PH 469: Applied Solid State Physics (Mid-Sem)

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1. Excess carriers are photo-generated at the $y = 0$ plane of an infinitely long n-type semiconductor sample, placed in a uniform electric field $E = E_0\hat{y}$, at room temperature. The excess carrier concentration within the semiconducting sample is determined to be

$$\delta p(y) = \Delta p e^{\theta y} \qquad \forall\, y > 0$$

$$= \Delta p e^{\lambda y} \qquad \forall\, y < 0$$

(a) Prove that $L_p^2 = -\theta\lambda$ (*Here,* L_p *is the hole diffusion length*)

(b) Plot $\delta p(y)$ versus y (5 + 3 = 8)

2. At $T = 0$, the Fermi level of a n-type semiconductor, with a direct bandgap of 1 eV, lies 984 meV above the valence band, whereas at $T = 100\ K$, the intrinsic Fermi level of the same semiconductor lies 6.5 meV below the midgap. If the relative dielectric constant of the semiconductor is $\kappa = 11$, what is the exciton binding energy in the semiconductor? (5)

3. If the Hall coefficient due to light holes is $R_H^{lh} = \frac{E_y}{j_x^{lh}B}$ and the Hall coefficient due to heavy holes is $R_H^{hh} = \frac{E_y}{j_x^{hh}B}$, then show that the Hall coefficient of the p-type semiconductor, at the limit of $\mu_p^{(lh,hh)}B \ll 1$ can be written as

$$R_H = \frac{E_y}{j_x B} = \frac{1}{|e|}\frac{\sigma_{hh}^2 R_H^{hh} + \sigma_{lh}^2 R_H^{lh}}{(\sigma_{hh} + \sigma_{lh})^2}.$$

(7)

4. An indirect band gap semiconductor having the minima along the ⟨100⟩ directions, and within the 1st Brillouin zone, has a bandgap of 0.77 eV, room temperature electron mobility of 600 cm^2/V-s, and momentum relaxation time of 86 *fs*. The constant energy surface in the conduction band, along the [100] direction, is represented by

$$\varepsilon(k) = \frac{\hbar^2}{2m^*}(k_x - k_{x0})^2 + \frac{\hbar^2}{4m^*}(k_y^2 + k_z^2)$$

What is the intrinsic carrier concentration of the semiconductor at room temperature, if the heavy hole and the light hole masses are given by $m_{hh}^* = 0.48m_0$ and $m_{lh}^* = 0.16m_0$?

(5)

5. A semiconductor, with a direct bandgap of 1.1 eV, has electron and hole effective masses of $m_e^* = 0.4m_0$ and $m_h^* = 0.7m_0$, respectively. This semiconductor is doped *n-type* such that the dopants are fully ionized at room temperature, for a doping density of $N_D = 2\text{x}10^{17}\text{cm}^{-3}$. Low level photoexcitation (at room temperature) of this *n-type* semiconductor creates excess carriers, such that at steady state, the quasi fermi levels are separated by 420 meV. If the hole lifetime is $\tau_p = 2\ \mu s$, estimate the optical generation rate.

(5)