University of Delaware

Department of Electrical and Computer Engineering

ELEG620: Solar Electric Systems Homework #2:

1. SRH or defect recombination is enhanced if a defect level is located at the midgap rather than close to the conduction or valence band. Explain why this is true.

Q1. Mathematical:

Recombination rate depends on concentrations of n & p via

$$U_T = \frac{np - n_i^2}{\tau_{h0}(n+n_1) + \tau_{e0}(p+p_1)}$$

τ_{h0} & τ_{e0} trap dependent lifetimes

n_1 & p_1 depend on trap level energy

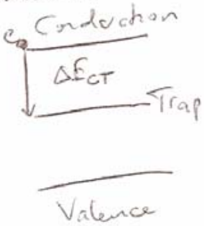
$$n_1 = N_C e^{\left(\frac{E_t - E_c}{kT}\right)} \qquad n_1 p_1 = n_i^2$$

Now the max of U_T is given when $n_1 \approx p_1$ if $\tau_{h0} \approx \tau_{e0}$. This happens if E_t lies roughly halfway between E_C & E_V.

Description:

Recombination via trap level is a two stage process.

1st



electron drops from conduction band to trap.

Probability depends on ΔE_{CT}

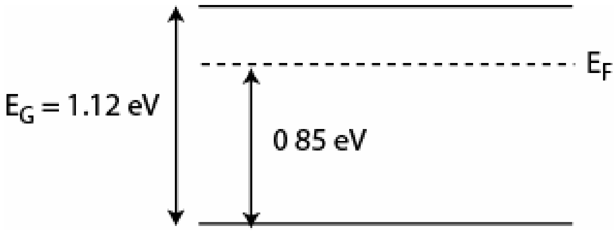
Depends on free states in trap level

2nd

Again probability depends on ΔE_{TV}.

If Trap is near CB ΔE_{TV} is large & so 2nd step very unlikely. If Trap is near VB then ΔE_{CT} is large & 1st step unlikely. Overall rate is product of both rates. Assuming everything else is equal then the max will occur when both rates are roughly equal. Again assuming all things equal this means Trap should be midway.

2. The simplified band structure of silicon (n_i = 1 x 10^{10} cm^{-3}) is shown below. Answer the following questions:



(a) What is the doping in the material (type and dopant density)

The material is n-type (seen from position of E_f compared to Ec or Ev). The doping density is:

$n = N_C \exp\left(\frac{E_F - E_C}{kT}\right) = n_i \exp\left(\frac{E_F - E_i}{kT}\right)$. Ni is given as n_i = 1 x 10^{10} cm^{-3}, and Ei is half the band gap (1.12 eV/2), so the answer is 7.6e14 cm^{-3}.

(b) What is the equilibrium minority carrier concentration?

$np = n_i^2$, and n from above is 7.6e14, so answer is 1.3e5 cm^{-3}.

(c) There is a uniform excess minority carrier concentration of 1 x 10^{15} cm^{-3} throughout the material. Calculate and sketch both the quasi-Fermi levels.

$p = n_i \exp\left(\frac{E_i - F_P}{kT}\right)$ and $n = n_i \exp\left(\frac{F_N - E_i}{kT}\right)$.

P carriers: $1\times10^{15} + 1.3\times10^{5} = (1\times10^{10})\exp\left(\frac{0.56 - F_P}{0.0258}\right)$ Fp = 0.26 eV above the valence band.

N carriers: $1\times10^{15} + 7.6\times10^{14} = (1\times10^{10})\exp\left(\frac{F_n - 0.56}{0.0258}\right)$ Fp = 0.87 eV above the valence band, or only 0.02 eV above where the equilibrium Fermi level is.

3. A semi-infinitely long piece of material has a constant injection of minority carrier at one edge, denoted by N_{inj}.

(a) Using τ for the minority carrier lifetime and D for the diffusivity, calculate the minority carrier diffusion current in the slab. Be sure to indicate what type of current (electron or hole) you are calculating.

Assuming that the electric field is negligibly, the transport equation becomes (for electrons)

$J_n = qD_n \frac{dn(x)}{dx}$. Combining this with the continuity equations gives:

$\frac{dJ_n}{dx} = qD_n \frac{d^2 n(x)}{dx^2} = q(U(x) - G(x))$ and rearranging gives: $\boxed{\frac{d^2 n(x)}{dx^2} = \frac{U(x) - G(x)}{D_n}}$.

The recombination is given by $U = \dfrac{\Delta n}{\tau_n}$ and there is no generation, so the general equations becomes:

$\dfrac{d^2 n(x)}{dx^2} = \dfrac{n(x)}{L_n}$ (using $L_n = \sqrt{D_n \tau_n}$). The general solution is $\Delta n(x) = A e^{-x'/L_n} + B e^{x'/L_n}$. We know that far away from the injecting surface, the carrier concentration must be finite, so in order to maintain a finite n(x), B must be zero. So far everything is identical to the diode equation.

The other boundary condition is that n(x=0) = N_{inj}, so A = N_{inj}. So the particular solution is:

$\Delta n(x) = N_{inj} e^{-x'/L_n}$. We find the external current by plugging back into the transport equation $J_n = qD_n \dfrac{dn(x)}{dx}$ and finding the solution at x=0 to get $\boxed{J_n = -q \dfrac{D_n}{L_n} N_{inj}}$

(b) What happens (describe, don't calculate) as the minority carrier lifetime tends towards very large values?

As the minority carrier lifetime gets very large, the carrier concentration in the device becomes nearly constant, and the diffusion current becomes very small.

(c) If the slab were made much thinner, and the surface recombination is large, briefly describe what would happen to the diffusion current.

Increasing the surface recombination velocity would lower the carrier concentration at one end of the slab. Therefore, across the slab, dn/dx would increase, and the current would increase.

4. Draw the band diagram of a pn junction under equilibrium and forward bias. Include the Fermi and quasi-Fermi levels, as appropriate.