Tutorial Questions EE 207

(Density of states, Fermi level, Doping, Carrier concentrations)

1. In an intrinsic semiconductor, the ratio of effective masses of electron and hole is $\frac{m_n^*}{m_p^*} = 0.7$ then find out the position of fermi energy level relative to mid energy gap level i.e. $\frac{(E_c - E_v)}{2}$.
2. If the effective density of states are independent of temperature, then find out variation of the intrinsic carrier density with respect to temperature and extract bandgap of semiconductor from that.
3. Calculate the thermal-equilibrium electron and hole concentrations in a compensated P- type semiconductor. Consider a silicon semiconductor at T=300 K, in which $N_a = 10^{16}\ cm^{-3}$ and $N_d = 3 \times 10^{15}\ cm^{-3}$. (Take $n_i = 1.5 \times 10^{10}\ cm^{-3}$)
4. Draw the variation of the fermi energy with respect to temperature, in an energy band diagram for any typical semiconductor.
5. Find out the position of donor energy level relative to conduction band edge in silicon, if the donor atom is phosphorus, and its $m_n^* = 1.08m_0$ and $\epsilon_r = 11.9$ for silicon

6. Does law of mass action ($np = n_i^2$), valid in all conditions for intrinsic and extrinsic semiconductors? Support your answer with proper argument.

7. Determine the position of fermi energy level with respect to valence band energy in p type GaAs at T = 300 K. The doping concentrations are $N_a = 5 \times 10^{16} cm^{-3}$ and $N_d = 4 \times 10^{15} cm^{-3}$. (Consider effective mass and effective density of states for GaAs from text book)

8. (a) We all know in an intrinsic semiconductors p = n. Is it means Intrinsic Fermi level E_i is exactly at the mid-gap $\frac{(E_c - E_v)}{2}$? Give your answer with reasoning.

(b) In a semiconductor $N_c = 2 \times N_v$. Find the position of Intrinsic Fermi level with respect to mid-gap $\frac{(E_c - E_v)}{2}$.

9. Silicon is doped with boron atoms of concentration $N_a = 1.5 \times 10^{10} cm^{-3}$, find the carrier concentrations in the crystal. Find the position of Fermi level

   i) With mid-gap i.e. $\frac{(E_c - E_v)}{2}$ and

   ii) With Intrinsic Fermi level E_i.

10. Calculate the Fermi level of silicon doped with 10^{15}, 10^{17}, and 10^{19} phosphorus atoms/cm^3, at room temperature, assuming complete ionization. From the calculated Fermi level, check if the assumption of complete ionization is justified for each doping. Assume that ionized donors is given by

$$n = \frac{N_D}{1 + e^{(E_f - E_D)/kT}}$$

11. Plot the Fermi-Dirac (FD) and the Maxwell-Boltzmann (MB) distribution curves for energies ranging between 0 and 0.5 eV at T = 300K, given that E_F =0.25 eV Interpret the curves and comment on the appropriateness of replacing the FD distribution by the MB distribution

12. Four electrons exist in a one-dimensional infinite potential well of width a = 100 nm. Assuming the free electron mass, what is the Fermi energy at T = 0 K.

13. The Fermi energy level for a particular material at T = 300 K is 6.25 eV. The electrons in this material follow the Fermi-Dirac distribution function. (a) Find the probability of an energy level at 6.50 eV being occupied by an electron. (b) Repeat part (a) if the temperature is increased to T = 950 K. (Assume that E_F is a constant.) (c) Calculate the temperature at which there is a 1 percent probability that a state 0.30 eV below the Fermi level will be empty of an electron.

14. (a) Estimate the tunnelling probability of a particle with an effective mass of $0.067m_o$ (an electron in gallium arsenide), where rn_o is the mass of an electron, tunnelling through a rectangular potential barrier of height V = 0.8 eV and width 150 nm. The panicle kinetic energy is 0.20 eV. (b)Repeat part (a) if the effective mass of the panicle is $1.08m_o$ (an electron in silicon).

15. Does E_i lies exactly at the centre of E_G for an intrinsic semiconductor. If not, why?

16. Calculate the difference in e^- concentration for Maxwell Boltzmann and Fermi-Dirac integrals when η=-3. Us

$$\mathcal{F}_{1/2}(\eta) \simeq [e^{-\eta} + \xi(\eta)]^{-1}$$

$$\text{where } \xi(\eta) = 3\sqrt{\pi/2}[(\eta + 2.13) + (|\eta - 2.13|^{2.4} + 9.6)^{5/12}]^{-3/2}$$

$$N_C = 2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2} \quad \text{. . . effective density of conduction band states}$$

$$N_V = 2\left(\frac{2\pi m_p^* kT}{h^2}\right)^{3/2} \quad \text{. . . effective density of valence band states}$$

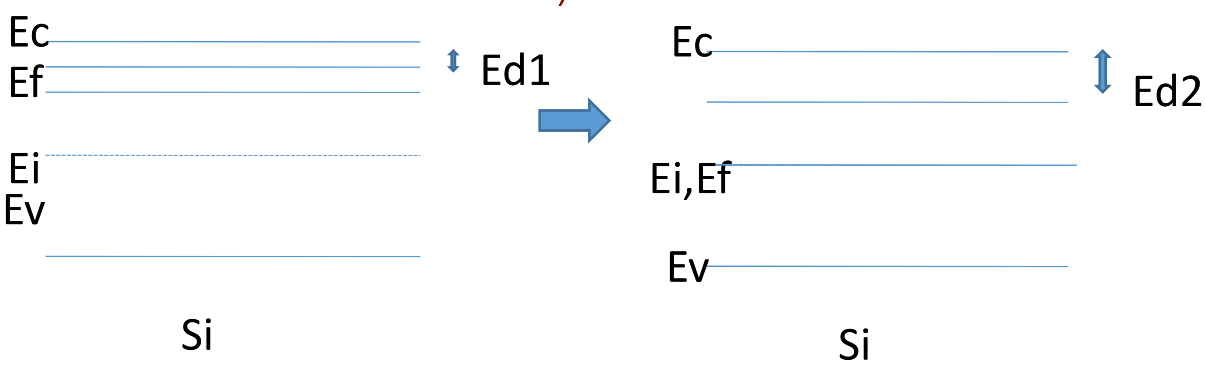
$$\mathcal{F}_{1/2}(\eta) = \frac{2}{\sqrt{\pi}} F_{1/2}(\eta)$$

$$F_{1/2}(\eta) = \int_0^\infty \frac{\xi^{1/2}\,d\xi}{1 + e^{\xi-\eta}} \quad \text{. . . Fermi-Dirac integral of order 1/2}$$

$$\eta_c = (E_F - E_c)/kT$$

$$\eta_v = (E_v - E_F)/kT$$

17. Ed1=0.0259 eV, Ed2=2*0.0259 eV. Electron concentration in case 1 is 10^18. Find the % by which Nd has to be increased so that electron concentration in case 2 also becomes the same. (T=300 K, Nc=3.2*10^19/cc)(neglect thermally generated carriers)



Consider sufficiently enough temperature such that there is no thermal generation. Find N_{d1}/N_{d2}, so that $n_1=n_2$ (electron concentrations are equal in both cases) Given: E_{d1}=25 meV , E_{d2}=50 meV, 70% ionization in both cases.

18.

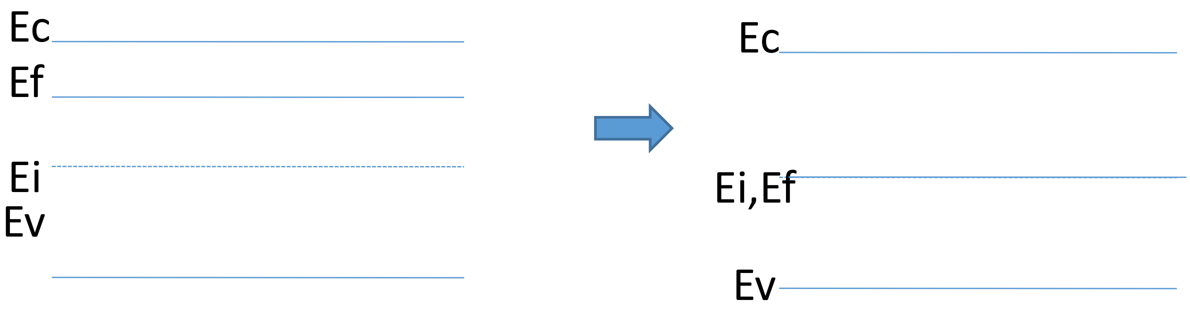


Fig:1 Si (300 K) (Nc=3.2*10^19/cc) Fig:2 Si (T K)

Find ΔT to go from fig1 to fig2. Find n/n_i for the two cases (n is total electron concentration).

19. An n-type Si bar with $N_d = 10^{17} cm^{-3}$ is doped with $N_a = 10^{10} cm^{-3}$. State old and new values of hole concentration in the bar. (Assume complete ionization)

20. A semiconductor has E_g=1.40 eV and m_h^*= $0.5m_0$; m_e^* = $0.1m_0$ at T = 300 K.
(a) Calculate the position of the intrinsic Fermi level,E_f with respect to the middle of the band gap.
(b)Calculate the intrinsic carrier concentration n_i.
(c)Impurity atoms are added so that the Fermi level E_f, is 0.35 eV above the middle of the band gap.
(i)Are the impurities donors or acceptors?
(ii)What was the concentration of the impurities added?

21. (a) If $E_c - E_f$= 0.2eV in GaAs at T = 500K, calculate the values of the equilibrium Carrier concentrations, n and p.

(b) Assuming that the value of n you obtained in (a) remains constant, calculate $E_c - E_f$ and p at T = 300K.

22. For an n-type Silicon sample with $10^{16} cm^{-3}$ phosphorous donor impurities and a donor level at E_D=0.045eV, find the ratio of the neutral donor density to the ionized donor density at 77 K where the Fermi level is 0.0459 eV below the bottom of the conduction band.

23. (a) n type GaAs sample has $10^{15}/cm^3$ concentration of shallow donors. Assume all donors are ionized at room temperature. What are the concentrations of electrons and holes (n_0 and p_0) at room temperature, given that the intrinsic carrier density n_i is 2 x 10^6 /cm^3. What is the position of E_F with respect to E_C, given that the effective density of states in the conduction band at 300 K is N_C = 4.7 x 10^{17} /cm^3.

(b) In order to make high resistivity (semi-insulating) GaAs, the above type of material is counter doped with deep level acceptors having energy level at E_A-E_V = 0.75 eV. So now the material has 10^{15} / cm^3 shallow donors and 10^{16} /cm^3 deep acceptors. What is the position of E_F with respect to E_V, given that at 300 K, N_C = 4.7 x 10^{17}/ cm^3, and N_V = 7.0 X 10^{18}/cm^3. What are the concentrations of electrons and holes (n_0 and p_0) in this material?