HW4 - Solutions

(1) P-N junctions

P	N

(1) $N_A = 1.6\times10^{15}\ cm^{-3}$, $N_D = 1\times10^{17}\ cm^{-3}$, $T = 300K$, $E_g = 1.4eV$, $\epsilon_{GaAs} = 13\epsilon_0$, $N_c = 5\times10^{17}\ cm^{-3}$, $N_v = 7\times10^{18}\ cm^{-3}$

(a)

$$V_i = \frac{1}{\beta q}\ln\left(\frac{N_A N_D}{n_i^2}\right) \quad \text{and} \quad n_i^2 = N_c N_v \exp(-\beta E_g)$$

$$\Rightarrow \boxed{qV_i = E_g + \frac{1}{\beta}\ln\left(\frac{N_A N_D}{N_c N_v}\right)} = 1.14eV$$

(b)

$$\boxed{W = \sqrt{\frac{2\epsilon_s}{q}\frac{(N_A+N_D)}{N_A N_D}V_i} \cong 1\mu m}$$

(2) $N_A = 2\times10^{16}\ cm^{-3}$ in the P-region

$N_D = 10^{16}\ cm^{-3}$, $N_D = 10^{17}\ cm^{-3}$ in the N-regions.

$n_i = 10^{10}\ cm^{-3}$ at $T = 300K$.

(2)

P-type region = $p \simeq N_A = 2\times10^{16}\ cm^{-3}$

and $n = \frac{n_i^2}{p} = 5\times10^{3}\ cm^{-3}$

N-type region: $n \simeq N_D - N_A = 9\times10^{16}\ cm^{-3}$

$p = \frac{n_i^2}{n} = 1.11\times10^{3}\ cm^{-3}$

$V_i = \frac{1}{q\beta}\ln\left(\frac{n_n p_p}{n_i^2}\right)$

$T = 300$	$T = 400$
$V_i = 0.79V$	$V_i = 0.63V$

(3)

$N_A = 10^{16}\ cm^{-3}$ $\quad n_i = 10^{10}\ cm^{-3}$

$N_D = 5\times10^{16}\ cm^{-3}$

$$\boxed{V_i = \frac{1}{q\beta}\ln\left(\frac{N_D N_A}{n_i^2}\right) = 0.76\,V}$$

$$\boxed{W = \sqrt{\frac{2\varepsilon_s}{q}\frac{(N_A+N_D)(V_i - V_A)}{N_A N_D}}}$$

$W = l_n + l_p$ and $l_n N_A = l_p N_A$ so $l_n = W N_A/(N_A+N_D)$

$$\boxed{E_{max} = -\frac{q N_D l_n}{\varepsilon_s} = -\frac{q N_D N_A}{\varepsilon_s(N_D+N_A)}W = -\frac{2(V_i - V_A)}{W}}$$

(3)

$$V_n = -\frac{q N_D l_n^2}{2\epsilon_s} = -\frac{q N_D N_A^2 W^2}{2\epsilon_s (N_A+N_D)^2} = -\frac{|V_i - V_A| N_A}{N_A + N_D}$$

	$V_A = 0\,V$	$V_A = 0.5\,V$	$V_A = -2.5\,V$
$W_{(\mu m)}$	0.35	0.205	0.72
E_{max} V/cm	-43.77	-25.9	-90.7
V_{th} (V)	0.125	0.042	0.54

(4)

$N_A = 10^{18}\ cm^{-3}$

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

$A = 10^{-5}\ cm^2$

$$\Rightarrow \boxed{V_i = 0.83\,V}$$

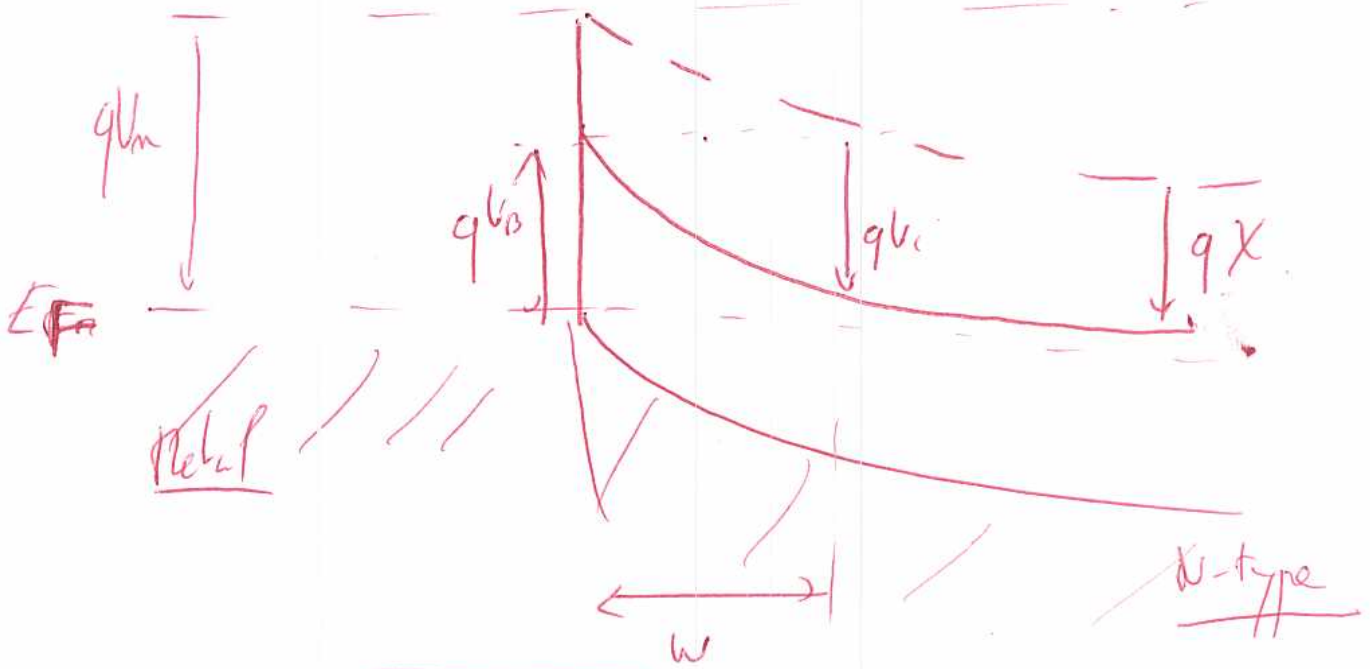
$$\boxed{W = 0.33\ \mu m}$$

$$\boxed{C = \frac{A\epsilon_s}{W} = 3.17\ pF}$$

II Metal – Semiconductor Junctions

(1)

$N_{cl} = 10^{17}\,cm^{-3}$

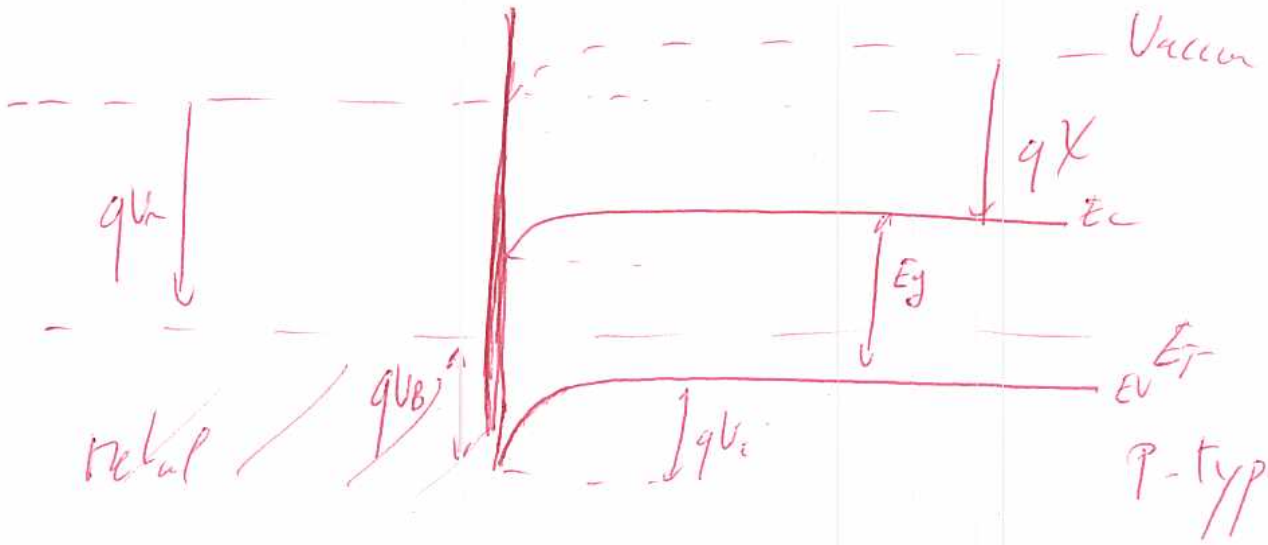


$$\boxed{qV_B = q(V_m - \chi) = 0.45\,eV}$$

$$qV_B = qV_i + (E_C - E_F) = qV_i + \frac{1}{\beta}\ln\left(\frac{N_c}{N_d}\right)$$

$$\boxed{qV_i = qV_B - \frac{k_B T}{q}\ln\left(\frac{N_c}{N_d}\right) \cong 0.30\,V}$$

*



$$V_B = \frac{E_g}{q} + (\chi - V_m) = 0.67\,V$$

$$V_i = V_B - \frac{(E_F - E_V)}{q} = V_B - \frac{k_B T}{q} \ln\left(\frac{N_V}{N_A}\right) = 0.53\,V$$

(2)

$N_d = 10^{17}\,cm^{-3}$ $\quad V_A = -5\,V$

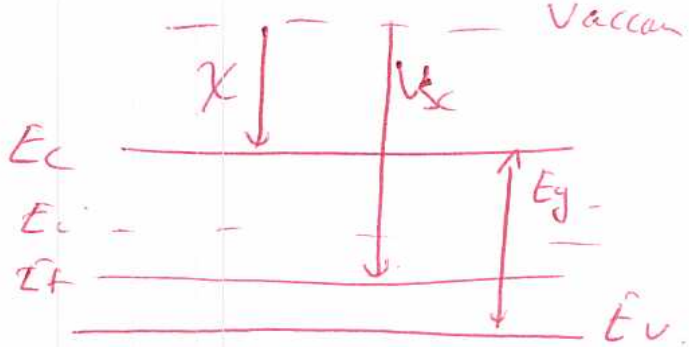
$$W = \sqrt{\frac{2\epsilon (V_i - V_A)}{q N_d}} = 0.26\,\mu m$$

$$E = -\frac{q N_d W}{\epsilon} = -4.0 \times 10^5\,V/cm$$

$$V_{surface} = -\frac{q N_d W^2}{2\epsilon} = 5.3\,V \equiv V_i - V_A$$

$$C = \frac{\epsilon_0}{W} = 40\,nF/cm^2$$

III MOS capacitors



* nMOS

$V_{FB} = V_m - V_{sc}$

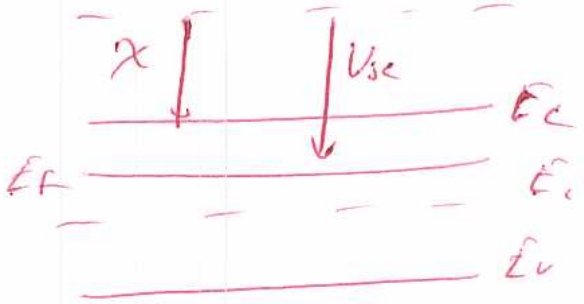
(difference between work functions)

$V_{sc} = \chi + \frac{E_g}{2} + (E_i - E_F)$ where $(E_i - E_F) = \frac{1}{\beta} \ln\left(\frac{N_A}{n_i}\right) = 0.3$

$V_{sc} = 4.05 + \frac{1.11}{2} + 0.349 = 4.954\,V$

$\boxed{V_{FB} = 4.1 - V_{sc} = -0.854\,V}$

* pMOS



$V_{FB} = V_m - V_{sc}$

$V_{sc} = \chi + \frac{E_g}{2} - (E_F - E_i)$

$(E_F - E_i) = \frac{1}{\beta} \ln\left(\frac{N_d}{n_i}\right) = 0.349\,V$

$V_{sc} = 4.25\,V$

$\boxed{V_{FB} = -0.15\,V}$

* n (NO)

$$V_T = V_{FB} + 2V_F + \frac{\sqrt{4\epsilon_{Si} q N_A V_F}}{C_{ox}}$$

$\sim 0.42V$

$$V_F = \frac{k_B T}{q} \ln\left(\frac{N_A}{n_i}\right)$$

$$V_F = 0.349V$$

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = 0.00115 F/m^2$$

$$\boxed{V_T = 0.2(V}$$

* p (NO)

$$V_T = V_{FB} - 2V_F - \frac{\sqrt{4\epsilon_{Si} q N_D V_F}}{C_{ox}}$$

(2) surface potential

(1) depletion charge

$$\boxed{V_T = -1.27V}$$