Homework 7

1) $N_a = 10^{15}\,cm^{-3}$ $A = 0.001\,cm^2$ $\varepsilon = 11.8\varepsilon_0$

$V_R = 1V$ $\varepsilon_0 = 8.85\times10^{-12}\,F/m$ $W = \left[\frac{2\varepsilon(V_0+V_R)}{q}\cdot N_A^{-1}\right]^{\frac{1}{2}}$ $V_0 = \frac{kT}{q}\ln\left(\frac{N_a N_d}{n_i^2}\right)$

$C_j = \frac{\varepsilon A}{W}$ $E_{Fn} \approx \frac{1}{2}E_G = E_c - E_F = 0.56eV$

$N_d = N_c e^{-\frac{E_{Fn}}{kT}} = 2.8\times10^{19} e^{-\frac{0.56}{0.0259}} = 1.1\times10^{13}\,cm^{-3}$

$C = A\sqrt{\frac{q\varepsilon N_a}{2(V_0+V_R)}}$ $\frac{1}{C^2} = \frac{2(V_0+V_R)}{q\varepsilon N_a A^2}$ $n_i^2 = N_c N_v e^{-\frac{E_G}{kT}} = 2.8\times10^{19}\cdot 1.04\times10^{19} e^{-\frac{1.12}{0.0259}} = 10^{20}\,cm^{-6}$

$n_i = 10^{10}\,cm^{-3}$

$E_F - E_i = kT\ln\left(\frac{N_d}{n_i}\right)$

$0.56 = 0.0259\ln\left(\frac{N_d}{10^{10}}\right)$ $N_d = 10^{10} e^{\frac{0.56}{0.0259}} = 2.45\times10^{19}$

$N_a = 10^{15}$ $V_0 = \frac{kT}{q}\ln\left(\frac{10^{15}\cdot 2.45\times10^{19}}{10^{20}}\right) = 5.36\times10^{18}\,eV$ $(0.858V)$

$N_a = 10^{17}$ $V_0 = \frac{kT}{q}\ln\left(\frac{10^{17}\cdot 2.45\times10^{19}}{10^{20}}\right) = 6.1\times10^{18}\,eV$ $(0.977V)$

$C = \frac{2.892\times10^{-10}}{\sqrt{V_0+V_R}}$

★ $V_R = 1V$

$N_a = 10^{15}$ $C = \frac{2.892\times10^{-10}}{\sqrt{0.858+1}} = 2.12\times10^{-10}\,F = \underline{0.212nF}$

$N_d = 10^{17}$ $C = \frac{2.892\times10^{-10}}{\sqrt{1.977}} = 2.05\times10^{-10}\,F = \underline{0.205nF}$

★ $V_R = 5V$

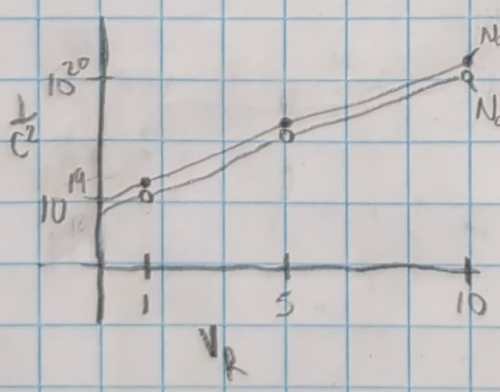
$N_a = 10^{15}$ $C = \frac{2.892\times10^{-10}}{\sqrt{5.858}} = \underline{0.119nF}$

$N_a = 10^{17}$ $C = \frac{2.892\times10^{-10}}{\sqrt{5.977}} = \underline{0.118nF}$

★ $V_R = 10v$

$N_a = 10^{15}$ $C = \frac{2.892\times10^{-10}}{\sqrt{10.858}} = \underline{0.088nF}$

$N_a = 10^{17}$ $C = \frac{2.892\times10^{-10}}{\sqrt{10.977}} = \underline{0.087nF}$



$N_a = 10^{17}$ — Slope $m = \frac{1.32\times10^{20} - 2.38\times10^{19}}{10-1} = \underline{1.197\times10^{19}\,F^{-2}/V}$

$N_a = 10^{15}$ — Slope $m = \frac{1.29\times10^{20} - 2.22\times10^{19}}{10-1} = \underline{1.197\times10^{19}\,F^{2}/V}$

2) $N_d = 3\times10^{16}\ cm^{-3}$ $D_p = 10\ cm^2/s$ $\tau_p = 0.1\mu s$ $A = 10^{-4}\ cm^2$ $V_R = 10V$

a) $C_j = A\sqrt{\frac{q\varepsilon N_d}{2(V_0+V_R)}}$ $N_a \approx 10^{19}\ cm^{-3}$ $n_i = 10^{10}\ cm^{-3}$

$$V_0 = \frac{kT}{q}\ln\left(\frac{N_a N_d}{n_i^2}\right) = 0.0259\ln\left(\frac{3\times10^{16}\times10^{19}}{10^{20}}\right) = 0.907\,V$$

$$C_j = 10^{-4}\sqrt{\frac{q\varepsilon\cdot3\times10^{16}}{2(.907+10)}} = 1.52\times10^{-12}\,F = \underline{1.52\,pF} \quad @\ V_R = 10V$$

b) $C_S = \frac{qI\tau_p}{kT} = \underline{I}\cdot 3.861\times10^{-9}$ $I_S = qA\frac{D_p n_i^2}{L_p N_d} = 1.602\times10^{-23}\cdot\frac{10^{21}}{3\times10^{15}} = 5.333\times10^{-16}\,A$

$$I = I_S\left(e^{qV_F/kT}-1\right) = 5.33\times10^{-16}\left(e^{23.17}-1\right) = 6.24\times10^{-6}\,A$$

$$C_S = I\cdot 3.861\times10^{-9} = 2.41\times10^{-11}\,F = \underline{24.1\,pF} \quad @\ V_F = 0.6V$$

3) $N_d = 10^{16}\ cm^{-3}$ $\mathcal{E}_0 = 4\times10^5\ V/cm$

$N_a x_{p0} = N_d x_{n0}$ $x_{p0} = \frac{N_d x_{n0}}{N_a}$ $W = x_{p0}+x_{n0} = \sqrt{\frac{2\varepsilon(V_0+V_R)}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)}$

$V_R >> V_0$ and $\frac{1}{N_a} << \frac{1}{N_d}$

$W = \sqrt{\frac{2\varepsilon V_R}{qN_d}}$ $W = x_{n0}\left(\frac{N_d}{N_a}+1\right) \rightarrow W \approx x_{n0}$

$\underline{x_{n0} = \sqrt{\frac{2\varepsilon V_R}{qN_d}}}$ $\underline{x_{p0} = \frac{N_d}{N_a}\sqrt{\frac{2\varepsilon V_R}{qN_d}}}$

$$\mathcal{E}_0 = \frac{qN_d x_{n0}}{\varepsilon} = \frac{qN_d}{\varepsilon}\sqrt{\frac{2\varepsilon V_R}{qN_d}} = \underline{\sqrt{\frac{2qN_d V_R}{\varepsilon}}} \qquad 4\times10^5 = \sqrt{\frac{2\times1.602\times10^{-19}\cdot10^{16}\cdot V_R}{1.045\times10^{-12}}} = \sqrt{3.062\times10^9 V_R}$$

$(4\times10^5)^2 = 3.062\times10^9\cdot V_R$ $\underline{V_R} = \frac{16\times10^{10}}{3.062\times10^9} = \underline{52.25\,V}$ $\underline{52.25V >> 0.9V}$

4) $E_c = 10^6$ V/cm $\quad N_a = N_d = 4\times10^{18}$ cm^{-3}

$$E = \frac{qN_dW}{\varepsilon_s} \qquad W = \sqrt{\frac{2\varepsilon_s V_b}{qN_d}} \qquad E_c = \frac{qN_d}{\varepsilon_s}\sqrt{\frac{2\varepsilon_s V_b}{qN_d}} = \sqrt{\frac{2qN_dV_b}{\varepsilon_s}}$$

$$E_c^2 = \frac{2qN_dV_b}{\varepsilon_s} \rightarrow V_b = \frac{E_c^2\varepsilon_s}{2qN_d} = \frac{10^{12}\cdot 11.8\cdot 8.85\times10^{-14}}{2\cdot 1.602\times10^{-19}\cdot 4\times10^{18}} = 0.815\text{ V}$$

0.815 V = Voltage required for breakdown

5) $V_0 = 0.956$ V $\quad N_d = 10^{17}$ cm^{-3} $\quad W_n = 1\mu$m $\quad V_{br} = 13$ V

$$W = \sqrt{\frac{2\varepsilon_s(V_{br}+V_0)}{qN_d}} = \sqrt{\frac{2\cdot 11.8\cdot 8.85\times10^{-14}(13.956)}{1.602\times10^{-19}\cdot 10^{17}}} = 4.266\times10^{-5}\text{ m} = 42.66\,\mu\text{m}$$

42.66 μm >> 1 μm so diode punches through

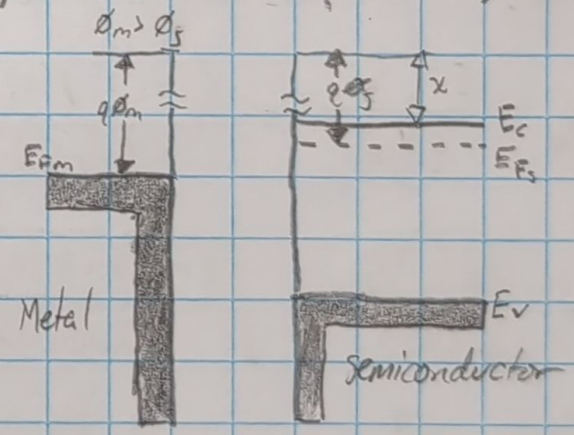
6) $N_d = 10^{17}$ cm^{-3} $\quad \phi_m = 4.8$ eV $\quad \chi = 4$ eV $\quad N_d = 10^{17}$ cm^{-3} $\quad n_i = 1.5\times10^{10}$ cm^{-3}

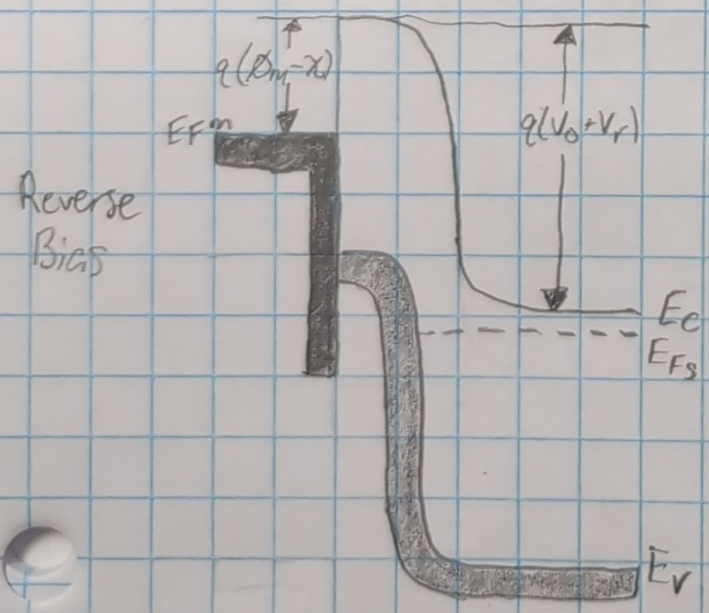
$$\phi_B = \phi_m - \chi = 0.8\text{ eV}$$

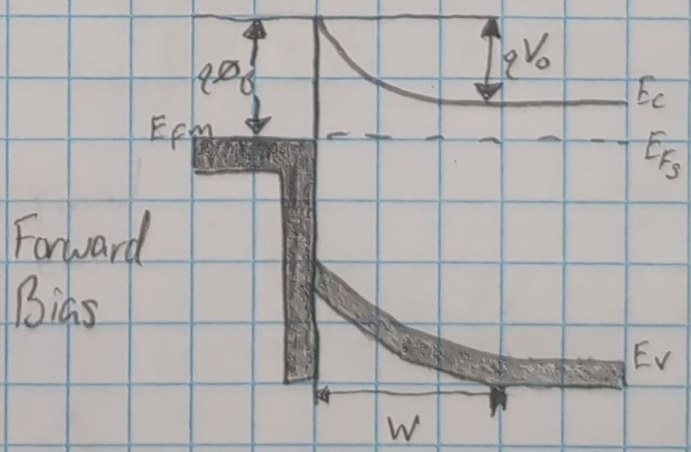
$$V_{bi} = \phi_B - V_n \qquad V_n = V_t\ln\left(\frac{N_d}{n_i}\right) = 0.0259\ln\left(\frac{10^{17}}{1.5\times10^{10}}\right) = 0.407\text{ V}$$

$$V_{bi} = 0.8 - 0.407 = 0.326\text{ V}$$

$$W = \sqrt{\frac{2\varepsilon_s V_{bi}}{qN_d}} = 6.52\,\mu\text{m}$$







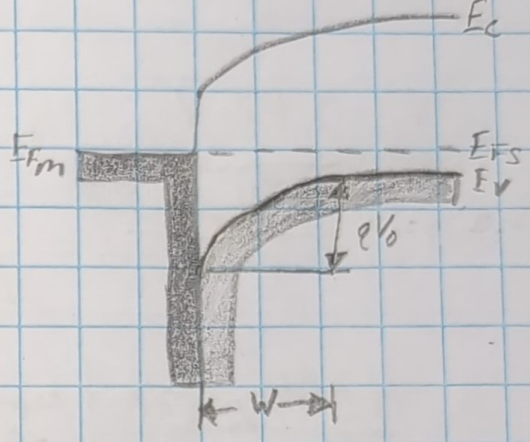
7) $\phi_m = 4.3V$ $N_a = 10^{17} cm^{-3}$ $\phi_{sc} > \phi_m$ $\chi = 4V$ $E_g = 1.12 eV$
$n_i = 1.5 \times 10^{10} cm^{-3}$

a)

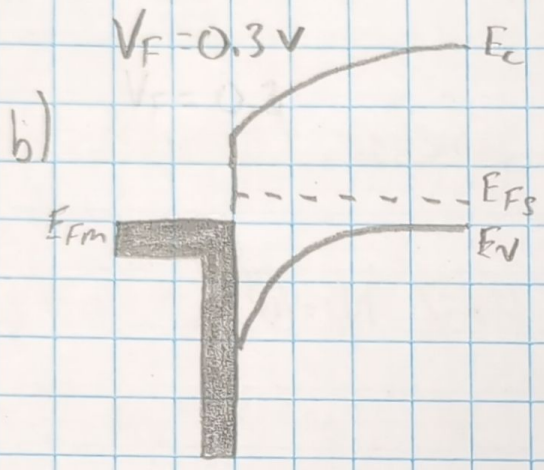
$$V_o = \phi_B - V_p \qquad \phi_B = E_g - (\phi_m - \chi) = 1.12 - 0.3 = 0.83\,V$$

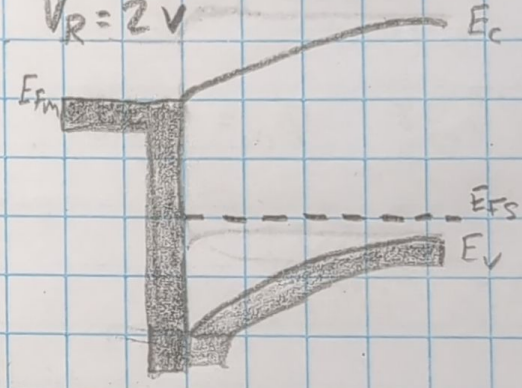
$$V_p = V_T \ln\left(\frac{N_a}{n_i}\right) = 0.0259 \ln\left(\frac{10^{17}}{1.5\times10^{10}}\right) = 0.407\,V$$

$$V_o = 0.83 - 0.407 = \underline{0.423\,V}$$



b)





8) $I_F = 1mA$ @ $0.6V$ $\tau_p = 0.1\mu s$ $\mu_p = 450 cm^2/V\text{-}s$

$$N_d = \frac{E_c^2 \cdot 2\varepsilon_s}{q V_{br}} = \frac{(3\times10^5)^2 \times (2\times11.8\times8.85\times10^{-14})}{1.602\times10^{-19}\cdot 150} = 7.82\times10^{15}\,cm^{-3}$$

$$W = \sqrt{\frac{2\varepsilon_s V_{br}}{q N_d}} = \sqrt{\frac{2\cdot11.8\times8.85\times10^{-14}\cdot150}{1.602\times10^{-19}\cdot7.82\times10^{15}}} = 5\times10^{-4}\,m = 500\mu m$$

$$e^{V/V_T} - 1 \approx 10^{10} \qquad I = qAN_d\frac{D_p}{L_p^2}10^{10} \qquad 10^{-3} = 1.25\times10^{14}\cdot A$$

$$A = \frac{10^{-3}}{1.25\times10^{14}} = \underline{7.99\times10^{-18}\,cm^2}$$

Square Area

$$L_s = \sqrt{A} = \underline{2.83\times10^{-9}\,cm}$$

Circular Area

$$r = \sqrt{\frac{A}{\pi}} = \underline{1.59\times10^{-9}\,cm}$$

$$d = 2r = \underline{3.19\times10^{-9}\,cm}$$