Problems Designed by: Dr. Suren Patwardhan

SOMAIYA
VIDYAVIHAR UNIVERSITY
K J Somaiya College of Engineering

Module 2 Unit 1

SEMICONDUCTORS – NUMERICAL PROBLEMS

Fundamental constants:

1. Elementary charge $q = 1.6 \times 10^{-19}$ C
2. Avogadro's number $N_0 = 6.023 \times 10^{23}$/mol
3. Boltzmann constant $k = 1.38 \times 10^{-23}$ J/K = 8.62×10^{-5} eV/K
4. $kT = 0.025$ eV and $\frac{kT}{q} = 0.025$ volt at room temperature (RT)

1. Determine resistivity of intrinsic Si. Electron and hole mobility in Si are 0.13 and 0.05 m^2/V-s respectively. Intrinsic carrier concentration for Si = $10^{10}/cm^3$.
2. Calculate the majority and minority carrier concentrations and resistivity if we dope Si in previous example with $10^{16}/cm^3$ phosphorous atoms.
3. Density of Si is 2340 kg/m^3 and its atomic weight is 28 gm/mol. If a Si crystal is doped with 1 ppb boron atoms, what type of material would it become. Determine boron concentration in cm^{-3}.
4. Calculate intrinsic concentration for GaAs at RT. Given effective density of states in the CB and VB of GaAs to be 4.37×10^{17}/cc and 8.68×10^{18}/cc respectively. Energy band gap of GaAs = 1.42. eV
5. Estimate the drift velocity and drift current density if a Si sample doped with $10^{16}/cm^3$ donor impurity is subjected to an electric field of 50 V/cm. Given mobility of electrons in Si to be 0.13 m^2/V-s.
6. Estimate the diffusion current density in p-type Si, if hole concentration drops from $3 \times 10^{18}/cm^3$ to 5 $\times 10^{14}/cm^3$ over a space of 10 µm. given diffusion coefficient for holes in Si to be 10 cm^2/s. ~~The acceptance angle of an optical fibre is 25°. Calculate refractive index of cladding if refractive index~~ of ~~core is 1.5~~2.

   $5 \times 10^{17}/cm^2$

7. Determine the probability that an electron is present in CB in intrinsic Ge at RT. Given energy band gap of Ge = 0.66 eV.
8. If Si is doped with indium atoms at a concentration of $10^{16}/cm^3$, determine the probabilities of getting an electron in the CB. $n_i = 10^{16}/m^3$, $E_g = 1.12$ eV
9. A Si sample is doped with 10^{17}/cc donor impurity. Due to doping, a donor level is introduced at 0.05 eV below the CB. Calculate the probability that this donor is ionized at RT. Intrinsic concentration in Si at RT = 10^{10}/cc.
10. Calculate the proportion of electrons having energy E_C and $E_C + 10kT$ in Si at RT

---

(1) $\rho_i = ?$ $\mu_e = 0.13\ m^2/Vs$, $\mu_h = 0.05\ m^2/Vs$, $n_i = 10^{10}\ /cm^3$

$n_i = \frac{10^{10}}{10^{-6}}\ /m^3$

$n_i = 10^{16}\ /m^3$

$\sigma_i = (n_i)(e)(\mu_e + \mu_h)$

$$\rho_i = \frac{1}{\sigma_i} = \frac{1}{(n_i)(e)(\mu_e+\mu_h)}$$

$$= \frac{1}{10^{16} \times 1.6 \times 10^{-19} \times (0.13+0.05)} = \frac{1}{10^{-3} \times 1.6 \times 0.18}$$

$$\rho_i = \frac{10^3}{0.288} = \underline{\underline{3472.2\ \Omega m}}$$

(2) $p_n = ?$, $n_n = ?$, $N_D = 10^{16}/cm^3 = 10^{22}/m^3$

$\therefore n_n \approx N_D = 10^{22}\ /m^3$

$(p_n)(n_n) \simeq n_i^2$

$$p_n = \left(\frac{n_i^2}{n_n}\right) = \frac{10^{32}}{10^{22}} = 10^{10}\ /m^3$$

$$\rho_n = \frac{1}{(n_n)(e)(\mu_e)} = \frac{1}{10^{22} \times 1.6 \times 10^{-19} \times 0.13}$$

$$\rho_n = \frac{10^{-3}}{0.208}$$

$$\rho_n = \underline{\underline{4.8077 \times 10^{-3}\ \Omega m}}$$

(3) $d = 2340\ kg/m^3$ $A = 28 \times 10^{-3}\ kg/mol$,
doping 1 ppb (ie 10^9) boron

$N_A = p = ?$

$$\text{density}(d) = \frac{\text{mass}}{\text{Volume}} = \frac{(n)(A/N_0)}{\text{Volume}} = \left(\frac{n}{\text{Vol}}\right)\left(\frac{A}{N_0}\right)$$

$$\therefore \frac{n}{\text{Volume}} = \frac{(d)(N_0)}{A} = \frac{2340 \times 6.023 \times 10^{23}}{28 \times 10^{-3}} = \frac{2340 \times 6.023 \times 10^{26}}{28}$$

Number of silicon atoms per unit volume $\left(\frac{n}{\text{vol}}\right) = 503.35 \times 10^{26}$

$\therefore$ doping is $(1/10^9)$ $\therefore \frac{p}{\text{Volume}} = 503.35 \times 10^{17}$

$= 5.03 \times 10^{19}\ /m^3$

$= \underline{\underline{5.03 \times 10^{13}\ /cm^3}}$

$n_i = ?$ $N_c = 4.37 \times 10^{17} / cc = 4.37 \times 10^{23} / m^3$

$N_V = 8.68 \times 10^{18} / cc = 8.68 \times 10^{24} / m^3$

$E_g = 1.42\ eV$

$$n_i = \sqrt{(N_c N_V)}\ e^{-E_g/2KT}$$

$$= \left(4.37 \times 10^{23} \times 8.68 \times 10^{24}\right)^{1/2} \cdot \exp\left[\frac{-1.42}{2 \times 8.62 \times 10^{-5} \times 300}\right]$$

$$n_i = \left(37.9316 \times 10^{47}\right)^{1/2} \exp\left[\frac{-1.42}{0.05172}\right]$$

$$n_i = \left(3.79316 \times 10^{48}\right)^{1/2} \exp\left[-27.45\right]$$

$$n_i = 1.9476 \times 10^{24} \cdot \frac{1}{8.34 \times 10^{11}} = \frac{1.9476}{8.34} \times 10^{13}$$

$$n_i = 0.2335 \times 10^{13} = \underline{\underline{2.335 \times 10^{12} / m^3}}$$

(5) $V_d = ?$, $J_d = ?$ $n = 10^{16} / cm^3 = 10^{22} / m^3$

$E = 50 \times 10^2\ V/m$, $\mu_e = 0.13\ m^2/Vs$

$$v_d = (\mu_e)(E) = 0.13 \times 50 \times 10^2 = 13 \times 50 = \underline{\underline{650\ m/s}}$$

$$J_d = (n)(e)(V_d) = 10^{22} \times 1.6 \times 10^{-19} \times 650$$

$$J_d = 1040 \times 10^3 = \underline{\underline{1.040 \times 10^6\ A/m^2}}$$

(6) $p_1 = 3 \times 10^{18} / cm^3$ $dp = (30000 - 5) \times 10^{14}$

$p_2 = 5 \times 10^{14} / cm^3$ $dp = 29995 \times 10^{14} / cm^3$

$dx = 10 \times 10^{-6}\ m$ $(dp) = 29995 \times 10^{20} / m^3$

$$D = 10\ cm^2/sec = 10 \times 10^{-4}\ m^2/sec$$

$$J_{diff} = (D)(e)\left(\frac{dp}{dx}\right) = 10 \times 10^{-4} \times 1.6 \times 10^{-19} \times \frac{29995 \times 10^{20}}{10^{-5}}$$

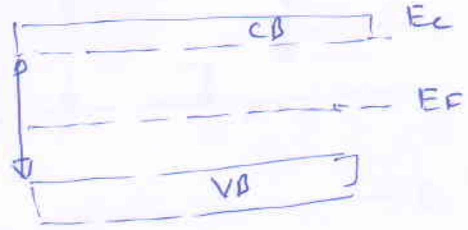
$$= 10^{-3} \times 1.6 \times 10^{-19} \times 29995 \times 10^{25}$$

$$= 1.6 \times 29995 \times 10^{3} = 47992 \times 10^{4} = \underline{\underline{4.792 \times 10^{8}\ A/m^2}}$$

(7) $f(E) = \dfrac{1}{1+\exp\left(\dfrac{E-E_F}{kT}\right)}$

$E_c - E_F = \dfrac{E_g}{2}$

$= 0.33$



$\dfrac{E_c-E_F}{kT} = \dfrac{0.33}{0.025}$

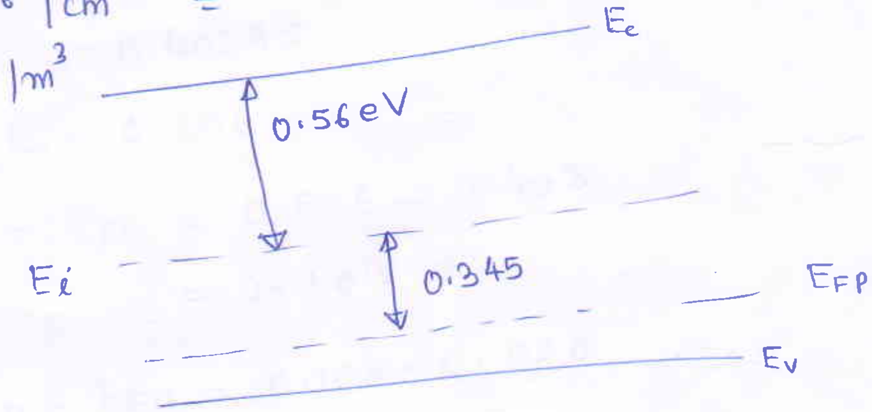
$\dfrac{E_c-E_F}{kT} = 13.2$

$\exp\left(\dfrac{E_c-E_F}{kT}\right) = \exp(13.2) = 5.4\times10^{5}$

$f(E_c) = \dfrac{1}{5.4\times10^5} = 0.1851\times10^{-5} = \underline{\underline{1.851\times10^{-6}}}$

(8) $N_A = 10^{16}/cm^3 = 10^{22}/m^3, \; n_i = 10^{16}/m^3$

$p_p = 10^{22}/m^3$



$E_{FP} - E_i = -kT\ln\left(\dfrac{p_p}{n_i}\right)$

$E_i - E_{FP} = kT\ln\left(\dfrac{p_p}{n_i}\right) = 0.025\ln\left(\dfrac{10^{22}}{10^{16}}\right)$

$= 0.025\ln(10^6)$

$E_i - E_{FP} = 0.025\times13.815 = 0.345$

$\therefore E_c - E_{FP} = 0.56+0.345 = 0.905$

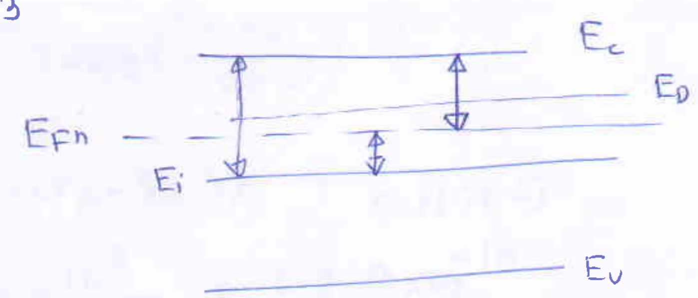
$f(E_c) = \dfrac{1}{1+\exp\left(\dfrac{0.905}{0.025}\right)} \approx \exp(-36.2)$

$= \dfrac{10^{-15}}{5.26} = \underline{\underline{1.9\times10^{-16}}}$

(9)

$N_D = n_n = 10^{17}/cc = 10^{23}/m^3$

$n_i = 10^{16}/m^3$



$$E_{Fn} - E_i = kT \ln\left(\frac{n_n}{n_i}\right) = 0.025 \ln\left(\frac{10^{23}}{10^{16}}\right)$$

$$= 0.025 \times \ln(10^7)$$

$$= 0.025 \times 16.118$$

$$= 0.40295$$

$$E_c - E_i = 0.506$$

$$E_c - E_{Fn} = 0.506 - 0.403$$

$$= 0.103 \text{ eV}$$

$$E_D - E_{Fn} = 0.103 - 0.050$$

$$= 0.053$$

$$f(E_D) = \frac{1}{1+\exp\left(\frac{E_D - E_{Fn}}{kT}\right)}$$

$$\exp\left(\frac{0.053}{0.025}\right) = \exp(2.12) = 8.33$$

$$f(E_D) = \frac{1}{1+8.33} = \frac{1}{9.33} = \underline{\underline{0.107}}$$

(5)

(10)

$$f(E_c) = \frac{1}{1+\exp\left(\frac{0.56}{0.025}\right)}$$

$E_c + 10KT$

$$\approx \exp(-22.4) = \frac{1}{\exp(22.4)}$$

$$= \frac{10^{-9}}{5.348} = 1.869 \times 10^{-10}$$

$$f(E_c + 10KT) = \frac{1}{1+\exp\left(\frac{E_c + 10KT - E_F}{KT}\right)}$$

$$E_c + 10KT - E_f = 0.56 + 10KT = 0.56 + 10 \times 0.025$$

$$= 0.56 + 0.25$$

$$= 0.81 \text{ eV}$$

$$\exp\left(\frac{0.81}{0.025}\right) = \exp(32.4) = 1.17 \times 10^{14}$$

$$f(E_c + 10KT) = \frac{10^{-14}}{1.17} = 8.5 \times 10^{-15}$$

$$\therefore \frac{n(E = E_c)}{n(E = E_c + 10KT)} = \frac{1.87 \times 10^{-10}}{8.5 \times 10^{-15}} \simeq 10^4$$

$$= \underline{\underline{2.2 \times 10^4}}$$