Rubric Assignment 2

Q.1

GaAs: $V_{bi} = 1.20V$, $n_i = 1.8 \times 10^6\ cm^{-3}$

$$x_p = 0.2W = 0.2(x_n + x_p)$$

or

$$\frac{x_p}{x_n} = 0.25$$

Also

$$N_d x_n = N_a x_p$$

$$\Rightarrow \quad \frac{x_p}{x_n} = \frac{N_d}{N_a} = 0.25$$

Now

$$V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

$$1.20 = 0.0259 \ln\left(\frac{0.25 N_a^2}{n_i^2}\right)$$

Then

$$\frac{0.25 N_a^2}{n_i^2} = \exp\left(\frac{1.20}{0.0259}\right)$$

or

$$N_a = 2n_i \exp\left[\frac{1.20}{2(0.0259)}\right]$$

or

$$\boxed{N_a = 4.14 \times 10^{16}\ cm^{-3}}$$ 2 Marks

b, $$\boxed{N_d = 0.25\,N_a = 1.04 \times 10^{16}\ cm^{-3}}$$ 2 Marks

c, $$x_n = \left[\frac{2\epsilon V_{bi}}{e} \left(\frac{N_a}{N_d} \right) \left(\frac{1}{N_a + N_d} \right) \right]^{1/2}$$

$$= \left[\frac{2 \times (13.1)(8.85 \times 10^{-14})(1.20)}{1.6 \times 10^{-19}} \times \left(\frac{4}{1} \right) \frac{1}{4.14 \times 10^{16} + 1.04 \times 10^{16}} \right]^{1/2}$$

$$\boxed{x_n = 0.366\ \mu m}$$ 2 Marks

d, $$\boxed{x_p = 0.25\,x_n = 0.0916\ \mu m}$$ 2 Marks

e, $$E_{max} = \frac{e N_d x_n}{\epsilon} = \frac{e N_a x_p}{\epsilon}$$

$$= \frac{(1.6 \times 10^{-19})(1.04 \times 10^{16})(0.366 \times 10^{-4})}{(13.1)(8.85 \times 10^{-14})}$$

$$\boxed{E_{max} = 5.25 \times 10^{4}\ V/cm}$$ 2 Marks

Q.2

a, By poisson's eqn we know that

$$\frac{dE}{dx} = \frac{\rho}{\varepsilon_s} \rightarrow 1 \text{ Marks}$$

Here

$$\frac{dE}{dx} = \frac{-4.2 \times 10^{4} \, V/cm - 0}{0 - 2 \times 10^{-4} \, cm} = +ve \text{ quantity}$$

$$\Rightarrow \rho/\varepsilon_s = +ve \rightarrow 1 \text{ Marks}$$

2 Marks

Hence the Semiconductor is $\boxed{\text{n-type}}$ Since the depleted charged ions are +ve.

b, Schottky barrier diode (n-type)

$$N_d = 2.5 \times 10^{15} \, cm^{-3}$$

$$\phi_B = 0.55 V$$

$$V_{bi} = \phi_B - \phi_n \rightarrow 1 \text{ Marks}$$

$$\phi_n = V_t \ln\left(\frac{N_c}{N_d}\right) = 0.0259 \ln\left(\frac{2.8 \times 10^{19}}{2.5 \times 10^{15}}\right)$$

$$\phi_n = 0.24 V \rightarrow 1 \text{ Marks}$$

a i, $V_{bi} = \phi_B - \phi_n$

$V_{bi} = 0.55 - 0.24$

$\boxed{V_{bi} = 0.31V}$ → 1 Marks

ii. $N_d = 3 \times 10^{16}\ cm^{-3}$

$\phi_n = 0.0259 \ln\left(\frac{2.8 \times 10^{19}}{3 \times 10^{16}}\right)$

$\phi_n = 0.17V$ → 1 Marks

$V_{bi} = 0.55 - 0.17$

$\boxed{V_{bi} = 0.38V}$ → 1 Marks

Change in V_{bi} = 0.07 V → 1 marks

So by increasing N_d, V_{bi} ↑es.

Q3

a, i, The depletion width W & maximum electric field $\mathcal{E}_m$ can be computed as follows

$$V_{bi} = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right) = 0.0259 \ln \frac{(10^{17})(2\times10^{16})}{(1.5\times10^{10})^2}$$

$$\boxed{V_{bi} = 0.77V} \rightarrow 1 \text{ Marks}$$

$$W = \sqrt{\frac{2\epsilon}{q}\frac{N_a+N_d}{N_a N_d}(V_{bi}-V_a)}$$

$$= \sqrt{\frac{2\times 11.8\times 8.85\times10^{-14}}{1.6\times10^{-19}}\frac{1.2\times10^{17}}{2\times10^{33}}\times 0.12} \quad cm$$

$$= 0.097\ \mu m$$

1 Marks

$$\mathcal{E}_m = \frac{2(V_{bi}-V_a)}{W} = \frac{2\times 0.12V}{0.097\times10^{-4} cm} = \boxed{25 kV/cm}$$

b, i, The equilibrium minority carrier densities are given by

$$p_{no} = \frac{n_i^2}{N_d} = \frac{(1.5\times10^{10})^2}{2\times10^{16}} = 1.125\times10^4 \ cm^{-3}$$

$$n_{p0} = \frac{n_i^2}{N_a} = \frac{(1.5 \times 10^{10})^2}{1 \times 10^{17}} = 2.25 \times 10^3 \, cm^{-3}$$

the minority carrier densities at x_p & x_n are given by

$$n(x_p) = n_{p0}\left(e^{V_a/V_T} - 1\right) = \boxed{1.8 \times 10^{14} \, cm^{-3}}$$ 1 Marks

$$p(x_n) = p_{n0}\left(e^{V_a/V_T} - 1\right) = \boxed{8.9 \times 10^{14} \, cm^{-3}}$$ 1 Marks

c, The diffusion coefficients are given by

$$D_p = V_T \mu_p = 0.0259 \times 500 = 12.9 \, cm^2/s$$

$$D_n = V_T \mu_n = 0.0259 \times 1500 = 38.7 \, cm^2/s$$

The minority carrier diffusion lengths in the neutral regions are

$$L_p = \sqrt{D_p \tau_p} = 80.3 \, \mu m$$

$$L_n = \sqrt{D_n \tau_n} \cdot 88 \, \mu m$$

The minority carrier densities at x_n & x_p are given by

$$J_p(x_n) = \frac{q D_p p_{n0}}{L_p}\left(e^{V_a/V_T} - 1\right) = \boxed{0.235 \, A/cm^2}$$ 1 Marks

$$J_n(x_p) = \frac{q D_n n_{p0}}{L_n}\left(e^{V_a/V_T} - 1\right) = \boxed{0.13 \, A/cm^2}$$ 1 Marks

d, The diode Current I is given by

$$I = A\left[J_p(x_n) + J_n(x_p)\right]$$

$$= 10^{-3}\,Cm^2\left(0.235 + 0.13\right)\,A/Cm^2$$

$\boxed{I = 0.365\ mA}$, 1 Marks

e, In the neutral p or n region, more than $5L_n$ or $5L_p$ away from the depletion region, the entire current density is due to drift of the majority carriers i.e. $J \approx J_n = q\mu_n \mathcal{E}^n_{neutral}\, n_{no}$ in the neutral n region, $5L_p$ away from the depletion region giving

$$\mathcal{E}^n_{neutral} = \frac{J}{q\mu_n n_{no}} = \frac{0.365\left[A/Cm^2\right]}{1.6\times10^{-19}[C]\times1500\left[\frac{Cm^2}{V\text{-}s}\right]\times2\times10^{16}\left[\frac{1}{Cm^3}\right]}$$

$$= \boxed{0.076\ V/Cm}$$ 1 Marks

Similarly

$$\mathcal{E}^p_{neutral} = \frac{J}{q\mu_p p_{po}} = \boxed{0.045\ V/cm}$$ 1 Marks

f, The reverse Saturation current I_s is given by

$$I_s = A\left(\frac{q D_p p_{no}}{L_p} + \frac{q D_n n_{po}}{L_n}\right)$$

$$\boxed{I_s = 4.5 \times 10^{-15}\ A}$$ 1 Marks