Ece 3040 : Hw 2

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1) Fermi Functions

a) equilibrium and T > 0K @ fermi level

↳ $E = E_f$

$\therefore \frac{1}{1+e^{E-E_F/KT}} = \frac{1}{2}$ } the probability of an electronic state being occupied is 50%.

b) $E_F = E_C$; $E = E_C + KT$

↳ $E - E_F \Rightarrow (E_C + KT) - E_C = KT$ } $\frac{1}{1+e^{KT/KT}} = \frac{1}{e}$

c) $f(E_C + KT) = 1 - f(E_C + KT)$ $\therefore$ $f(E_C + KT) = 0.5 = 50\%$

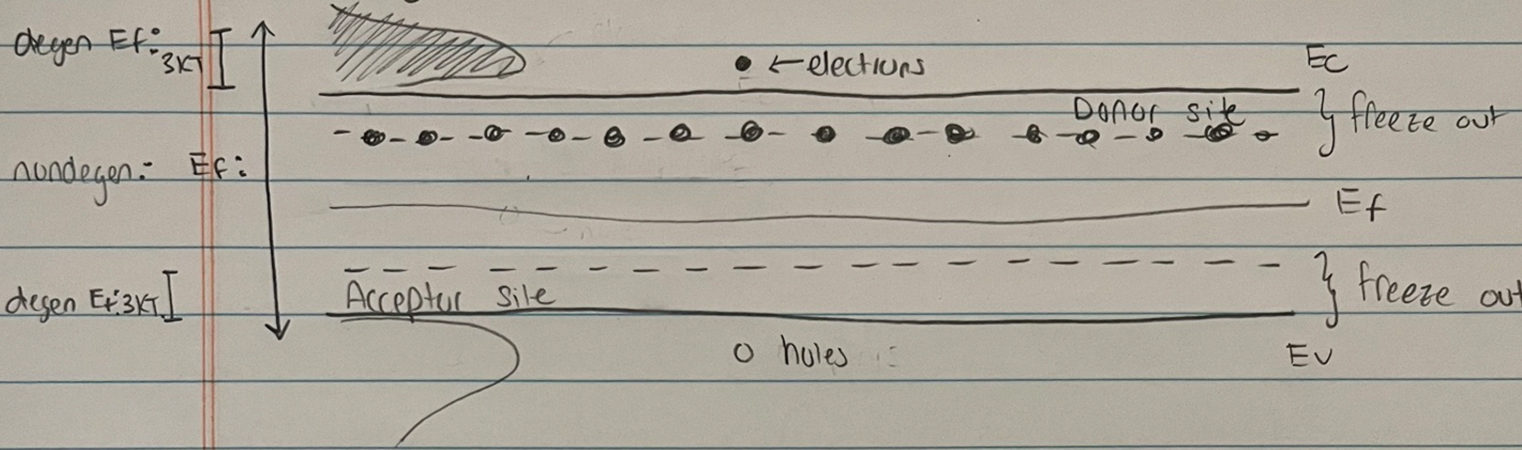
↳ the fermi level is located at $E_C + KT$

d) $E = E_F - KT$

↳ hole probability : $1 - \left(\frac{1}{1+e^{E-E_F/KT}}\right)$

$\therefore 1 - \left(\frac{1}{1+e^{-1}}\right) = 0.269$

2) Energy Band Model - Pierret Problem 2.3



↳ for intrinsic, n-type, p-type: E_i remains between the 2 bands in the middle

E_f: for n-type is closer to E_c

p-type is closer to E_v

3) Pierret 2.7: Prove the peak to be at $E_c + kT/2$ & $E_v - kT/2$

↳ Carrier distribution of electrons: $\int_{E_c}^{E_{top}} g_c(E) f(E)\, dE \Rightarrow g_c(E) f(E)$

Where $g_c(E) = \dfrac{m^*_n \sqrt{2m^*_n}}{\pi^2 \hbar^3} \cdot \dfrac{1}{1 + e^{E - E_f/kT}} = \dfrac{m^*_n \sqrt{2m^*_n}}{\pi^2 \hbar^3} \sqrt{E - E_c}\, e^{\frac{-(E - E_f)}{kT}}$

$\frac{d}{dE}(g_c(E) f(E)) = 0$ to get where the peak will occur

$$= \frac{\left(\frac{m^*_n \sqrt{2m^*}}{\pi^2 \hbar^3}\right)}{2\sqrt{E - E_c}} e^{\frac{-(E - E_f)}{kT}} - \frac{\left(\frac{m^*_n \sqrt{2m^*}}{\pi^2 \hbar^3}\right)}{kT} \sqrt{E - E_c}\, e^{\frac{-(E - E_f)}{kT}} = 0$$

↳ Solving this gives the peak to be at $E = E_c + kT/2$

- Pierret → Problem 2.16

a) Uniformly doped p type → $N_A = 1015/cm^3$; At $T \approx 0K$

↳ equilibrium hole and electron concentration? w/ $T \approx 0K$, n & p will approach 0

b) $N >> n_i$ & all impurities are ionized ; $n \approx N$ & $p \approx n_i^2/N$

↳ Since $N >> n_i$ & $n \approx N$, we can say the impurity is a donor

c) Si @ $T \approx 300K$; $n = 10^5/cm^3$

↳ $np = n_i^2$ & $n = 10^5/cm^3 \longrightarrow p = n_i^2/N_D = (10^{10}/cm^3)^2 / 10^5/cm^3 = 10^{15}/cm^3$

↳ non-degenerate assumption

e) $n_i = 10^{13}/cm^3$, $n = 2p$, $NA = 0$; n & $N_D = ?$

↳ $np = n_i^2$ where $n = 2p$ $\therefore n_i^2 = \frac{n^2}{2} \Rightarrow n = \sqrt{2}\, n_i$

Charge neutrality : $p - n + N_D - N_A = 0$

$\frac{n}{2} - n + N_D - 0 = 0$

$\Big\}\; N_D = \frac{n}{2} = \sqrt{2}\, n_i = 0.707 \times 10^{13}/cm^3$

- Pierret → Problem 2.17

c) $T = 300K$, $NA = 9 \times 10^{15}/cm^3$, $N_D = 10^{16}/cm^3$

↳ (2.28) : $n_i >> |N_D - N_A|$ $\therefore n \simeq p \simeq n_i \longrightarrow n \approx n_i = N_D - N_A = 10^{15}/cm^3$

↳ $p = n_i^2/(N_D - N_A) \approx (10^{10})^2/10^{15} = 10^5/cm^3$

d) $T = 450K$; $NA = 0$; $N_D = 10^{14}/cm^3$

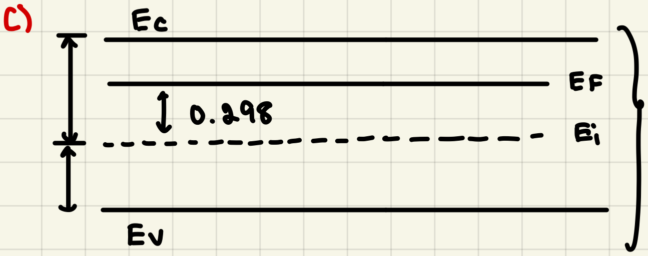
↳ $n_i(Si) \approx 5 \times 10^{13}/cm^3 \longrightarrow n = \frac{N_D - \cancel{N_A}}{2} + \left[\left(\frac{N_D - \cancel{N_A}}{2}\right)^2 + n_i\right]^{1/2}$

$n = \frac{10^{14}/cm^3}{2} + \left[\left(\frac{10^{14}/cm^3}{2}\right) + 5 \times 10^{13}/cm^3\right]^{1/2} = 1.21 \times 10^{14}/cm^3$

$p = \frac{n_i^2}{n} \longrightarrow \frac{(5 \times 10^{13}/cm^3)^2}{1.21 \times 10^{14}/cm^3} = 2.07 \times 10^{13}/cm^3$

• Pierret → Problem 2.18

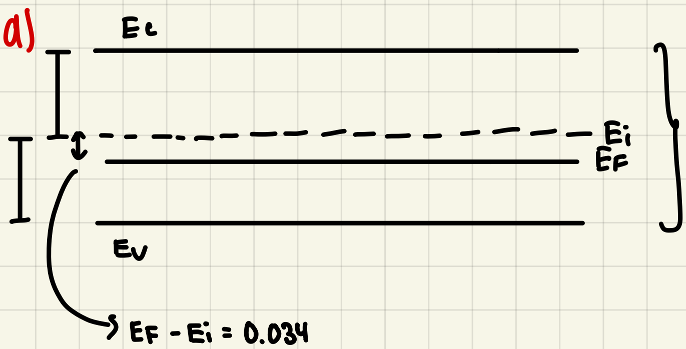
c)



@ T = 300K

$E_F - E_i = (0.0259)\ln\left(N_D - N_A / n_i\right) = 0.298\,eV$

a)



@ T = 450K

$E_F - E_i = kT\ln(n/n_i) = (0.0388)\ln\left(\frac{1.21\times10^{14}}{5\times10^{13}}\right)$

$= 0.034\,eV$

- Activity 1

1. The 2 photon energies that an electron in the gnd state of a H atom can absorb are 12.1eV and 10.1eV

2. The shortest wavelength it can radiate is 99nm ~ 100nm

- Activity 2

1. Bonding energy → As the hydrogen atoms get closer to each other, the energy exponentially decreases

   Proton - Proton Repulsion Energy → As the hydrogen atoms grow closer, the repulsion energy exponentially increases

2. The bond length is determined by the shared energy levels, the size of the atoms, and etc.

- Activity 3

1. 3.41×10^{20} energy states exist between 0.7eV and 0.72eV assuming the middle of the bandgap is at 0 energy

2. 4.43×10^{20} energy states exist between 0.8 eV and 0.82eV assuming the middle of the bandgap is at 0 energy