Solved Problems EE 207, Prof P. R. Nair, EE, IITB.

Topic : Generation - Recombination

Q1: For a sample with $k = 10^{-10}\ cm^{-3}$; $N_A = 10^{17}\ cm^{-3}$ estimate the minority carrier lifetime.

Hint

$$\frac{dn}{dt} = -k(np - n_i^2)$$

$$\frac{d\Delta n}{dt} \simeq kN_A \Delta n$$

$$\therefore \frac{1}{\tau} = kN_A.$$

Q2: If the above sample is illuminated with $G = 10^{18}\ cm^{-3}s^{-1}$; estimate the charge carrier densities.

Hint: Assuming low level injection

$$G = R = kN_A \Delta n$$

$$\Rightarrow \Delta n = \frac{G}{kN_A}$$

$$n = n_0 + \Delta n \qquad \Delta n = \Delta p$$

$$p = p_0 + \Delta p.$$

Check whether $\Delta n < p_0$. If not analyze in terms of either high level or by retaining all terms.

Q3! For the above sample, estimate the G ~~for which~~ beyond which high level injection condition should be considered?

HINT: When $\Delta n \approx N_A$, we need to consider high level injection conditions.

$$\Rightarrow \quad \Delta n \approx (k N_A)^{-1} G \approx N_A.$$

$$\Rightarrow \quad G \approx k N_A^2$$

Q4: For a sample with $k = 0$, $\tau_n = \tau_p$, estimate the carrier density as a function of G in the ⓐ low level ⓑ high level injection condition.

HINT

ⓐ $$G = R = \frac{\Delta n}{\tau_n}$$

$$\Delta n \approx G \tau_n$$

ⓑ $$G = R = \frac{\Delta n}{(\tau_n + \tau_p)} \Rightarrow \Delta n \approx 2 G \tau_n$$

Q5! Estimate the trap level at which R becomes half ~~of~~ that of its theoretical maximum (~~and~~ for intrinsic materials $(\tau_p = \tau_n)$.

~~Hint!~~ ~~R_{max}~~

HINT! For intrinsic material $R = \dfrac{np - n_i^2}{\tau_p (n + n_1) + \tau_n (p + p_1)}$

the R_{max} happens at $n_1 = n_i$

$$\Rightarrow \quad R_{max} = \frac{\Delta n}{(\tau_p + \tau_n)}$$

| Analysis done in Tutorial)

$$n_1 = n_i e^{(E_T' - E_i)/kT}.$$

So, ~~a~~ we need to find such that

$$R_{new} = R_{max}/2.$$

$$R_{new} = \frac{(np - n_i^2)}{\tau_n(p+p_1) + \tau_n(n+n_1)}$$

Assuming $E_T' > E_i$ | $n_1 > p_1$.

~~with low level injection~~

~~$R_{new} =$~~

For low level injection:

$n = n_i + \Delta n$

$p = n_i + \Delta n$

$np - n_i^2 = \Delta n (2n_i + \Delta n)$

$$R_{new} \approx \frac{\Delta n \times 2 n_i}{\tau_n n_i e^{(E_T' - E_i)/kT}} = \frac{\Delta n}{4\tau_n}.$$

$$\Rightarrow. \quad e^{(E_T' - E_i)/kT} \approx 8$$

<u>Q6:</u> Find the condition for $n, \& p$ at which R maximizes (assume $\tau_n > \tau_p$).

<u>HINT:</u> Similar analysis to Q5 will give the answer

Q7: Find the n/p ratio at R will be $1/10^{th}$ of R_{max}. (assume $\tau_n = \tau_p$).

HINT: Analysis similar to Q5

Q8: For a semiconductor with both SRH + ~~non~~ radiative recombination, find effective minority carrier lifetime

HINT: Start with $\frac{\partial n}{\partial t} = -k(np - n_i^2) + R_{SRH}$

and estimate.

Q9: If we remove all electrons and holes from an intrinsic semiconductor, estimate the time taken to reach equilibrium. (only radiative)

HINT: Solved in tutorials. Seek help from your friends who attended tutorial.

Q10: Repeat the above if only SRH recombination was present

HINT: Same as above.

Q11: A sample with $G = 10^{18}\ \text{cm}^{-3}\text{s}^{-1}$, $k = 0$, $\tau_n = \tau_p = 1\text{ms}$.

Draw the E-B diagram

HINT: First estimate, n + p (decide whether low level or high level injection)

then use

$$n = n_i e^{(E_{Fn} - E_i)/kT}$$

$$p = n_i e^{(E_i - E_{Fp})/kT}.$$