

$$\sigma = 0.06929\ S$$

$$\rho = \frac{1}{\sigma} = 14.431\ \Omega\,cm$$

$$R = \frac{\rho l}{A} = \frac{14.431\ cm}{1\,cm^2}$$

assuming the below dimensions of the slab



recalculate σ based on presense of light

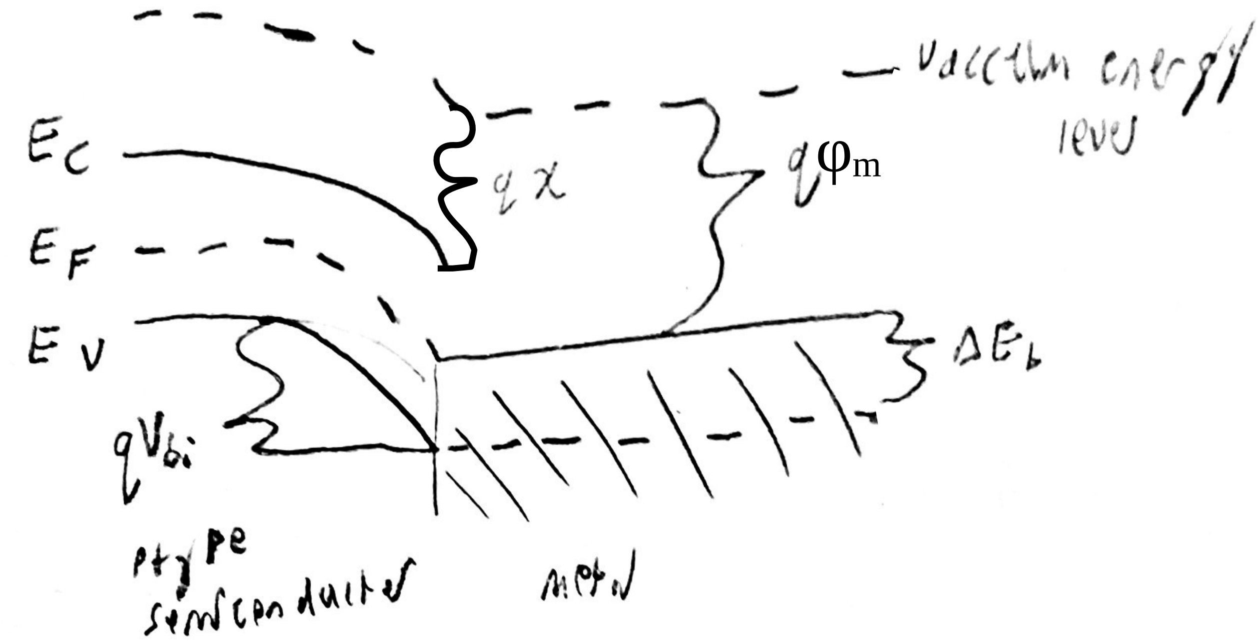
$$\sigma = (1.602\cdot10^{-19})\cdot((1.236*10^{14}) + (20\cdot10^{-3}\cdot10^{19}))\cdot3500$$

$$\sigma = 112.209\ S$$

$$R = \frac{1}{\sigma}\cdot\frac{l}{A} = 8.912\ \Omega$$

since photon energy is 0.9 eV and this is greater than the band gap energy of Ge (0.661 eV), it is sufficient to move electrons into the conduction band

problem 4



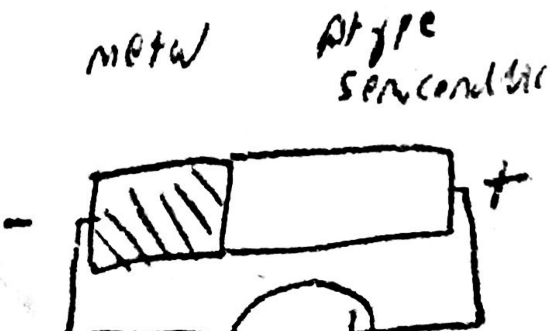
the interface is between a metal and a semiconductor, it is a Schottky barrier

condition for built-in potential to be zero

$$V_{bi}^{*} = 0 = V_{bi} - V_{applied}$$

remember that $\frac{k_B T}{q} = 0.026$ at room temp

applying forward bias



energy diagram

$\Delta E_b = q_m - \chi_s$

$\Delta E_b = 3.5 - 2.85$
$= 0.65$

find built-in potential:

$$V_{bi} = \Delta E - 0.026 \cdot \ln\left(\frac{N_V}{N_A}\right)$$

$$V_{bi} = 0.506\ V$$

this means that

$$\boxed{V_{applied} = 0.506\ V}$$

problem 4 continued

depletion region width

$$W_D = \sqrt{\frac{2\,\varepsilon_0 \varepsilon_s (V_{bi})}{q N_A}} = \boxed{20.15 \cdot 10^{-6}\ cm}$$

where $\varepsilon_0 = 8.854 \cdot 10^{-14}$

diffusion current density

$$J_{diff} = \frac{q^2 D_n N_v}{V_{th}} \sqrt{\frac{2q(V_{app} - V_{bi}) N_A}{\varepsilon_0 \varepsilon_s}}\, e^{\frac{\Delta E_b}{k_B T}} \left(e^{\frac{V_{app}}{V_{th}}} - 1 \right)$$

$$\downarrow$$

$$\boxed{J_{diff} = 1.327 \cdot 10^{16} \frac{A}{cm^2}}$$

where $\mu = 500$

$$D_n = \frac{k_B T \mu}{q}$$

$$D_n = 0.026 \cdot 500$$