ECE344 Fall07

HOMEWORK 4

P-N junctions

20 A silicon step junction maintained at room temperature is doped such that $E_F = E_v + E_G/4$ on the P-side and $E_F = E_c - E_G/4$ on the N-side. (a) Draw the equilibrium energy band diagram for this junction, (b) Determine an analytical expression for the built-in potential V_{bi}, (c) Give the numerical value of V_{bi}.

15 Consider a p-n junction diode in GaAs doped with $1.6 * 10^{15} cm^{-3}$ acceptors on the p-type side and $1 * 10^{17} cm^{-3}$ donors on the n-type side at a temperature of $300K$. Assume that GaAs has an energy gap of $E_G = 1.4eV$, a relative dielectric constant of 13, and effective band-edge densities of states of $Nc = 5 * 10^{17} cm^{-3}$ and $Nv = 7 * 10^{18} cm^{-3}$. (a) Calculate the built-in voltage of the device (derive first an expression for V_{bi}, in function of the inputs of the problem), (b) the depletion width.

15 An abrupt silicon p-n junction consists of a p-type region containing $2 * 10^{16} cm^{-3}$ acceptors and an n-type region containing also $10^{16} cm^{-3}$ acceptors in addition to $10^{17} cm^{-3}$ donors. We consider that the intrinsic concentration is $n_i = 10^{10} cm^{-3}$ at $T = 300K$. (a) Calculate the thermal equilibrium density of electrons and holes in the p-type region (n_p and p_p) as well as in the n-type region (n_n and p_n). (a) Derive an analytical expression for V_{bi} in function of n_n and p_p, (b) Calculate the built-in potential of the p-n junction at 300K, (c) Calculate the built-in potential of the p-n junction at 400 K ($n_i = 4.52 * 10^{12}$).

20 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 a n-type region containing $5 * 10^{16} cm^{-3}$ donors. Calculate the built-in potential of this p-n junction. For an applied voltage equals 0, 0.5 and -2.5V, calculate the total width of the depletion region (in μm), calculate maximum electric field in the depletion region (in kV/cm), calculate the potential across the depletion region in the n-type semiconductor (in Volt). We will put these nine results into a summary table.

	$V_a = 0V$	$V_a = 0.5V$	$V_a = -2.5V$
$W \mu m$			
$E(kV/cm)$			
$V_n(V)$			

10 Consider a GaAs P-N junction (ideal diode) with a reverse saturation current $I_0 = 10^{-18} A$, calculate the applied bias potential required to obtain a current of $10mA$.

20 An abrupt silicon p-n junction ($N_a = 10^{16} cm^{-3}$ and $N_d = 4 * 10^{16} cm^{-3}$) is biased with $V_a = 0.6V$. Give the expression of the ideal diode current assuming that the n-type region is much smaller than the diffusion length with $w_n = 1mm$ (Note that the hole diffusion current occurs in the "short" n-type region and therefore depends on the quasi-neutral width w_n in that region- **Hint:** $L_p = w_n$ in the expression), and assuming a "long" p-type region. Use $\mu_n = 1000 cm^2/V.s$ and $\mu_p = 300 cm^2/V.s$. The minority carrier lifetime is $10 \mu s$ and the diode area is $100 \mu m$ by $100 \mu m$. We will give the numerical values of all the physical quantities which are necessary to compute the current I (we will give I in mA and we use the fact that $n_i = 10^{10} cm^{-3}$.

Bonus Problem - Introduction to PIN Diode (25pts)

The pin (p-i-n) diode, generally made of silicon, is derived from the p-n junction adding an undoped silicon zone (i for intrinsic) of width $\Delta \sim 100\mu m$ between the p and n regions. Lacking an analytical solution of the band bending in an i region, we attempt to understand it intuitively in the next questions.

1. Let us first consider a abrupt P-N junction first. Using the full depletion approximation, give the expression of the charge Q per unit of area stored as fixed charges in the band-bending regions on either side of the metallurgical junction in function of $V_i - V_A$ (built-in minus applied potential) and the doping N_a and N_d.

2. A simple approximation to a p-i junction is a p-n junction with $N_d << N_a$ (a $p - n^-$ junction). Using the above result, what can you say about the width of the space charge region zone in the n^- region compared to the width of the corresponding zone in the p region ? In which spatial region does most of the variation of the electrostatic potential occur (justify your answer)?

3. Consider next the behavior of the space charge zone in an intrinsic semiconductor. Write down the Poisson equation and the equation expressing the charge density as a function of the electrostatic potential (we consider a potential difference V with respect to the intrinsic region), and deduce the differential equation satisfied by the potential (in function of n_i).

4. The above equation has no analytical solution. Nonetheless, one can estimate the order of magnitude of the characteristics distance over which the bands curve. To this end, rewrite this equation in an approximate form in the limit of very small potential variation and give a general solution in terms of a characteristic distance λ (you may need also to include the constant coefficients α, β). Express the characteristics distance λ (the "screening length" or Debye length) as a function of the intrinsic equilibrium carrier density $2n_i$. Calculate λ for silicon at room temperature.

5. Suppose that the above results remain valid for $V > k_B T/q$, sketch and explain the energy band diagram for a pin diode at equilibrium.