Electronic Devices and Circuits Lab (EE2301) Experiment 2 : Fundamentals of Semiconductors

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1 Aim

Our aim is to Understand the fundamentals semiconductors by plotting some graphs of below questions and understanding their behaviour.

1. How does the occupation probability as a function of the energy varies with respect to time? Under what circumstances does the Fermi-Dirac statistics reduce to Maxwell-Boltzmann statistics.

2. How the 3D density of states changes with respect to the energy ?

3. How the does the position of the Fermi energy changes with respect to doping ? (Use Maxwell-Boltzmann statistics) for P-type semiconductor.

4. How does the intrinsic carrier concentration changes with respect to the temperature? Assume effective density of states for conduction and valence band to be 2.8E19 cm^3 and 1.8E19 cm^3.Assume doping to be 1E17 cm^3 and comment on the nature of semiconductor. Plot n_i on a semilog scale versus (1000/T) for P-type semiconductor.

5. How does the electron density varies with energy (use Fermi-Dirac distribution) ?

2 Procedure

Question 1

• To know How the occupation probability as a function of the energy varies with respect to time . first we need to use the fermi-dirac statistics i.e. the probablity of an electron occupying a certain energy level is given by the below equation.

$$F(E) = \frac{1}{1 + exp(\frac{E-E_f}{K_b T})} \tag{1}$$

where E is the energy of the level,E_f is the fermi energy level, K_b is the boltzmann constant,and T is the temperature.

• Now we need to plot the graph using Octave with x-axis as Energy level and the y-axis as probability of occupancy for different temperatures.

• After this we need to understand one more thing i.e. under what conditions does fermi dirac statistics reduce to maxwell-boltzmann statistics.

• Maxwell boltzmann statistics is given by the below equation.

$$f(E) = \frac{1}{exp(\frac{E-E_f}{K_b T})} \tag{2}$$

• To understand maxwell-boltzmann statistics we can plot the graph of f(E) vs E.

• In the above equations for plotting graph the values used are E $\in [-2eV, +2eV]$,
$E_f = 0$, $K_b = 8.617 \times e^5$eV/K, T1 = 100 K, T2 = 200 K, T3 = 300 K, T4 = 400 K.

Question 2

• In this problem we need to plot how 3D Density of states varies with respect to Energy i.e density of states of a 3D semiconductor.

• Density of states with respect to Energy is given by the below equation.

$$D(E) = \left(\frac{1}{2\pi^2}\right)\left(\frac{2m^*}{\hbar^2}\right)^{1.5}\sqrt{E} \tag{3}$$

where E is energy, m^* is the effective mass, $\hbar$ is the reduced plancks constant.

- Now we need to plot the graph of D(E) with respect to E using octave.

- The values used in the density equation are E$\in$ $[0eV, +5eV]$,m* = 9.1 $\times10^{-31}$ Kg, $\hbar = h/2\pi$, h=6.626$\times10^{-34}$ J-s.

Question 3

- In this we need to find position of fermi energy with respect to P-type doping.

- The relation between fermi energy and hole concentration is derived below by approximating fermi-Dirac to maxwell boltzmann equation.

$$P_o = N_v exp\left(\frac{E_v - E_f}{KT}\right) \tag{4}$$

$$E_f = E_v + KTlog\left(\frac{N_v}{P_o}\right) \tag{5}$$

where E_f is the fermi energy,E_v is the valance band energy, N_v is the effective density of states function in valance band,P_o is the hole concentration, K is the boltzmann constant,T is the temperature.

- Now we need to plot E_f Vs P_o Using octave.

- The values used in the above equations are K = 1.38 $\times10^{-23}$, T = 200 K, E_v = 0.5 $\times1.6\times10^{-19}$ V, N_v = 3.92$\times10^{24}$ m^{-3}, $P_o \in$ [1$\times10^{24}$,50$\times10^{24}$].

Question 4

- In this problem we need to find how the intrinsic carrier concentration changes with respect to the temperature.

- Given that the effective density of states for conduction band and valance band to be 2.8E19 cm^3 and 1.8E19 cm^3 and doping to be 1E17 cm^3 for P-type semiconductor.

- The relation between intrinsic carrier concentration and N_v,N_c is given by the below equation.

$$n_i = \sqrt{N_c N_V} exp\left(\frac{-E_g}{2KT}\right) \tag{6}$$

where N_c,N_v are the effective density of states for conduction band and valance band respectively, E_g is the band gap, K is the boltzmann constant, T is the temperature.

- Now we need to plot n_i on a semilog scale with respect to (1000/T) using octave.

• The values used in the equation are N_c = 2.8E19 cm^3 , N_v = 1.8E19 cm^3,
E_g = 1.14 eV , K = 8.617×e^{5}eV/K, (1000/T) $\in [1, 10]$K^{-1}.

Question 5

• In this problem we need to how does the electron density varies with energy.

• we need to use the below equation for electron density .

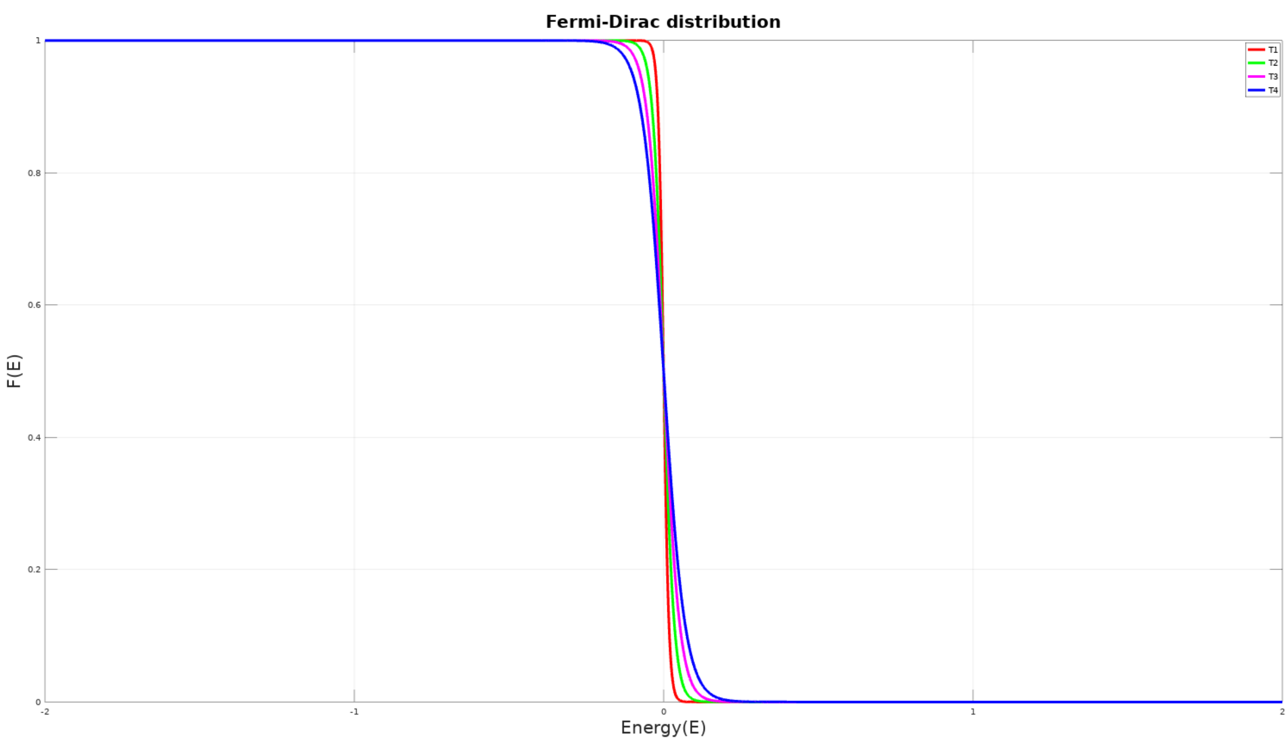
$$n(E) = D(E)F(E) \tag{7}$$

where $f(E) = \frac{1}{exp(\frac{E-E_f}{K_b T})}$, $D(E) = \left(\frac{1}{2\pi^2}\right)\left(\frac{2m^*}{\hbar^2}\right)^{1.5}\sqrt{E}$

• the values used are m^* = 9.1 $\times 10^{-31}$ Kg,
$\hbar = h/2\pi$, h=6.626$\times 10^{-34}$ J-s, K = 1.38 $\times 10^{-23}$,T=1000.

3 Results and Understandings

Question 1



Plot: F(E) Vs Energy

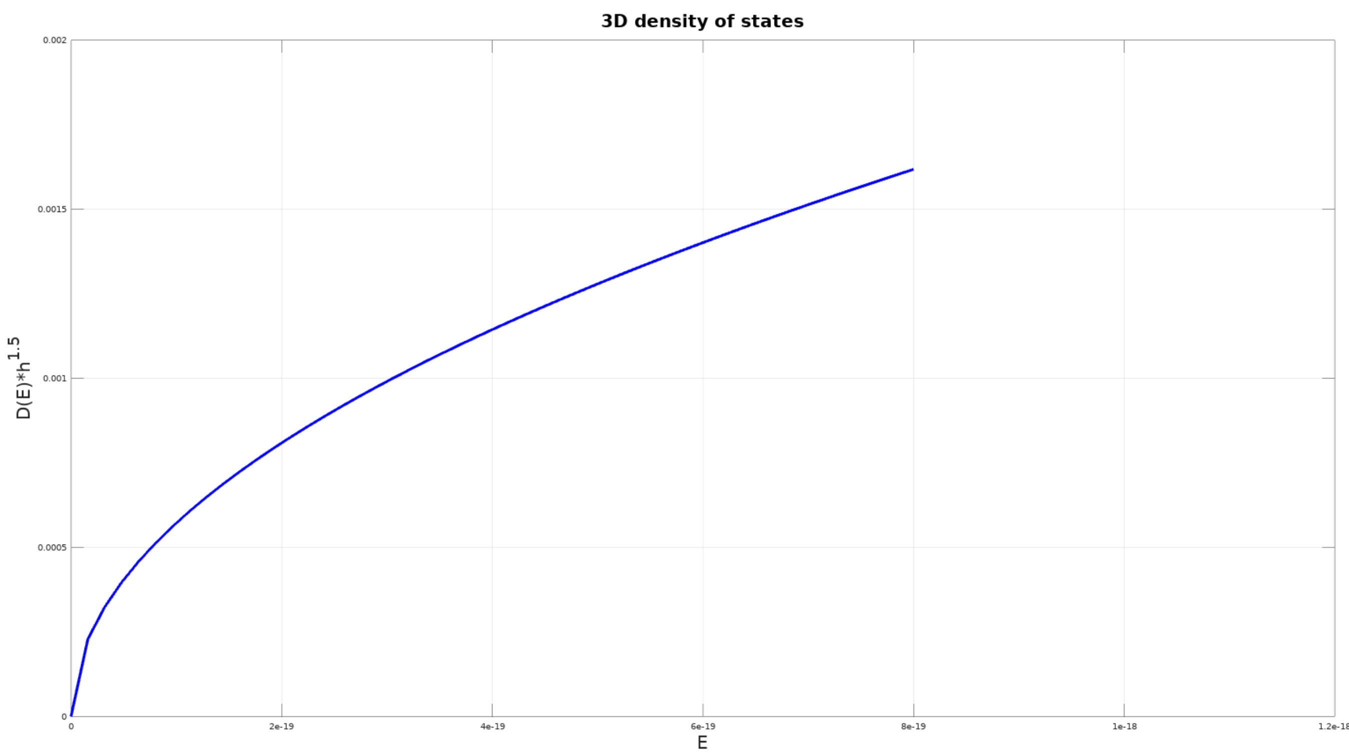
• The above plot shows how the occupational probability changes with energy for 4 different temperatures.

• It is pretty clear that as energy increases the probability at first stays constant , then decreases and stays at zero.

• When it comes to temperatures as we increase temperature the plot at the middle becomes less steeper.

• Fermic dirac distribution reduces to maxwell boltzmann when E-E_f >> KT which happens when E > E_c.

Question 2



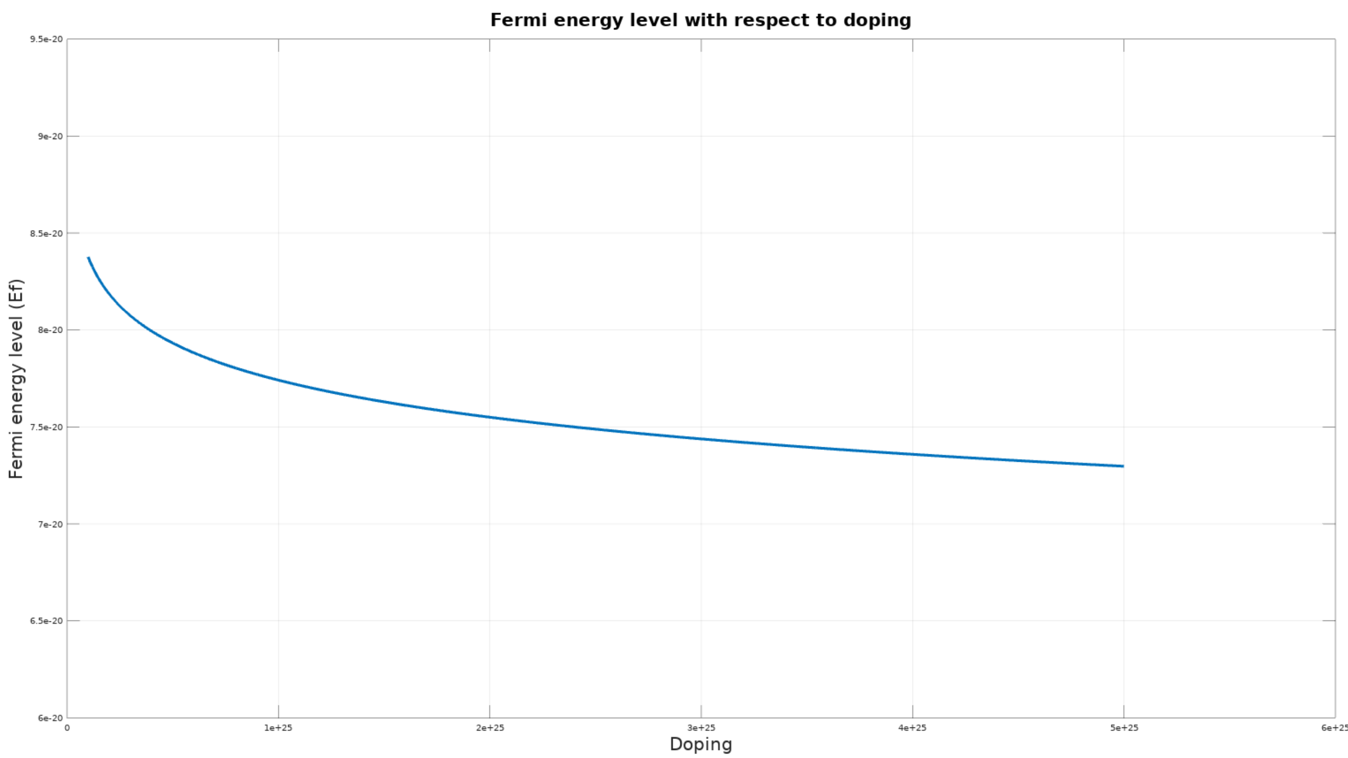
Plot: D(E) Vs Energy

• The above plot shows how the 3D density of states varies with energy.

- As we can see density of states increases as the energy increases .

- Y-axis represents D(E) $\times h^{1.5}$ for better scaling.

Question 3



Plot: E_f Vs doping

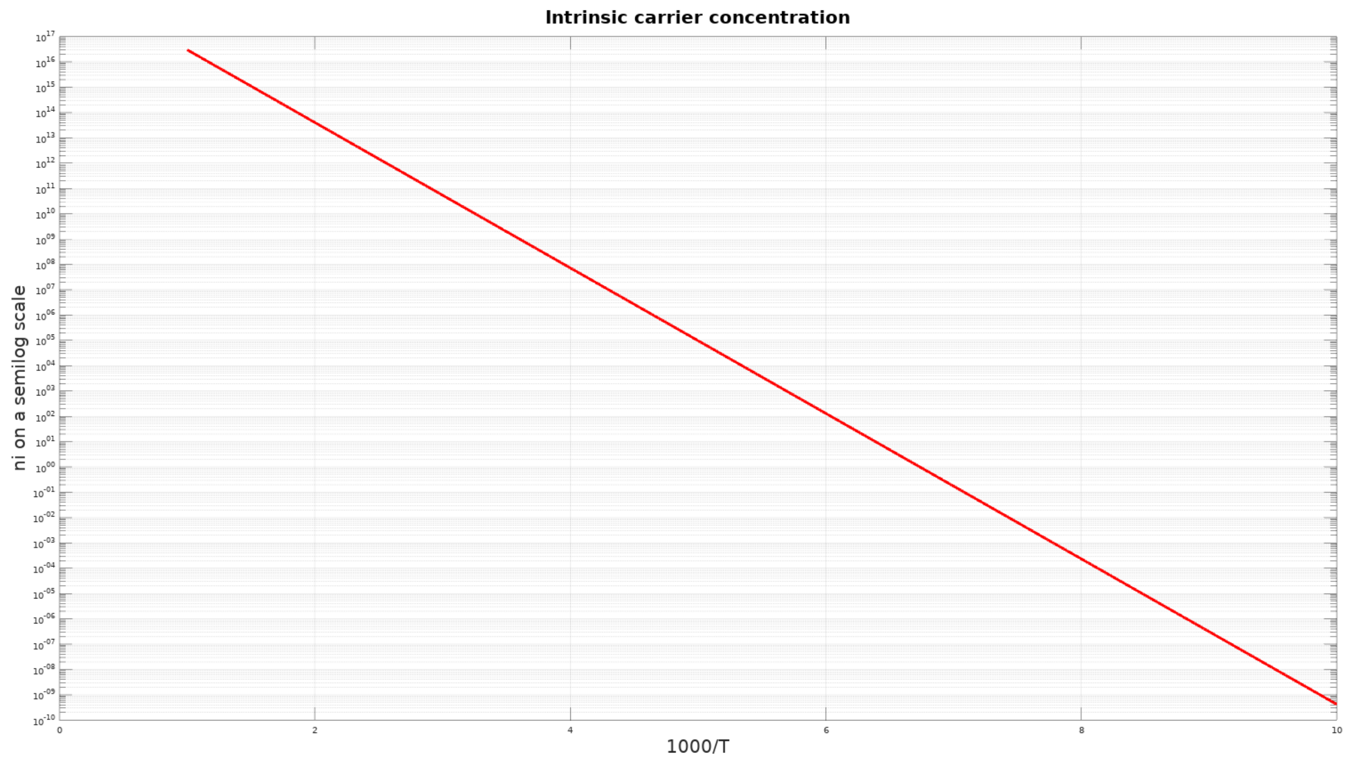
- The above plot shows fermi energy with respect to doping.

- Here we are using a p-type semiconductor.

- As we can see, as doping increases the fermi energy level moves closer to the valence band.

- we have used boltzmann statistics here.

Question 4



Plot: n_i Vs 1000/T

- The above plot shows n_i with respect to 1000/T.

- According to equation (6) at equilibrium intrinsic carrier concentration is constant i.e. it doesn't depend on doping concentration.

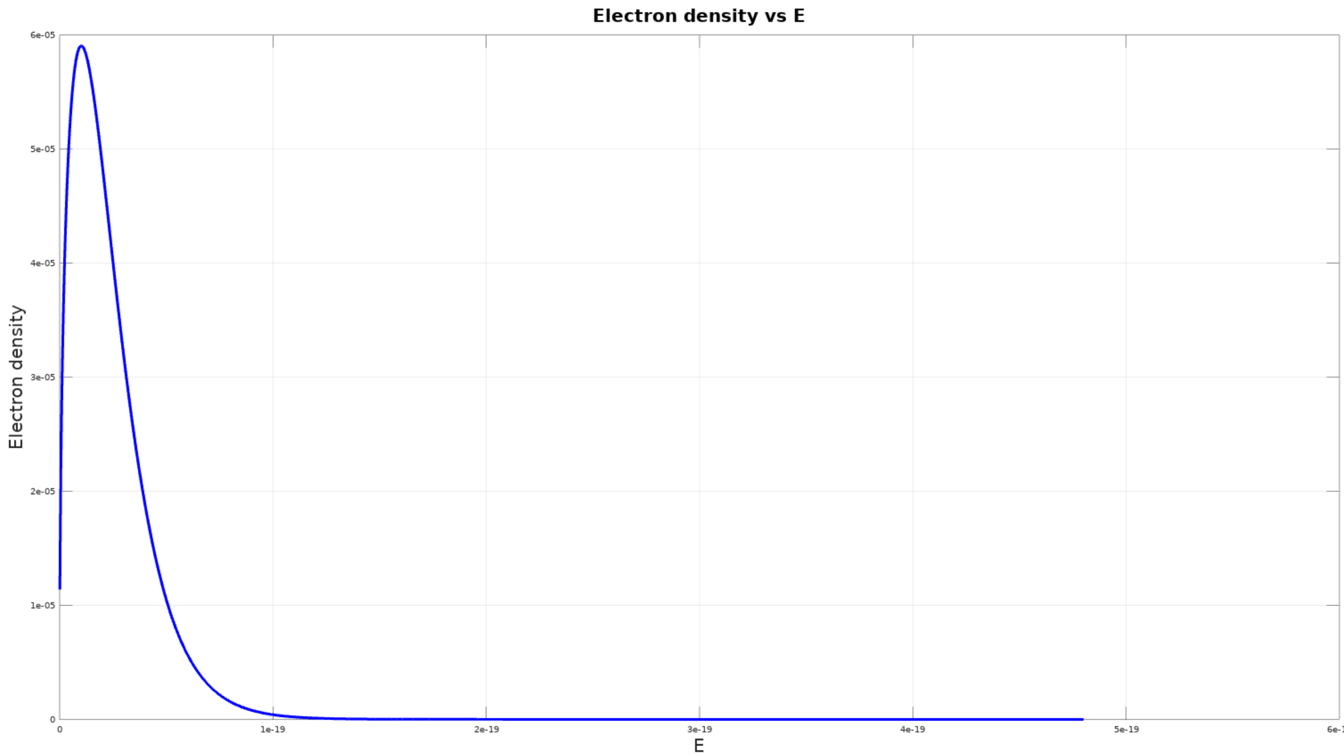
- As we can clearly see as the temperature decreases intrinsic carrier concentration increases.

- we use fermi dirac approximation as maxwell boltzmann statistics.

- This a P-type extrinsic semiconductor.

- The graph on semilog scale looks like straight line.

Question 5



Plot: Electron density Vs Energy

- The above plot shows Electron density with respect to E.

- As we can see from the graph Electron density increases to a point and then decreases to zero.

- Both occupancy probability and density of states has the impact on electron density.

- F(E) decreases as Energy increases and D(E) increases as energy increases,when we multiply them there comes a maximum point.

4 Conclusions

• In the question 1 we can conclude that occupational probability Vs energy looks like step function.

• And fermi dirac reduces to maxwell boltzmann when E > E_C

• In the question 2 the plot of density of states Vs energy is parabola.

• And as energy increases Density of states increases.

• In the question 3 the fermi energy with respect to doping is also a parabola but in different orientation.

• As doping increases fermi level decreases for p-type and as doping increases fermi level increases for n-type.

• In the question 4 on semilog scale intrinsic carrier concentration with respect to 1000/T is a straight line with negative slope.
• Also n_i remains constant at equilibrium i.e. its value doesn't depend on doping.

• In question 5 the electron density with respect to energy plot looks close to guassian distribution.

• After a certain energy its density becomes zero.

Thank you