Module 2 Unit 1

SEMICONDUCTORS - NUMERICALS

(As per Revised Curriculum SVU R-2023)

Physical constants:

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

Classwork:

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 x 10^{17}/cc and 8.68 x 10^{18}/cc respectively. Energy band gap of GaAs = 1.42.
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 x $10^{18}/cm^3$ to 5 x $10^{17}/cm^3$ over a space of 1 µm. given diffusion coefficient for holes in Si to be 10 cm^2/s.
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 probability of getting an electron in the CB. Given energy band gap of Si = 1.12 eV.
9. In above example, determine the probability of getting a hole in the VB. Comment on result of problem no 8 and 9.
10. Calculate the proportion of electrons having energy E_C and E_C + 10kT in Si at RT.

Homework:

1. If a GaAs sample is doped with Si at density 10^{14}/cc, estimate the probability that an electron is present in CB of GaAs at RT. (Si acts as n-type dopant in GaAs) Given intrinsic concentration in GaAs ar RT = 1.8 x $10^6/cm^3$.
2. Estimate electron mobility in previous example if a current density of 4 A/cm^2 is set up on applying electric field of 50 V/cm. q = 1.6 x 10^{-19} C. What could be the diffusivity and concentration gradient present if this drift current is balanced by diffusion current?
3. Intrinsic carrier concentration in Ge at RT is 2 x $10^{13}/cm^3$. Determine its resistivity. Given electron and hole mobility in Ge to be 0.39 and 0.19 m^2/V-s respectively. If this sample is doped with $10^{16}/cm^3$ Al atoms, what type of material would it become? Determine

resistivity of this doped sample. If the same sample is doped further by 5 x 10^{18}/cm^3 Sb atoms, what type of material would it become? Re-estimate its resistivity.

4. Determine position of Fermi level in each case in above example. Energy band gap of Ge = 0.67 eV.
5. When an electric field of intensity 2 x 10^4 V/m is applied to a p-type semiconductor, the drift current is compensated by diffusion of holes at a rate of 3 x 10^{20}/cm^4. Calculate the hole concentration at RT. Given kT/q = 0.025 volt at RT.
6. Si is doped with 10^{15}/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 x 10^{19}/cc and 1.83 x 10^{19}/cc respectively.
7. Determine intrinsic carrier concentration of a semiconductor at 100 K and 500 K. Given intrinsic carrier concentration at room temperature = 10^{12}/cm^3. Assume N_C, N_V and E_g do not change significantly over the given range of temperatures.
8. Conductivity of an intrinsic semiconductor changes from 2.88 x 10^{-3} S/cm to 1.1 x 10^{-2} S/cm when temperature increases from 27°C to 100°C. Calculate energy band gap of this material.
9. In a p-n junction diode, hole concentration in p-side is 10^{16}/cm^3 and on n-side it is 1000/cm^3. If the width of junction region between p and n sides is 50 µm, determine the diffusion current that will be generated. Cross sectional area of the diode is 2 mm x 2 mm and diffusion coefficient for holes in the material of diode = 10 cm^2/s.
10. 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.

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