

## Module 2 Unit 1

### SEMICONDUCTORS – NUMERICAL PROBLEMS

Fundamental constants:

1. Elementary charge  $q = 1.6 \times 10^{-19} \text{ C}$
2. Avogadro's number  $N_0 = 6.023 \times 10^{23}/\text{mol}$
3. Boltzmann constant  $k = 1.38 \times 10^{-23} \text{ J/K} = 8.62 \times 10^{-5} \text{ eV/K}$

Take  $kT = 0.025 \text{ eV}$  and  $\frac{kT}{q} = 0.025 \text{ volt}$  at room temperature (RT)

1. Determine resistivity of intrinsic Si. Electron and hole mobility in Si are  $0.13$  and  $0.05 \text{ m}^2/\text{V-s}$  respectively. Intrinsic carrier concentration for Si =  $10^{10}/\text{cm}^3$ .
2. Calculate the majority and minority carrier concentrations and resistivity if we dope Si in previous example with  $10^{16}/\text{cm}^3$  phosphorous atoms.
3. Density of Si is  $2340 \text{ kg/m}^3$  and its atomic weight is  $28 \text{ gm/mol}$ . If a Si crystal is doped with  $1 \text{ ppb}$  boron atoms, what type of material would it become. Determine boron concentration in  $\text{cm}^{-3}$ .
4. An n-type impurity is added to a semiconductor at  $0.01 \text{ ppm}$  concentration. Calculate resistivity of this doped sample. Given density of the semiconductor material  $5.3 \text{ gm/cm}^3$  and its molecular weight is  $144.65 \text{ gm/mol}$ . Given mobility of electrons in this material is  $8.5 \text{ m}^2/\text{V-s}$ .
5. Calculate intrinsic concentration for GaAs at RT. Given effective density of states in the CB and VB of GaAs to be  $4.37 \times 10^{17}/\text{cc}$  and  $8.68 \times 10^{18}/\text{cc}$  respectively. Energy band gap of GaAs =  $1.42$ .
6. Estimate the drift velocity and drift current density if a Si sample doped with  $10^{16}/\text{cm}^3$  donor impurity is subjected to an electric field of  $50 \text{ V/cm}$ . Given mobility of electrons in Si to be  $0.13 \text{ m}^2/\text{V-s}$ .
7. Estimate the diffusion current density in p-type Si, if hole concentration drops from  $3 \times 10^{18}/\text{cm}^3$  to  $5 \times 10^{14}/\text{cm}^3$  over a space of  $10 \text{ }\mu\text{m}$ . given diffusion coefficient for holes in Si to be  $10 \text{ cm}^2/\text{s}$ .
8. Electric field of intensity  $2 \times 10^4 \text{ V/m}$  is required to balance the hole diffusion current generated due to hole concentration gradient of  $3 \times 10^{21}/\text{cm}^4$ . Calculate hole concentration at RT.
9. Determine the probability that an electron is present in CB in intrinsic Ge at RT. Given energy band gap of Ge =  $0.66 \text{ eV}$ .
10. Estimate the probability that a hole is present in the VB in intrinsic Si at RT. Given energy band gap of Si =  $1.12 \text{ eV}$ . What would be the probability of getting an electron in the VB?
11. If a Ge sample is doped with phosphorous atoms at a concentration of  $10^{16}/\text{cm}^3$ , determine the shift in Fermi level from its intrinsic position.
12. If Si is doped with indium atoms at a concentration of  $10^{16}/\text{cm}^3$ , determine the probabilities of getting an electron and a hole in its VB. Compare with the results of example 10.
13. A Si sample is doped with  $10^{17}/\text{cc}$  donor impurity. Due to doping, a donor level is introduced at  $0.05 \text{ eV}$  below the CB. Calculate the probability that this donor has donated electrons (meaning it is ionized) at RT. Intrinsic concentration in Si at RT =  $10^{10}/\text{cc}$ .
14. Intrinsic carrier concentration in Ge at RT is  $2 \times 10^{13}/\text{cm}^3$ . Determine its resistivity. Given electron and hole mobility in Ge to be  $0.39$  and  $0.19 \text{ m}^2/\text{V-s}$  respectively. If this sample is doped with  $10^{16}/\text{cm}^3$  Al atoms, what type of material would it become? determine resistivity of this doped sample. If the same sample is doped further by  $5 \times 10^{18}/\text{cm}^3$  Sb atoms, what type of material would it become? Re-estimate its resistivity.

15. Si is doped with  $10^{15}/\text{cm}^3$  boron atoms. Determine the temperature at which, intrinsic concentration of Si would match the doping concentration. Given energy band gap for Si = 1.1 eV (assume it is constant of temperature). Given effective density of states in the CB and VB of Si are  $2.82 \times 10^{19}/\text{cc}$  and  $1.83 \times 10^{19}/\text{cc}$  respectively.
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#### HOME WORK

1. Calculate the proportion of electrons having energy  $E_c$  and  $E_c + 10kT$  in Si at RT.
  2. Estimate the probability that an electron is present in the CB and VB in Si at RT for the Si sample of example 15.
  3. Determine intrinsic carrier concentration in Si at (i) 100 K, (ii) 300 K (RT) and (iii) 500 K. Assume Si data as in example 15 of solved problems.
  4. Conductivity of an intrinsic semiconductor changes from  $2.88 \times 10^{-3} \text{ S/cm}$  to  $1.1 \times 10^{-2} \text{ S/cm}$  when temperature increases from  $27^\circ\text{C}$  to  $100^\circ\text{C}$ . Calculate energy band gap of this material.
  5. Mobility of electrons in Si is  $1300 \text{ cm}^2/\text{V-s}$ . These electrons possess average thermal energy given by  $E_{th} = kT$  at a given temperature. Let their mean thermal velocity be given by  $v_{th} = \sqrt{\frac{2E_{th}}{m}}$ , then estimate the electric field at which, the drift velocity of electrons would exceed their average thermal velocity at RT.
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