EN-204 – Materials for Energy Applications
Problem Set – Semiconductor Physics

1. A semiconductor device requires n-type material, and it is to be operated at 400K. Would Si doped with 10^{15}atoms/cc of as be useful in this application? Could Ge doped with 10^{15}atoms/cc **as** be used? (make the reasonable assumptions and state them clearly).

2. For silicon doped with 10^{15}#/cc phosphorous atoms find the temperature at which
   a. The material starts becoming intrinsic (assume that intrinsic condition starts at $n_i = 10N_d$)
   b. The carriers freeze out. (Note: Ideally freeze out occurs at 0K so assume freeze out starts to occur when $n_0 = 10^{-6}$% of N_d, $n_i = 1.5X10^{10}$/cc).

3. Prior to processing, a certain portion of semiconductor sample contains $N_D = 10^{14}$#/cc donors and $N_T = 10^{11}$#/cc R-G centers. After processing, the same portion of semiconductor contains $N_D = 10^{16}$ #/cc and $N_T = 10^{10}$ #/cc. Did the processing increase or decrease the minority carrier lifetime?

4. The probability that a state is filled at the conduction band edge (Ec) is precisely equal to the probability that a state is empty at the valence band edge (Ev). Where is the Fermi level located? (do proper derivation)

5. A Si sample is doped with 10^{14} boron atoms/cc and maintained at 470K. Determine the position of E_i and E_f-E_i.

6. Derive an expression relating the intrinsic level Ei, to the center of the band gap Eg/2. Calculate the displacement of Ei, from Eg/2 for Si at 300 K, assuming the effective mass values for electrons and holes are l.lxme and 0.56xme respectively.

7. Calculate the electron and hole density in germanium, silicon and gallium arsenide if the Fermi energy is 0.3 eV above the intrinsic energy level. Repeat if the Fermi energy is 0.3 eV below the conduction band edge. Assume that T = 300 K.

8. Taking the semiconductors to be non-degenerate, show that the energy at which the carrier distributions peak is Ec + kT/2 and Ev - kT/2 for the conduction and valence bonds, respectively.

9. For a non-degenerate semiconductor, the peak of the electron distribution versus energy inside the conduction band is showed to occur at Ec + kT/2 as per the previous problem. Expressed as a fraction of the electron population at the peak energy, what is the electron population in a non-degenerate semiconductor at E = Ec +5kT?

10. (a) Under equilibrium conditions at T> 0 K, what is the probability of an electron state being occupied if it is located at the Fermi level?

(b) If Ef is positioned at Ec determine the probability of finding electrons in states at Ec + kT.

(c) The probability a state is filled at Ec+kT is equal to the probability that the state is empty at Ec+kT . Where is the Fermi level located?

11. Calculate the number of states per unit energy in a 100 x 100 x 10 nm piece of pure perfect silicon 100 meV above and below the conduction band. Write the result in units of eV^{-1}.

12. 4H-SiC is doped with 2 x 10^{17} cm^{-3} nitrogen donor atoms (Ec – Ed = 90 meV). Use Nc = 4 x 10^{20} cm^{-3}.
    a. Calculate the electron density at 300 K.
    b. Calculate the hole density at 300 K after adding 2 x 10^{18} cm^{-3} aluminum acceptor atoms (Ea - Ec = 220 meV). Use Nv = 1.6 x 10^{20} cm^{-3}.

13. A silicon wafer is doped with Phosphorous atom density of 3ni/2. Find the number of empty donor states at an energy level 10 meV above the Fermi energy level. Assume that the intrinsic carrier density of the silicon wafer to be 8.81 x 109 cm-3. Also calculate the equilibrium electron and hole density of the material @ T=300 K. Understand how the carrier concentrations and other parameters would vary, if the dopant induced donor level is present at 100 meV above the Fermi energy level.

14. To excite the mercury line 5,461 °A an excitation potential of 7.69V is required. If the deepest term in the mercury spectrum lies at 84,181 cm−1, calculate the numerical values of the two energy levels involved in the emission of 5,461A°.

15. An electron is confined to a 1-micron thin layer of silicon. Assuming that the semiconductor can be adequately described by a one-dimensional quantum well with infinite walls, calculate the lowest possible energy within the material in units of electron volt. If the energy is interpreted as the kinetic energy of the electron, what is the corresponding electron velocity? (The effective mass of electrons in silicon is 0.26 m_0, where m_0 = 9.11 x 10-31 kg is the free electron rest mass).

16. Find the probability of occupancy of a state of energy (a) 0.05 eV above the Fermi energy (b) 0.05 eV below the Fermi energy (c) equal to the Fermi energy. Assume a temperature of 300 K.

17. Suppose that the Fermi level in a semiconductor lies more than a few kT below the bottom of the conduction band and more than a few kT above the top of the valence band, then show that the product of the number of free electrons and the number of free holes per cm^3 is given by $n_e n_h = 2.33 \times 10^{31} T^3 e^{-Eg/kT}$ where Eg is the gap width.

18. A current of 8×10^{-11} A flows through a silicon p–n junction at temperature 27 °C. Calculate the current for a forward bias of 0.5V.

19. Given that a piece of n-type silicon contains 8×10^{21} m^{-3} phosphorus impurity atoms, calculate the carrier concentrations at room temperature. It may be assumed that the intrinsic electron concentration in silicon at room temperature is 1.6 × 1016 m^{-3}.

20. Find the position of the Fermi level for 11 electrons in an infinite 1D potential well 100Å wide and the probability of exciting a carrier to the first excited state.

21. The N_c and N_v of GaAs at 300K are 4.7 x 10^{17} cm^{-3} and 7 x 10^{18} cm^{-3} respectively. Both N_c and N_v vary as $T^{3/2}$. Calculate the intrinsic carrier concentration at T=300K and 450K. Assume the bandgap is 1.42eV which does not vary with temperature over this range.

22. Band gap of Si depends on the temperature as
    $Eg = 1.17eV - 4.73 \times 10^{-4} (T^2/(T+636))$
    Find a concentration of electrons in the conduction band of intrinsic (undoped) Si at T = 77 K if at 300 K $n_i = 1.05 \times 10^{10}$ cm^{-3}.

23. Calculate the Fermi function at 6.5 eV if EF = 6.25 eV and T = 300 K. Repeat at T = 950 K assuming that the Fermi energy does not change. At what temperature does the probability that an energy level at E = 5.95 eV is empty equal 1 %.