EEE337/348: Tutorial 1

1) In the absence of phonon scattering, we can estimate the energy gained by an electron when it is subjected to an external force. Consider a GaAs sample with a band structure described by

$$E(k) = \frac{\hbar^2 k^2}{2m^*}.$$

An electron at the bottom of the conduction band is subjected to an electric field pulse of magnitude 5 kV/cm for a duration of 1 ps with the GaAs sample temperature of 300 K. Calculate the energy gained by this electron. [Hint: you can start by estimating the momentum gained from the applied electric field pulse]

2) Repeat the calculation in (1) with an electric field pulse magnitude of 50 kV/cm. Is the energy gained realistic? Explain your answer.

3) Define i) the density of states, $N(E)$ and ii) the Fermi distribution function, $f(E)$. In bulk semiconductors these are described by

$$N(E) = 4\pi\left(\frac{2m}{h^2}\right)^{\frac{3}{2}} E^{\frac{1}{2}} \quad \text{and} \quad f(E) = \frac{1}{1+\exp\left(\frac{E-E_F}{kT}\right)}.$$

4) i) Plot (using Matlab or Excel) the density of states up to 0.3 eV in GaAs. The density of states is usually expressed in $eV^{-1}cm^{-3}$, therefore you will need to perform some unit conversions [Hint: you may use $E=mc^2$ to convert kg to $Jm^{-2}s^2$ and note that 1 J = $1/1.6\times10^{-19}$ eV].

ii) The electron density is given by

$$n = \int_0^{E_{top}} N(E) f(E) dE.$$

Assuming that the Fermi level is equal to half the bandgap of GaAs, use a suitable software to calculate the electron density if E_{top} = 0.3 eV at 300 K.

5) The electron density influence the current conduction in semiconductor. We know that doping of semiconductor increases the electron density. This can be shown by calculating the dependence of Fermi level on carrier concentration. Assuming that a GaAs sample is doped with an n-type dopant concentration of 10^{17} cm^{-3} and all the dopants are activated, use the Joyce-Dixon approximation given below to estimate the Fermi level at 300 K. Compare the electron density to that in 4(ii).

$$E_F = kT\left[\ln\frac{n}{N_C} + \frac{1}{\sqrt{8}}\frac{n}{N_C}\right] \text{eV.}$$

6) The direct band gap of $Al_xGa_{1-x}As$ is given by 1.424 + 1.247x. GaAs/AlGaAs is one of the most important heterostructures used in lasers and transistors. Assuming that 60% of the band gap discontinuity is in the conduction band, calculate the conduction band and valence band barrier heights for GaAs/$Al_{0.3}Ga_{0.7}As$. Discuss whether this heterojunction is ideal for npn based heterojunction bipolar transistor (HBT).

Parameters for GaAs

Electron effective mass: 0.067 m_0

Temperature dependence of band gap: $1.519 - 5.405\times10^{-4}T^2/(T+204)$

At 300 K, $N_C = 4.45\times10^{17}$ cm^{-3} and $N_V = 7.0\times10^{18}$ cm^{-3}

Useful Constants

Fundamental Electronic Charge e = 1.60218 x 10^{-19} C
Electron Rest Mass m_0 = 9.1095 x 10^{-31} kg

Vacuum Permittivity Epsilon$_0$ = 8.85418 x 10^{-12} F.m^{-1}
Speed of Light in Vacuum c_0 = 2.99792 x 10^8 m.s^{-1}

Planck's Constant h = 6.62617 x 10^{-34} J.s
Wavelength of a 1 eV photon = 1.23977 x 10^{-6} m
1 cm^{-1} = 0.12408 meV
1 meV = 8.0593 cm^{-1}

Boltzmann's Constant k_B = 8.6174 x 10^{-5} eV.K^{-1} = 1.38066 x 10^{-23} Joules.K^{-1}
Avogadro's Constant N_A = 6.022 x 10^{26} (kgMole)$^{-1}$
Electron Volt eV = 1.60218 x 10^{-19} J