SSDL

Department of Electrical and Computer Engineering
University of Florida
Ph.D. Qualifying Exam 2015-2016
AREA: SOLID STATE DEVICES

Question 1) Basic physics of semiconductors and pn junctions

Consider an ideal p^+-n junction (i.e. $N_a >> N_d$) at 300 K, with a cross-sectional area A = 10^{-3} cm^2.

For a p-n junction, the I-V relationship is given by $I = qA\left(\frac{D_p}{L_p}p_n + \frac{D_p}{L_n}n_p\right)\left(e^{qV/kT} - 1\right)$.

For a p-n junction, the depletion region width is given by $W = \sqrt{\frac{2\varepsilon_0\varepsilon_r(V_0 - V)}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)}$.

a) Suppose that the built-in (contact) potential is V_0 = 0.5 V and the donor concentration on the n-side is $N_d = 4\times10^{15}$ cm^{-3}. Assume that the depletion region width W is in the n-side of the junction entirely and calculate W at equilibrium. (30 points).

b) If the hole diffusion coefficient is D_p = 10 cm^2/s and the hole diffusion length is $L_p = 3.16\times10^{-3}$ cm, calculate the current at a forward bias of 0.7 V at 300 K. (30 points).

c) Now assume that D_n=D_p and L_n=L_p and the diode is forward biased. What fraction of the forward diffusion current is due to minority carrier injection of electrons into the p^+ region if the acceptor concentration on the p-side is N_a = 10^{19} cm^{-3}? (20 points).

d) Now assume that we fabricate an **identical** Germanium (Ge) p^+-n junction instead of Silicon (Si). Assume for this problem that all materials properties of Si and Ge are identical except that Ge has a smaller bandgap than Si. Will the Si or Ge p^+-n junction have a higher reverse saturation current I_0? Explain in a few sentences using appropriate equations to justify your answer. (20 points).

Physical constants:
q = 1.6 x 10^{-19} C
kT (at T=300 K) = 0.0259 eV
ε_0 = 8.85 x 10^{-14} F/cm

Properties of Silicon:
E_g = 1.11 eV
ε_r = 11.8
n_i (at T=300 K) = 1.5 x 10^{10} cm^{-3}

SSD2

Question 2) Quantum Mechanics

Consider a 1D electron wavefunction given by

$$\psi_n(x,t) = A\sin(\frac{n\pi x}{L})\exp(\frac{-iEt}{\hbar})$$

where A is the normalization constant, L and E are also constants, and n = 1,2,3,4,….(i.e. a positive integer).

Assume that the wavefunction is zero (i.e. $\psi_n(x,t) = 0$) when $x < 0$ and $x > L$.

a) Calculate the value of the normalization constant A. (30 points).

b) Calculate the probability of finding the electron in the region $0 \le x \le L/4$ for arbitrary n. (30 points).

c) What is the probability of finding the electron in the region $0 \le x \le L/2$ for arbitrary n? For this part, give the answer without calculating any integrals. (10 points).

d) Calculate the expectation value of the momentum of the electron for arbitrary n. (30 points).

Potentially useful integral formulas:

$$\int \cos^2 ax\, dx = \frac{x}{2} + \frac{\sin 2ax}{4a} \qquad \int \sin^2 ax\, dx = \frac{x}{2} - \frac{\sin 2ax}{4a}$$

$$\int x\cos^2 ax\, dx = \frac{x^2}{4} + \frac{x\sin 2ax}{4a} + \frac{\cos 2ax}{8a^2}$$

$$\int x\sin^2 ax\, dx = \frac{x^2}{4} - \frac{x\sin 2ax}{4a} - \frac{\cos 2ax}{8a^2}$$

$$\int \sin ax \cos ax\, dx = \frac{\sin^2 ax}{2a}$$