Final exam

Wednesday, 18 December 2024 11:18

Q1)

From the $1/C^2$ plot, we have:

$$\frac{1}{C^2} = (\phi_{bi} - V)\cdot\frac{1}{A^2}\cdot\frac{2}{\varepsilon_s q N_D}$$

$$\text{slope} = \frac{-2}{A^2 \varepsilon_s q N_D}$$

$$\text{Slope A} = \frac{0.9-10}{0+5}\times 10^{26} = -1.82\times10^{26}$$

$$\text{Slope B} = -6.25\times10^{25}$$

B has the smallest slope, thus largest doping

$$N_D^A = \frac{-2}{A^2 \varepsilon_s q\cdot \text{slope}^A} = 1\times10^{16}\ cm^{-3}$$ (this was not required)

$$N_D^B = 2.95\times10^{16}\ cm^{-3}$$

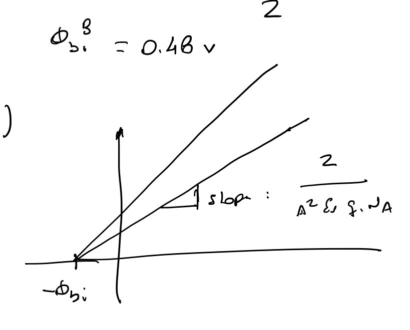
$$\left.\frac{1}{C^2}\right|_{V=0} = \phi_{bi}\cdot\frac{2}{A^2\varepsilon_s q N_D}$$

thus:

$$\phi_{bi}^A = \frac{A^2 \varepsilon_s q N_D \cdot \left.1/C^2\right|_{V=0}}{2} = 0.49V$$

$$\phi_{bi}^B = 0.48V$$

2)



Question 2:

1) $q\phi_{bi} = q\varphi_{Bn} - q\varphi_n$

$\therefore \phi_{bi} = \varphi_{Bn} - \varphi_n$ (in volts)

$$\varphi_n = \frac{kT}{q}\ln\left(\frac{N_C}{N_D}\right) = 0.21V$$

$$\phi_{bi} = 0.7 - 0.21 = 0.49V$$

the difference is possibly due to a total depletion of the wafer because it might be too thin.

2) Since it is depleted:

$$\rho = q\cdot N_D$$

$$\frac{dE}{dx} = \frac{qN_D}{\varepsilon_s}$$

$$\int dE = \int \frac{qN_D}{\varepsilon_s}dx$$

$$E(x) - E(0) = \frac{qN_D}{\varepsilon_s}x \quad [1]$$

. potential is $\frac{d\phi}{dx} = -E$

$$d\phi = -\frac{qN_D}{\varepsilon_s}x - E(0)\,dx$$

$$\phi(x) - \phi(0) = -\frac{qN_D}{\varepsilon_s}\frac{x^2}{2} - E(0).x \quad [2]$$

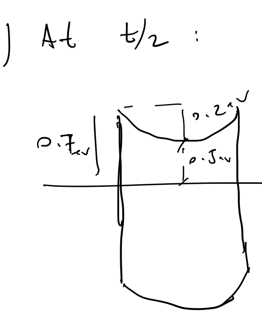
1) At $t/2$, $E(t/2) = 0 \Rightarrow E(0) = -\frac{qN_D.t}{2.\varepsilon_s}$

2) $\phi(t/2) - \phi(0) = \phi_{bi}$

$$\phi_{bi} = -\frac{qN_D}{\varepsilon_s}\cdot\frac{t^2}{8} + \frac{qN_D}{\varepsilon_s}\frac{t^2}{4} = \frac{qN_D}{\varepsilon_s}\frac{t^2}{8}$$

$$\therefore\ t = \sqrt{\frac{8\varepsilon_s\phi_{bi}}{qN_D}} = 3.2\times10^{-5}\ cm$$

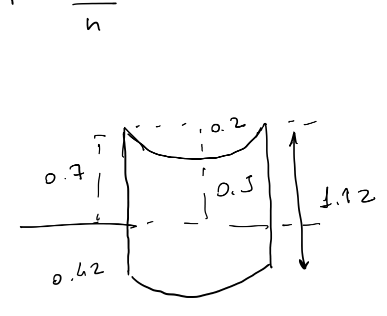
3) At $t/2$:



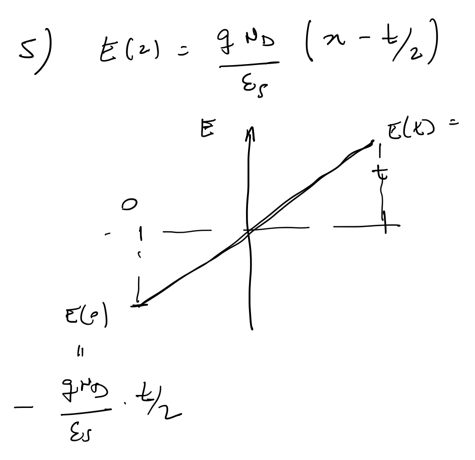
$$n = N_c\exp\left(-\frac{0.5}{kT}\right) = 1.29\times10^{11}\ cm^{-3}$$

$$p = \frac{n_i^2}{n} = 7.75\times10^{8}\ cm^{-3}$$ (not required from students)

4)



5) $E(x) = \frac{qN_D}{\varepsilon_s}(x - t/2)$



Exercise 3:

$$V_{th} = -\phi_{bi} + \phi_{s,th} + \gamma\cdot\sqrt{\phi_{s,th}} = \underline{-1\,V}$$

$$\phi_{bi} = W_s - \underline{W_m}$$

$$W_s = \chi_{Si} + E_g - \frac{kT}{q}\log\left(N_V/N_A\right) = 5.01\,eV$$

$$\phi_{s,th} = \frac{2kT}{q}\ln\left(\frac{N_c}{n_i}\right) = 0.84V$$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = 3.45\times10^{-7}\ C/cm^2$$

$$\gamma = \frac{\sqrt{2\varepsilon_s q N_A}}{C_{ox}} = 0.52\ V^{1/2}$$

$$\phi_{bi} = \underbrace{-V_{th}}_{+1V} + \underbrace{\phi_{s,th}}_{0.84V} + \underbrace{\gamma\sqrt{\phi_{s,th}}}_{0.52\sqrt{0.84}} = 2.32V$$

$$\boxed{W_M = W_s - q\phi_{bi} = 2.69\,eV}$$

2) $V_{th} = -1V$

so at 0V, we are in inversion.

$$x_d = x_{d,max} = \sqrt{\frac{2\varepsilon_s\phi_{s,th}}{qN_A}} = ~~1.52\times10^{-7}~~\ cm$$ 1e5 cm

3) $Q_i = -2.8\times10^{12}\times1.6\times10^{-19}\ C/cm^2 = -4.48\times10^{-7}\ C/cm^2$

$$Q_i = -C_{ox}(V - V_{th})$$

$$V = -\frac{Q_i}{C_{ox}} + V_{th} = 0{,}29V$$

4) $V_{FB} = -\phi_{bi} = -2{,}32V$

$$Q_c = C_{ox}(V - V_{FB})$$

$$V = -\frac{Q_c}{C_{ox}} + V_{FB} = -3{,}62V$$

5) $I_G = 0$

Exercise 4:

1) I would choose the largest BFOM materials

Diamond:

$$BFOM = \varepsilon\cdot\mu_e\cdot E_c^3 = 2.44\times10^{12}$$

2) highest mobility: GaAs

3) $R_{on} = \frac{4\cdot V_{BV}^2}{BFOM} = 1.64\times10^{-6}\ \Omega\,cm^2$