Semiconductor Devices

***P-N* Junction**

1. Show that the capacitance of a *p-n* junction is the same as that of a parallel-plate capacitor with a plate separation equal to the width of the depletion layers and filled with a dielectric with the same value of ε. A *p-n* junction of area $1mm^2$ is made of germanium with equal acceptor and donor densities of 10^{21} m^{-3}. Estimate the width of the depletion layers and the capacity of the junction for zero applied voltage. (For Ge, E_G = 0.75eV, ε = 16.)

2. A *p-n* junction, with a cross section of 3.6 x 10^{-7} m^2, is fabricated from silicon, with an intrinsic electron concentration of 1.50 x 10^{16} electrons/m^3 at 300 K. The *n* side has 2.40 x 10^{17} donors/m^3, while the *p* side has 3.40 x 10^{16} acceptors/m^3. Assume each donor is singly ionized and each acceptor has captured one electron. What is: (a) the contact potential, (b) the width of the depletion region, (c) the magnitude of the electric field at the junction, and (d) the total impurity charge in the depletion region on the *n* side of the junction?

3. Estimate the ratio of the forward and the reverse biased currents in a *p-n* junction diode when the applied voltage is 0.5 V.

4. The mobility of electrons in a semiconductor is $0.2m^2$ $V^{-1}s^{-1}$ and the recombination time for electrons 10^{-4}s. A *p-n* diode is made from this material in which the *p*-region is doped with 10^{20} acceptors/m^3 and the *n*-region is doped with 10^{23} donors/m^3. The junction area is $5mm^2$. Estimate the maximum current that could pass if the junction is forward biased with 0.5 V (Assume N_eN_h = 10^{33} m^{-6}).

5. A symmetric *p-n* junction, with a uniform cross section of 5.0 x 10^{-7} m^2, has minority carrier concentrations $n_p = p_n$ = 7.1 x 10^{13} carriers/m^3, with diffusion constants $D_n = D_p$ = 4.3 x 10^{-3} m^3/s, and diffusion lengths $L_n = L_p$ = 2.30 x 10^{-5} m. For a forward bias of 0.5 V find (a) the total current, (b) the hole current at the transition region boundary on the *n* side, and (c) the electron current at the transition region boundary on the *p* side. A 0.50-V reverse bias is now applied to the *p-n* junction. Find (d) the total current (e) the hole current at the transition region boundary on the *n* side and (f) the electron current at the transition region boundary on the *p* side.

6. If electron tunnelling across a *p-n* junction does not occur until the depletion layer is less than 10 nm, estimate the minimum doping which would be necessary in order that a germanium tunnel diode will operate (ε = 16).

Solar Cells

7. Explain the operation of a solar cell in which a *p-n* junction is illuminated. Assume a closed circuit containing an external resistance *R*. Make qualitative sketches of the current voltage relationships with and without incident light. What is the minimum

frequency which the light must have? How can the current-voltage characteristic be used to obtain the photoelectrically generated power? Discuss the various parameters that influence the efficiency.

8. Show that the maximum output power of a solar cell is:

$$P_M \cong I_L \left[V_{OC} - \frac{k_B T}{q} \ln(1 + \frac{qV_M}{k_b T}) - \frac{k_B T}{q} \right]$$

where I_L is the photocurrent, V_{OC} is the open circuit voltage and V_M is the maximum voltage

Heterostructures and Quantum Wells

9. Assuming an infinitely deep potential well, estimate the emission wavelength of a 10nm GaAs quantum well laser. The electron density at the normal operating point of the laser is $10^{16} m^{-2}$: what is the electron quasi-Fermi level (chemical potential) and how many levels are occupied? $(m_e^* = 0.07 m_e, m_h^* = 0.35 m_e)$

10. Assuming that $E_G(Al_xGa_{1-x}As) = (1.42 + 1.59x)$eV, and a conduction/valence bandgap discontinuity ratio of 60:40, estimate the depth of the electron potential well in a 10nm GaAs/$Al_{0.3}Ga_{0.7}As$ quantum well structure. Determine the number of confined states assuming the electron mass is the same in both materials, and compare it with the result for the infinite potential well case.