SSD1

SOLID STATE DEVICES

SSD-1. Basic physics of semiconductors and pn junctions

a) A Silicon sample at 300 K is doped with Phosphorus at a donor concentration of $N_D=10^{15}$ cm^{-3}. Calculate the equilibrium concentration of electrons (n_0) and holes (p_0). (20 points).

For the below parts, assume that the Silicon sample in part (a) is uniformly illuminated, resulting in an optical electron-hole pair generation rate $G_L = 10^{12}$ cm^{-3}s^{-1}. Use electron and hole minority carrier recombination lifetimes of $\tau_n = \tau_p = 10^{-1}$ s.

b) Find the electron concentration n under steady state conditions. (20 points).

c) Find the hole concentration p under steady state conditions. (20 points).

d) Is the low-level injection condition satisfied? Why or why not? Explain in a sentence or two. (20 points).

e) Consider that the light is suddenly turned off at $t = 0$. Find the hole concentration p at $t = 1$ s. (20 points).

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

Continuity equations under low-level injection conditions:

For electrons: $$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{\partial J_n}{\partial x} + G_L - \frac{(n - n_0)}{\tau_n}$$

For holes: $$\frac{\partial p}{\partial t} = -\frac{1}{q}\frac{\partial J_p}{\partial x} + G_L - \frac{(p - p_0)}{\tau_p}$$

Transport equations:

For electrons: $$J_n = q\mu_n nE + qD_n \frac{\partial n}{\partial x}$$

For holes: $$J_p = q\mu_p pE - qD_p \frac{\partial p}{\partial x}$$

SSD2

SOLID STATE DEVICES

SSD-2. Quantum Mechanics

Consider the 1D "particle in a box" problem, where the potential $V(x)$ is zero for $-a < x < a$, and infinite elsewhere. The solutions are given by

$$\psi_n(x) = \frac{1}{\sqrt{a}}\cos\left(\frac{n\pi x}{2a}\right), \quad n = 1,3,5\ldots(\text{odd}), \; -a < x < a$$

$$\psi_n(x) = \frac{1}{\sqrt{a}}\sin\left(\frac{n\pi x}{2a}\right), \quad n = 2,4,6\ldots(\text{even}), \; -a < x < a$$

$$E_n = \frac{\hbar^2\pi^2 n^2}{8ma^2}, \; n = 1,2,3\ldots$$

For the below parts, consider a particle in the $n = 4$ state of this 1D "particle in a box" problem, namely $\psi_4(x)$.

a) Write down explicitly the expression for the wavefunction of the particle at any time t, namely $\Psi_4(x,t)$. (20 points).

b) Calculate the probability of finding the particle in the region $\frac{a}{2} \le x \le a$. (20 points).

c) Calculate the probability current density $j(x, t)$ for this particle. (20 points).

d) Sketch the probability density $P(x)$ for this particle as a function of x, clearly labeling the values on the x- and y- axes. (20 points).

e) Calculate the expectation value of the energy of this particle $\langle E \rangle$. (20 points).