Solutions to Homework #2 ECE6450

1.) A.) From the assumption that $n << n_i$,

$$D = D_i + \left[\frac{n}{n_i}\right] D^{1-} + \left[\frac{n}{n_i}\right]^2 D^{2-} + \left[\frac{n}{n_i}\right]^3 D^{3-} + \left[\frac{n}{n_i}\right]^4 D^{4-}$$

$$\ldots. + \left[\frac{p}{n_i}\right] D^{1+} + \left[\frac{p}{n_i}\right]^2 D^{2+} + \left[\frac{p}{n_i}\right]^3 D^{3+} + \left[\frac{p}{n_i}\right]^4 D^{4+}$$

$$= D_i$$

Thus, for As,

$$D_{A_s} = 0.066 e^{\left(\frac{-3.44}{8.617e-5T}\right)}$$

while for P,

$$D_p = 3.9 e^{\left(\frac{-3.66}{8.617e-5T}\right)}$$

thus, for all T>350 C (a very low temperature as far as diffusions go) $D_P > D_{As}$. If we want to limit the base from diffusing further, we should pick the slower diffusing impurity; ===> Arsenic.

B.) During the predeposition, a thin layer of material is deposited into the silicon wafer. During the drive in step, the material deposited in the silicon during the predeposition is "driven in" to a deeper depth. Thus, the junction depth of this process is determined by the "drive in" step. This is consistent with the assumption of (D_1t_1)^0.5<<(D_2t_2)^0.5 (which we will verify in part F of this problem). From the problem statement, we find 2 equations to solve 2 unknowns:

$$C(x = 3\ um, t_2) = 10^{15}\ cm^{-3} \text{ as well as } C(x = 1\ um, t_2) = 10^{16}\ cm^{-3}$$

$$10^{15} = \frac{Q_T}{\sqrt{\pi}\sqrt{D_2 t_2}} e^{\left(\frac{-(3x10^{-4}\ cm)^2}{4\left(\sqrt{D_2 t_2}\right)^2}\right)}$$

$$10^{16} = \frac{Q_T}{\sqrt{\pi}\sqrt{D_2 t_2}} e^{\left(\frac{-(1x10^{-4}\ cm}{4(\sqrt{D_2 t_2})^2}\right)^2}$$

This leads to,

$$Q_T = 10^{15}\sqrt{\pi}\sqrt{D_2 t_2}\, e^{\left(\frac{+(3x10^{-4}cm)^2}{4(\sqrt{D_2 t_2})^2}\right)}$$

$$\sqrt{D_2 t_2} = \sqrt{\frac{(3x10^{-4})^2 - \left(1x10^{-4}\right)^2}{4\ln(10)}} = 9.32x10^{-5}cm = 0.932\mu m$$

then,

$$Q_T = 2.2x10^{12}cm^{-2}$$

C.)

$$D_{As} = 0.066e^{\left(\frac{-3.44}{8.617e-5(1150+273)}\right)} = 4.32x10^{-14}cm^2/\sec$$

So,

$$t_2 = 2.01x10^5 \sec = 55.8 hours \quad \textbf{\textit{(in practice ,way too long)}}$$

Note that at this point, we have determined all parameters for the drive in.

D.)

$$D_{As} = 0.066e^{\left(\frac{-3.44}{8.617e-5(900+273)}\right)} = 1.1x10^{-16}cm^2/\sec$$

E.)

$$2.2x10^{12} = \frac{2}{\sqrt{\pi}}2x10^{20}\sqrt{1.1x10^{-16}t_1}, \Rightarrow t_1 = 0.87\sec$$

Note: this time is way too short (real furnace processes should be greater than ~15 minutes or so).
If you were really going to build this transistor, you would want to lower the predeposition temperature to make t_1 longer.

F.) Comparing characteristic diffusion lengths for the predeposition, L_1 and drive in, L_2, one finds, L_1=9.7e-9 cm << L_2=9.32e-5 cm. Thus, our use of separate predeposition and drive in analyses is valid.

G.)

$$C_s = \frac{2.2x10^{12}}{\sqrt{\pi 4.32x10^{-14}}\, 2.01x10^5} = 1.3x10^{16}cm^{-2}$$

Thus, since L_1 and t_1 are VERY small, and Cs is much lower than n_i @ T=1150 C, our assumption of D=D_i appears valid. Notice that the profile is fairly flat, dropping ~1decade to the base -collector junction.

2.) A.) If a high surface concentration is desired (this improves the transistor performance by providing a high number of electrons available to be "emitted" into the base), we would choose to do the emitter under predeposition conditions (no drive in, i.e. leave on the source of impurities). This will insure that our surface concentration is saturated at the maximum value determined by the impurity solubility at the diffusion temperature. Simply put, the use of a predeposition (infinite source) diffusion, insures the impurity surface concentration will never be depleted (it is continuously being supplied).

B.) We need a p-type dopant: Again, we want a high surface concentration, so use Boron (Al, and Ga would also work, but according to Figure 2-4 in your book, have lower solid solubilities in Si). From figure 2-4 in your book, [B] (at x=0 um) = 5e20 cm^{-3} at 1200 C (solubility limited) and at 1 um, [B]=10^{16} cm^{-3}. Thus, we have,

$$10^{16} = 5x10^{20} erfc\left(\frac{1e-4}{2\sqrt{D_3 t_3}}\right)$$

using the expressions given in Appendix V of your book,

$$\text{Let } w = \frac{1x10^{-4}}{2\sqrt{D_3 t_3}}$$

$$\frac{10^{16}}{5x10^{20}} = 0.00002 = erfc(w) = 1 - erf(w)$$

$$0.99998 = erf(w)$$

from the table in appendix V, w~3.02 (you could interpolate between 3.01 and 3.02 to get the exact number). Thus,

$$\sqrt{D_3 t_3} = 1.65x10^{-5}\ cm\ or\ 0.165\ \mu m$$

Using,

$$D_B = 0.037e^{-3.46/(8.617e-5(1200+273))} = 5.36x10^{-14} cm^2/\sec$$

Thus,

$$t_3 = 5109\sec = 1.4 hours$$

C.)

$$Q_T = \frac{2}{\sqrt{\pi}} 5x10^{20}(1.65x10^{-5}) = 9.3x10^{15}\,cm^{-2}$$

D.) Using the profiles for the drive in and predeposition, you can not expressly calculate the base movement due to the emitter diffusion temperature being different from the base diffusion temperature. However, you can estimate the movement based on the characteristic diffusion length, which is approximately the depth from the surface where the concentration is 1/2 the surface concentration.

At T=1200 C, D_{As} = 1.1e-13. Since the time required for the emitter was 5109 sec, the characteristic diffusion length for the base during the emitter diffusion is 0.24 um. This is less than 10% of the emitter depth. Thus, this movement is probably okay, but for a good transistor design, one should recalculate the base junction depth to take this into account.