NE 205: Semiconductor Devices and IC Technology
Indian Institute of Science, Bangalore.
Autumn Semester 2019, Digbijoy N. Nath
Homework I Total points: 40

Plots must be quantitative, calculated exactly. Label the Y- and X-axes clearly. Use MATLAB or Mathematica, etc. Hand-drawn plots will fetch ZERO marks.

1. Magnesium (Mg) is a p-dopant and deep acceptor in GaN with an activation energy of $\mathbf{E_A}$ **= 200 meV above the valence band.** Plot the position of the Fermi level ($E_F - E_V$) in p-type GaN if the Mg doping is changed from 10^{16} cm^{-3} to 10^{19} cm^{-3}. Assume the effective mass of hole is $0.60m_0$. Band gap of GaN is 3.4 eV. Assume room temperature and a valley degeneracy factor of g = 4. 6

2. In the above question, if Mg doping is fixed at 10^{18} cm^{-3}, estimate the position of the Fermi level at temperatures of 5 K, 50 K, 100 K, 300 K, 500 K and 800 K. Neglect change of band gap and effective mass with temperature (but do not neglect variation of N_V with temperature). 6

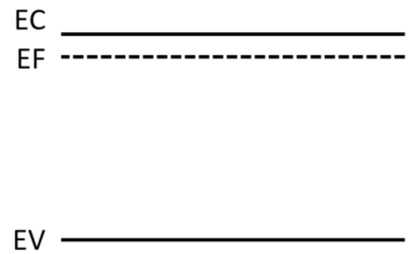
3. A piece of GaAs is doped n-type with $N_D = 2x10^{16}$ cm^{-3}. The donor energy level is 20 meV below the conduction band edge (i.e. $E_C - E_D$ = 20 meV) at all temperatures. Electron effective and hole effective mass for GaAs are $0.05m_0$ and $0.5m_0$ respectively, and the effective masses are independent of temperature.
The variation of band gap of GaAs with temperature is:
$E_G(T) = 1.52 - 5.405 \text{ x } 10^{-4}\ T^2/(T + 204)$ (in eV, where T is in Kelvin).

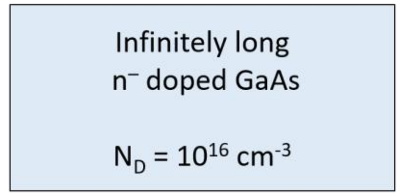
   a) Plot the intrinsic carrier concentration (n_i) versus temperature for the range T = 1 K to 1000 K. Do not neglect band gap variation with temperature, and estimate N_C, N_V yourself from effective mass values. 6

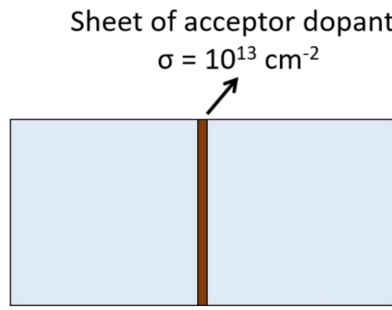
   b) Plot the free electron concentration (n_0) versus temperature for the range T = 1 K to 300 K. Below what temperature does carrier freeze-out kick start? Freeze-out can be defined when n_0 (T) < 10% of n_0(300 K). 6

4. Consider a free electron in a one-dimensional crystal with period 5 Å. An electric field of 1 kV/cm is applied along the crystal on this electron. How much time would the electron take to reach the Brillouin zone boundary? What is the velocity (in cm/s) of the electron when it reaches this point? Assume effective mass of electron is 0.2 times its free electron mass. 4

5. Consider a very long slab of n-doped GaAs as shown below. It is moderately doped at $N_D = 10^{16}$ cm^{-3} and its energy band diagram is shown to its left.







Now, a sheet of acceptor (N_A) dopants is introduced in the middle of the slab as shown. The sheet is infinitesimally thin and has an areal charge density $\sigma = 10^{13}$ cm^{-2}. [Note: it is charge per unit area].

a) Draw the energy band diagram of the new structure after introduction of the acceptor sheet charge. Also, draw the charge diagram of the same. 4

b) Does the sheet of acceptor charge deplete some region of the n-doped GaAs around it? If no, justify. If yes, find out the depletion width on either side. 4

c) Estimate the electric field at the location of the acceptor sheet charge and draw the electric field profile of the structure. 4