Semiconductor fundamentals: energy bands and Fermi-level, carrier concentrations

Problem - 1

Answer with reason. If the intrinsic carrier concentration (n_i) in Si, Ge and GaAs samples at room temperature are compared, which of the following statements is true.

(a) n_i of Si > n_i of Ge > n_i of GaAs.

(b) n_i of GaAs > n_i of Si > n_i of Ge.

(c) n_i of Ge > n_i of Si > n_i of GaAs.

Problem - 2

An n-type Si sample is illuminated uniformly from $t=t_{ON}$ sec, resulting in increase in carrier concentration with time. After a while if the light source is removed at $t=t_{OFF}$ sec, the excess carrier concentration vanishes with time. Derive expressions for the time-dependent excess hole concentration as a function of hole life time and photo-generation rate for (a) $t_{ON} < t < t_{OFF}$ and (b) $t > t_{OFF}$.

Problem - 3

Solve the following integral to obtain the analytical expression for electron concentration in a semiconductor sample (assume every other term as constant except E):

$$n=\int_{E_c}^{\infty} 4\pi\left(\frac{2m_e}{h^2}\right)^{(3/2)}\sqrt{(E-E_c)}\exp\left(\frac{-(E-E_f)}{kT}\right)dE$$

Problem - 4

Electron and hole concentration of a semiconductor sample is given by

$$n = N_c \exp\left(\frac{-(E_c - E_f)}{kT}\right) \qquad p = N_v \exp\left(\frac{-(E_f - E_v)}{kT}\right)$$

where E_c (E_v) and N_c (N_v) are the conduction (valence) band edge and effective density of states at the conduction (valence) band, respectively. Now express n and p in terms of n_i (intrinsic carrier concentration), E_f (Fermi level), E_i (Fermi level for intrinsic semiconductor) and kT. Note that k is Boltzmann constant, T is temperature in Kelvin.

Problem - 5

Derive an expression of the intrinsic carrier concentration n_i in terms of E_g (band gap), N_c, N_v and kT. Now plot n_i versus 1/T in a semilog axis (logarithmic y-axis and linear x-axis).

Problem - 6

Answer with reason.

When the temperature is increased, the position of the Fermi level in an n-type semiconductor

(A) moves towards the conduction band edge

(B) moves towards the valence band edge

(C) moves towards the middle of the band gap

(D) remains unchanged

Problem - 7

Show that the effective density of states (N_c) represents the density of states in a strip only 1.2 kT wide near the edge of the conduction band. Assume the density of states in the conduction band as

$$D(E) = 4\pi \left(\frac{2m_e}{h^2}\right)^{(3/2)} \sqrt{(E - E_c)}$$