Microelectronics Technology

ECSE - 2210

Midterm Exam

Solution

Spring Semester 2014

Question 1

(a) Sample absorbs 250 mW power. Light has wavelength of 450 nm.

Absorbed number of photons per unit time =

$$= \frac{P}{h\nu} = \frac{P}{h\frac{c}{\lambda}} = \frac{0.25\,W \quad s \quad 450\times10^{-9}\,m}{6.63\times10^{-34}\,Js \quad 3\times10^{8}\,m}$$

$$= \frac{0.25 \quad 450}{6.63\times3}\;\frac{10^{-9}}{10^{-34}\;10^{8}}\;\frac{J \quad s \quad m}{s \quad Js \quad m}$$

$$= \underline{\underline{5.66\times10^{17}\,\frac{1}{s}}}$$

Generation rate $= G = \frac{5.66\times10^{17}\,s^{-1}}{10^{-3}\,mm^{3}} =$

$$= 5.66\;\frac{10^{17}}{10^{-3}}\;\frac{s^{-1}}{10^{-3}\,cm^{3}} = \underline{\underline{5.66\times10^{23}\,cm^{-3}\,s^{-1}}}$$

(b) Emitted power

$$P = \frac{E}{t} = 10^{17}\,s^{-1}\times 1\,eV = \frac{10^{17}}{s}\;1.6\times10^{-19}\,CV$$

$$= 1.6\times10^{-2}\,W = \underline{\underline{16\,mW}}$$

(c) Quantum efficiency $= \frac{\text{Emission rate}}{\text{Absorption rate}} =$

$$= \frac{10^{17}\ \frac{1}{s}}{5.66 \times 10^{17}\ \frac{1}{s}} = \underline{\underline{17.7\%}}$$

(d) Power efficiency $= \frac{\text{Emitted power}}{\text{Absorbed power}} =$

$$\frac{16\ \text{mW}}{250\ \text{mW}} = \underline{\underline{6.4\%}}$$

(e) Non-radiative recombination caused by defects, impurities, or traps (also called "luminescence killers")

Question 2

2. Circle the correct answer:
   (a) For a semiconductor sample with quantum efficiency of 1, the wavelength of the absorbed light must be shorter than the wavelength of the emitted light. **(T)** F I
   (b) The Einstein relation suggests that particles that have a high mobility diffuse very little (and vice versa). T **(F)** I
   (c) In a constant electric field electrons propagate with a drift velocity that is constant over time. **(T)** F I
   (d) Generally, charge carriers diffuse more rapidly at $T = 300$ K than they do at 200 K. **(T)** F I
   (e) A silicon (Si) pn junction can be intentionally doped with phosphorus (P) donors, and carbon (C) acceptors. T **(F)** I
   (f) The continuity equation expresses the fact that all carriers must be accounted for. **(T)** F I

T = True; F = False; I = Impossible to answer with information provided

Remarks

(a) Required by energy conservation

(b) $D \propto \mu$

(c) $v = \mu \mathcal{E}$

(d) Driving force for diffusion is the thermal energy $E_{thermal} = kT$

(e) C is not an acceptor in Si

(f) This is correct.

Question 3

Si sample. $n = 10^{10}\,cm^{-3}$ $\mathcal{E} = 100\,V/cm$

For Si : $n_i = 10^{10}\,cm^{-3}$

(a) $np = n_i^2 \Rightarrow p = \frac{n_i^2}{n} = \frac{(10^{10}\,cm^{-3})^2}{10^{10}\,cm^{-3}}$

$= \underline{\underline{10^{10}\,cm^{-3}}}$

(b) $\mu_n = 1500\,cm^2/Vs$ $\mu_p = 450\,cm^2/Vs$

$V_{Drift} = \mu_n \mathcal{E} = 1500\,cm^2/Vs \; 100\,\frac{V}{cm} = 15 \times 10^4\,\frac{cm}{s}$

$= \underline{\underline{1500\,\frac{m}{s}}}$

(c) $V_{Drift} = \mu_p \mathcal{E} = 450\,\frac{cm^2}{Vs}\;100\,\frac{V}{cm} = \underline{\underline{450\,\frac{m}{s}}}$

(d) Electron drift current density

$J_n = e n v = 1.6 \times 10^{-19}\,C \times 10^{10}\,cm^{-3}\;15 \times 10^4\,\frac{cm}{s}$

$= 24 \times 10^{-5}\,\frac{C}{s}\,\frac{1}{cm^2} = 240 \times 10^{-6}\,\frac{A}{cm^2}$

$= \underline{\underline{240\,\mu A/cm^2}}$

(e) $J_p = e\,p\,v = 1.6 \times 10^{-19}\,C \times 10^{10}\,cm^{-3} \times 4.5 \times 10^{4}$

$\frac{cm}{s} = 7.2 \times 10^{-5}\,\frac{C\,cm^{-3}\,cm}{s} = 72 \times 10^{-6}\,\frac{A}{cm^2}$

$= 72\,\frac{\mu A}{cm^2}$

(f) $J_{Diffusion} = J_{Drift} = \left| -e D_n \frac{dn}{dx} \right| = 240\,\frac{\mu A}{cm^2}$

$\Rightarrow \frac{dn}{dx} = 240\,\frac{\mu A}{cm^2}\,\frac{1}{e}\,\frac{1}{D_n} = \frac{240 \times 10^{-6}\,A}{1.6 \times 10^{-19}\,C\;\;cm^2}\;\frac{s}{39\,cm^2}$

$= 3.85 \times 10^{13}\,\frac{1}{cm^3\,cm}$

Question 4

Si pn junction. $N_D = 10^{18} cm^{-3}$ $N_A = 10^{16} cm^{-3}$

(a) Depletion layer thickness

$$V_{bi} = V_D = \frac{kT}{e} \ln \frac{n_{no} p_{po}}{n_i^2}$$

$$= 26 mV \ln \frac{10^{18} cm^{-3} \, 10^{16} cm^{-3}}{10^{20} cm^{-6}} = 26 mV \ln(10^{14})$$

$$= 838 mV$$

$$W_D = \sqrt{\frac{2 \varepsilon_r \varepsilon_0 V_{bi}}{e} \frac{N_D + N_A}{N_D N_A}} =$$

$$= \sqrt{\frac{2 \times 11.9 \times 8.85 \times 10^{-12} \frac{As}{Vm} \, 0.838 V}{1.6 \times 10^{-19} C} \frac{1.01 \times 10^{18} cm^{-3}}{10^{34} cm^{-6}}}$$

$$= \sqrt{111 \times \frac{10^6}{10^{15}} \frac{1}{m} cm^3} = \sqrt{111 \times 10^{-9} \frac{1}{100 cm} cm^3}$$

$$= \sqrt{11.9 \times 10^{-8} \, 10^{-2}} \, cm = 3.45 \times 10^{-5} cm$$

$$= 0.345 \times 10^{-4} cm = \underline{\underline{0.345 \mu m}}$$

(b) (1) Electron drift current

(2) Hole drift current

(3) Electron diffusion current

(4) Hole diffusion current

(c) Shockley equation:

$$J = e\left(\frac{D_p}{L_p} p_{no} + \frac{D_n}{L_n} n_{po}\right)\left(e^{eV/kT} - 1\right)$$

It is $n_{no} \gg p_{po}$ $\Rightarrow$ $n_{po} \gg p_{no}$.

$\Rightarrow$ Second summand $\gg$ First summand

In forward direction, the diffusion current dominates. $\Rightarrow$ Electron diffusion current dominates.

(d) Under equilibrium conditions (i.e. $V = 0$), the four currents cancel out.

(e) J_s can be reduced by:

(1) Increasing N_A

(2) Increasing N_D

(3) Increasing E_g (and thus decreasing n_i)