Problems

1. A silicon p-n junction ($N_a = 10^{16}$ cm^{-3} and $N_d = 4 \times 10^{16}$ cm^{-3}) is biased with $V_a = -3$ V. Calculate the built-in potential, the depletion layer width and the maximum electric field of the junction.

2. An abrupt silicon p-n junction consists of a p-type region containing 10^{16} cm^{-3} acceptors and an n-type region containing also 10^{16} cm^{-3} acceptors in addition to 10^{17} cm^{-3} donors.

   a) Calculate the thermal equilibrium density of electrons and holes in the p-type region as well as both densities in the n-type region.

   b) Calculate the built-in potential of the p-n junction.

   c) Calculate the built-in potential of the p-n junction at 100°C.

3. For a p-n junction with a built-in potential of 0.62 V

   a) What is the potential across the depletion region at an applied voltage, V_a, of 0, 0.5 and -2 Volt?

   b) If the depletion layer is 1 micrometer at $V_a = 0$ Volt, find the maximum electric field in the depletion region.

   c) Assuming that the net doping density $|N_d - N_a|$ is the same in the n-type and p-type region of the diode, carefully sketch the electric field and the potential as a function of position throughout the depletion region. Add numeric values wherever possible.

4. An abrupt silicon ($n_i = 10^{10}$ cm^{-3}) p-n junction consists of a p-type region containing 10^{16} cm^{-3} acceptors and an n-type region containing 5×10^{16} cm^{-3} donors.

   a) Calculate the built-in potential of this p-n junction.

   b) Calculate the total width of the depletion region if the applied voltage V_a equals 0, 0.5 and -2.5 V.

   c) Calculate maximum electric field in the depletion region at 0, 0.5 and -2.5 V.

   d) Calculate the potential across the depletion region in the n-type semiconductor at 0, 0.5 and -2.5 V.

5. Consider an abrupt p-n diode in thermal equilibrium with as many donors in the n-type region as acceptors in the p-type region and a maximum electric field of -13 kV/cm and a total depletion layer width of 1 µm. (assume $e_s / e_0 = 12$)

   a) What is the applied voltage, V_a?

   b) What is the built-in potential of the diode?

   c) What is the donor density in the n-type region and the acceptor density in the p-type region?

   d) What is the intrinsic carrier density of the semiconductor if the temperature is 300 K ?

6. A silicon (n_i = 10^{10} cm^{-3}) p-n diode with N_a = 10^{18} cm^{-3} has a capacitance of 10^{-8} F/cm^2 at an applied voltage of 0.5 V. Find the donor density.

7. A silicon (n_i = 10^{10} cm^{-3}) p-n diode has a maximum electric field of -10^6 V/cm and a depletion layer width of 1 µm. The acceptor density in the p-type region is four times larger than the donor density in the n-type region. Calculate both doping densities.

8. Consider a symmetric silicon p-n diode (N_a = N_d)

   a) Calculate the built-in potential if N_a = 10^{13}, 10^{15} and 10^{17} cm^{-3}. Also, calculate the doping densities corresponding to a built-in potential of 0.7 V.

   b) For the same as in part a), calculate the total depletion layer widths, the capacitance per unit area and the maximum electric field in thermal equilibrium.

   c) Repeat part a) and b) with N_a = 3 N_d.

9. A one-sided silicon diode has a breakdown voltage of 1000 V for which the maximum electric field at breakdown is 100 kV/cm. What is the maximum possible doping density in the low doped region, the built-in potential, the depletion layer width and the capacitance per unit area? Assume that bulk potential of the highly doped region is E_g/2 (= 0.56 V).

10. A silicon p-n junction (N_a = 10^{16} cm^{-3} and N_d = 4 x 10^{16} cm^{-3}) is biased with V_a = 0.6 V. Calculate the ideal diode current assuming that the n-type region is much smaller than the diffusion length with w_n' = 1 µm and assuming a "long" p-type region. Use m_n = 1000 cm^2/V-s and m_p = 300 cm^2/V-s. The minority carrier lifetime is 10 µs and the diode area is 100 µm by 100 µm.

11. Derive equation 4.4.14.

12. Calculate the relative error when using the "short diode" approximation if L_n = 2 w_p' and L_p = 2 w_n'.

13. A silicon p-n junction (N_a = 10^{15} cm^{-3}, w_p = 1 µm and N_d = 4 x 10^{16} cm^{-3}, w_n = 1 µm) is biased with V_a = 0.5 V. Use m_n = 1000 cm^2/V-s and m_p = 300 cm^2/V-s. The minority carrier lifetime is 10 µs and the diode area is 100 µm by 100 µm.

    a) Calculate the built-in potential of the diode.

    b) Calculate the depletion layer widths, x_n and x_p, and the widths of the quasi-neutral regions.

    c) Compare the width of the quasi-neutral regions with the minority-carrier diffusion-lengths and decide whether to use the "long" or "short" diode approximation. Calculate the current through the diode.

    d) Compare the result of part c) with the current obtained by using the general solution (equation 4.4.14)

e) Using the approximation chosen in part c) calculate the ratio of the electron current to the hole current traversing the depletion region.

14. An abrupt silicon p-n diode consists of a p-type region containing 10^{18} cm^{-3} acceptors and an n-type region containing 10^{15} cm^{-3} donors.

a) Calculate the breakdown field in the n-type region.

b) Using the breakdown field from part a), calculate the breakdown voltage of the diode.

c) What is the depletion layer width at breakdown?

d) Discuss edge effects and specify the minimum junction depth needed to avoid these effects.

15. A 1 cm^2 solar cell consists of a p-type region containing 10^{18} cm^{-3} acceptors and an n-type region containing 10^{15} cm^{-3} donors. $w_p{}' = 0.1$ µm and $w_n >> L_p$. Use m_n = 1000 cm^2/V-s and m_p = 300 cm^2/V-s. . The minority carrier lifetime is 10 µs . The diode is illuminated with sun light, yielding a photocurrent density of 30 mA/cm^2.

a) Calculate the open circuit voltage and short-circuit current of the solar cell.

b) Calculate the maximum power generated by the call and the corresponding voltage and current.

c) Calculate the fill factor of the solar cell.

d) Calculate the fill factor for the same cell when a concentrator illuminates it so that the photocurrent density equals 300 A/cm^2.