ECE 340 Homework IV Spring 2003

Due: Wednesday, February 12, 2003

(30 Points)

1. *Reconstruct Fig. 3-18. On the graph, plot the carrier concentration as a function of temperature for two silicon samples doped with the same donor but at two different concentrations of 1x10^{14}/cm^{3} and 1x10^{16}/cm^{3}, respectively.*

2. *A compensated germanium sample is doped with 5x10^{13}/cm^{3} acceptors and 5x10^{15}/cm^{3} donors. (a) What are the electron and hole concentrations, respectively, at room temperature under equilibrium conditions? Repeat for (b) 5x10^{13}/cm^{3} acceptors and 5x10^{14}/cm^{3} donors (c) 5x10^{13}/cm^{3} acceptors and 6x10^{13}/cm^{3} donors and (d) 5x10^{13}/cm^{3} acceptors and 5.1x10^{13}/cm^{3} donors. Determine the percentage of error in each case for the majority carrier concentration if one simply assumes that the majority carrier concentration approximately equals the difference between the densities of donors and acceptors.*

Solutions:

From Fig 3-17, $n_i(300K) = 2.5\times10^{13}\,cm^{-3}$.

Use charge neutrality equation: $N_d^+ + p = N_a^- + n$, $N_d^+ = 5\times10^{15}\,cm^{-3}$, $N_a^- = 5\times10^{13}\,cm^{-3}$

Since at thermal equilibrium, $p = \dfrac{n_i^2}{n}$,

We have: $n^2 - \left(N_d^+ - N_a^-\right)n - n_i^2 = 0$, solving this quadratic equation gives:

$$n = \frac{\left(N_d - N_a\right) \pm \sqrt{\left(N_d - N_a\right)^2 + 4n_i^2}}{2}, \quad p = \frac{n_i^2}{n}$$

N_d (cm^{-3})	5×10^{15}	5×10^{14}	6×10^{13}	5.1×10^{13}
n (cm^{-3})	4.95×10^{15}	4.51×10^{14}	3.05×10^{13}	2.55×10^{13}
p (cm^{-3})	1.26×10^{11}	1.39×10^{12}	2.05×10^{13}	2.45×10^{13}
Assume $p' = N_a - N_d$ (cm^{-3}) Percent of error $= \left(p - p'\right)/p$	4.95×10^{15} 0.002%	4.5×10^{14} 0.31%	1×10^{13} 67%	1×10^{12} 96%

1. *(a) Construct a semi-logarithmic plot such as Fig. 4-7 for Si doped with $3x10^{16}/cm^3$ donors and having $3x10^{14}$ EHP/cm^3 created uniformly at t = 0. Assume that $t_n = t_p$ = 2 μ s. How much time is needed before the minority carrier concentration equals the intrinsic carrier concentration?*
   (b) Calculate the recombination coefficient a_r for part (a). Assume that this value of a_r applies when the Si sample is uniformly exposed to a steady-state optical generation rate $g_{op} = 10^{20}$ EHP/cm^3-s. Find the steady-state excess carrier concentration $Dn = Dp$.
   (c) Repeat part (b) to find the steady-state excess carrier concentration $Dn = Dp$ for $g_{op} = 1x10^{22}$ EHP/cm^3-s. Determine the percentage of error if one simply uses eq. 4-14 to calculate the steady-state excess carrier concentration.

Solution:

(a) $n_0 = 3\times10^{16} cm^{-3}$,

$p_0 \ll n_0$, $d\,n = d\,p \ll n_0$, this is a low-level injection situation.

$d\,n(t) = d\,p(t) = \Delta n e^{-t/t_n}$,

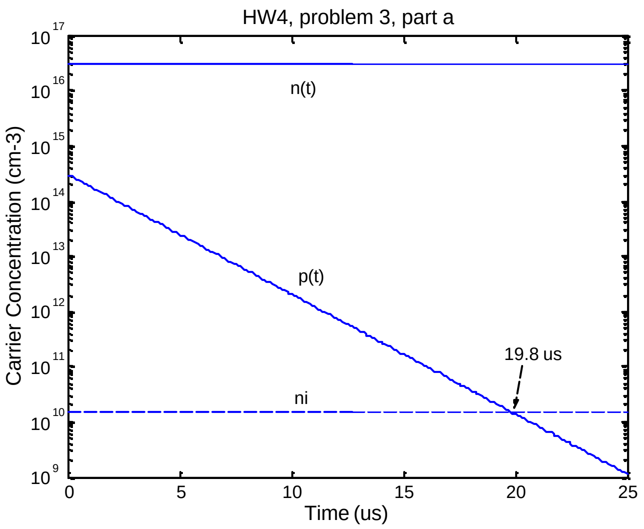
$n(t) = n_0 + d\,n(t) = 3\times10^{16} + 3\times10^{14} e^{-t/2us} cm^{-3}$

$p(t) = p_0 + d\,p(t) \approx d\,p(t) = 3\times10^{14} e^{-t/2us} (cm^{-3})$

Time t needed for minority carrier to decay to n_i:

$3\times10^{14} e^{-t/2us} = n_i = 1.5\times10^{10}$

$t = 19.8 m\,s$



(b) $a_r = \dfrac{1}{t_n (n_0 + p_0)} \approx \dfrac{1}{2\times10^{-6} s \times 3\times10^{16} cm^{-3}} = 1.67\times10^{-11} cm^3 s^{-1}$, This is still a low-level injection

Steady state: $d\,n = d\,p = g_{op} t_n = 10^{20}\times2\times10^{-6} = 2\times10^{14} cm^{-3}$

(c) This is no longer a low-level injection case. In equation 4-12, we can't ignore $d\,n^2$ term, therefore:

$g_{op} = a_r[(n_0 + p_0)]d\,n + d\,n^2]$, neglect n_0 term, and assume a_r still applies at this condition, plug in the number and solve the quadratic equation, we have:

$d\,n = 1.37\times10^{16} cm^{-3}$

If simply use 4-14, then,

$d\,n = d\,p = g_{op} t_n = 10^{22}\times2\times10^{-6} = 2\times10^{16} cm^{-3}$

$$Error = \frac{2\times10^{16} - 1.37\times10^{16}}{1.37\times10^{16}} = 46\%$$