Level 3 Condensed Matter Physics- Part II
Weekly problem 3 solutions

(1) i) The intrinsic carrier concentration (n_i) is given by [1 mark]:

$$n_i = \sqrt{N_c N_v}\exp\left(-\frac{E_g}{2kT}\right) = 9.7 \times 10^{15}\ \mathrm{m}^{-3}$$

The built-in voltage (V_{bi}) is therefore [1 mark]:

$$\phi_{bi} = \frac{kT}{e}\ln\left(\frac{N_A N_D}{n_i^2}\right) = 0.71\ \mathrm{V}$$

ii) The space charge width on the *n*-side [1 mark]:

$$w_n = \left[\frac{2\epsilon_r\epsilon_0\phi_{bi}}{e}\left(\frac{N_A}{N_D}\right)\left(\frac{1}{N_A + N_D}\right)\right]^{1/2} = 0.38\ \mu\mathrm{m}$$

and on the *p*-side [1 mark]:

$$w_p = \left[\frac{2\epsilon_r\epsilon_0\phi_{bi}}{e}\left(\frac{N_D}{N_A}\right)\left(\frac{1}{N_A + N_D}\right)\right]^{1/2} = 0.12\ \mu\mathrm{m}$$

iii) The magnitude of the maximum electric field is [1 mark]:

$$\mathcal{E}_{\max} = \frac{eN_D w_n}{\epsilon_r\epsilon_0} = \frac{eN_A w_p}{\epsilon_r\epsilon_0} = 2.9 \times 10^6\ \mathrm{V/m}$$

(2) The charge Q stored per unit junction area is:

$$Q = eN_A w_p = eN_D w_n = 3.0 \times 10^{-4}\mathrm{C/m^2}$$

The capacitance per unit area is therefore $C = Q/\phi_{bi}$ = 4.3 x 10^{-4} F/m^2. [2 marks]

An alternative, but equivalent, definition of capacitance per unit area is:

$$C = \frac{\epsilon_r\epsilon_0}{d}$$

where d is the capacitor plate spacing. Substituting $d = (w_n + w_p)$ gives C = 2.1 x 10^{-4} F/m^2. This is different by a factor of 2 to the previous answer due to the approximate nature of the calculation. Both approaches are nevertheless acceptable. [2 marks]

(3) The current is given by [1 mark]:

$$I(V) = I_0\left[\exp\left(\frac{eV}{kT}\right) - 1\right]$$

Substituting I = 25 mA for 0.2 V forward bias gives I_0 = 11 μA [2 marks].