Indian Institute of Technology
PH205
Mid-semester Examination (2023)

Full marks: 30 **Time: 120 minutes**

1. (a) Draw a schematic of the energy band diagram for GaAs showing the different valleys in the conduction band and the bandgap value. [2]

   (b) Derive the energy dependence of the electronic density of states *N(E)* for a one-dimensional semiconductor, taking the effective mass of electron as m*. [3]

2. The absorption coefficient (α) of GaAs is given as $\alpha(\omega) = 5.6 \times 10^4 \frac{\sqrt{(\hbar\omega - E_g)}}{\hbar\omega}$ cm^{-1}. If α is measured as a function of wavelength/frequency of incident light, briefly describe a graphical method (you may look for linear plot) to find the bandgap (E_g) of GaAs from the frequency dependent absorption data. Note that the $\alpha(\omega)$ data is available only for $\hbar\omega > E_g$. [2]

3. In an n-type Si, the Fermi level is 0.3 eV below the conduction band edge. Find the electron (n) and hole (p) concentrations in the same at room temperature (300K). (For Si, E_g=1.1 eV, intrinsic carrier density $n_i = 1.5\times10^{10}$ cm^{-3} and kT =0.026 eV). [3]

4. For a hypothetical semiconductor, $\mu_n = \mu_p = 1000$ cm^2/V-s and $N_c = N_v = 10^{19}$ cm^{-3}. If the electrical conductivity (σ) of the intrinsic semiconductor at 300 K is 4×10^{-6} (Ω-cm)$^{-1}$, what is the conductivity at 600 K. Neglect temperature dependent changes in N_c and N_v. Note that $n = N_c \exp\left[\frac{E_F - E_C}{kT}\right]$ and $p = N_V \exp\left[\frac{E_V - E_F}{kT}\right]$ [4]

5. A Si sample with 10^{15}/cm^3 donors is uniformly optically excited at room temperature such that 10^{19}/cm^3 electron-hole pairs are generated (g_{op}) *per second*. Find the separation of the quasi-Fermi levels (E_{Fn}, E_{Fp}) in eV. Electron and hole lifetimes (τ) are both 10^{-6} s. Take μ_n=1300 cm^2/V-s, μ_p=463 cm^2/V-s. Note that excess carrier density $\delta n = \delta p = g_{op}.\tau$ and $E_{Fn} - E_{Fp} = kT \ln (np / n_i^2)$ [2]

6. (a) How long time (in sec) does it take an average electron to drift 1 μm length in a pure Si at an electric field of 100 V/cm? Take mobility μ_n=1500 cm^2/V-s. [2]

   (b) An abrupt Si p-n junction has $N_a = 10^{18}$ cm^{-3} on one side and $N_d = 5\times10^{15}$ cm^{-3} on the other. Calculate the contact potential V_0 and draw an equilibrium band diagram for the junction showing the value of V_0. Note that $V_0 = kT \ln \frac{N_a N_d}{n_i^2}$. [2]
   e.

7. Consider a *linearly graded* p-n junction, with doping density varying linearly with distance (x) from the junction in each side and is described by $N_d = N_a = Gx$, G is a constant. The doping is symmetrical such that width of the depletion region extends to *W/2* on each side. Using Poisson's equation, find the electric field as a function of x (distance from the junction), and show that the total width of the depletion region, $W = \left[\frac{12\epsilon(V_0 - V)}{qG}\right]^{1/3}$, V and V_0 are the applied bias and built-in potential of the junction, respectively, and ε is the dielectric permittivity of the material. [2+2]

8. Write *short notes* (with diagram, if applicable) on ***any three*** of the following: [2x3]

   (a) Band structure modification, (b) Modulation doping, (c) I-V characteristics of non-ideal diode, (d) Optical gain in semiconductors, (v) Varactor diode.