3.155J/6.152J
Microelectronic Processing
Spring Term, 2005

Bob O'Handley

Martin Schmidt

Problem Set 3 SOLUTIONS **Sept . 21, 2005** **Due Oct. 2, 2005**

Problem 1

$$C(z,t) = \frac{Q}{\sqrt{\pi D t}} \exp\left(-\frac{z^2}{4Dt}\right)$$

$$\frac{dC}{dt} = \left(-\frac{Q}{2t\sqrt{\pi D t}} + \frac{Q}{\sqrt{\pi D t}}\frac{z^2}{4Dt^2}\right)\exp\left(-\frac{z^2}{4Dt}\right) = C(z,t)\left(\frac{z^2}{2Dt} - 1\right)\frac{1}{2t}$$

$$\frac{dC}{dz} = \frac{-2z}{4Dt}C(z,t)$$

$$\frac{d^2C}{dz^2} = -\frac{2}{4Dt}C(z,t) + \frac{4z^2}{16D^2t^2}C(z,t) = C(z,t)\left(\frac{2z^2}{4Dt} - 1\right)\frac{2}{4Dt}$$

Thus,

$$\frac{dC(z,t)}{dt} = D\frac{d^2C(z,t)}{dz^2}$$

Problem 2

D_0(900 C) = 1, E_0(900 C) = 3.5 eV, $D = 9.46 \times 10^{-16}$ cm^2/s. Using $t = 1800$ s, the diffusion length is $a = 26.1$ nm.

Problem 3

a) From Fig. 1.16 in Plummer or 3.4 in Campbell, $n_i \approx 1\times 10^{18}$ cm^{-3}.

b) i) From Plummer Table 7-5:

$D^0.0 = 0.05$ cm^2/s, $D^0.$E = 3.5 eV, $D^+.0 = 0.95$, $D^+.E = 3.5$

Using the relation $D = D^0.0\exp\left(-\frac{D^0.E}{kT}\right) + D^+.0\exp\left(-\frac{D^+.E}{kT}\right)\left(\frac{n}{n_i}\right) + \ldots$

$$D^{\text{eff}} = 1.19\times 10^{-19}\,\text{cm}^2\text{s}^{-1} + 2.26\times 10^{-18}\,\text{cm}^2\text{s}^{-1}\left(\frac{n}{10^{18}\,\text{cm}^{-3}}\right)$$

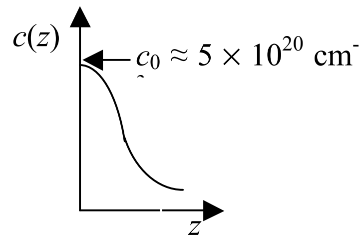
For $N_D = 2\text{x}10^{18}$, Plummer Eq. 1.16 or 1.17 gives $n = 2.41 \times 10^{18}$.

Then D^{eff} = 1.19 x 10^{-19} + 5.46 x 10^{-18} = 5.57 x 10^{-18} cm^2/s.
For N_D = 1x10^{18}, n = 1.62 x 10^{18}.
Then D^{eff} = 1.19 x 10^{-19} + 3.66 x 10^{-18} = 3.78 x 10^{-18} cm^2/s.

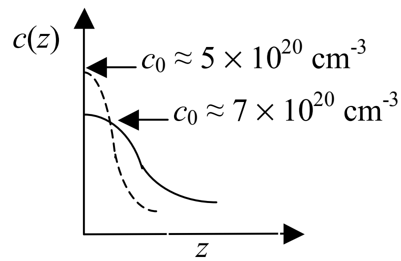
c) Diffusion lengths in the two cases are $a = 2\sqrt{Dt}$ = 2.83 nm and 2.33 nm, respectively.

Problem 4

a) The idea of this failed problem was to calculate the *dose* of a dopant diffused into a substrate under high, constant external concentration conditions so that the diffusion constant is clearly dependent on depth. (One could only get the exact $c(x)$ profile by numerical integration of the diffusion equation.)



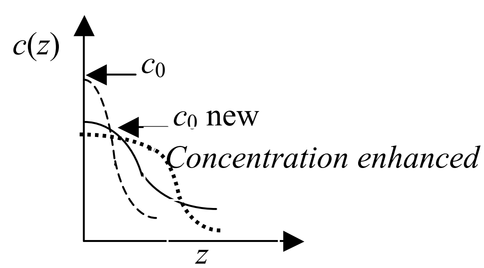
b) This part was aimed at probing your realization that now the boundary conditions had changed and the diffusion was done from a constant dose (erfc solution). If the numbers had been more carefully selected, you could have assumed that the junction depth would increase with time as $(Dt)^{1/2}$ or inverted the solution



$$C(z,t) = C_s \exp\left(-\frac{z^2}{4Dt}\right) = \frac{Q}{\sqrt{\pi Dt}} \exp\left(-\frac{z^2}{4Dt}\right) = N_A = 10^{15} \text{cm}^{-3}$$

to solve for the time required to put the junction at the desired depth. But this is not easily solved for t unless you first work under the assumption that the exponential time dependence dominates and start with, say t = 10 s in the pre-exponential factor (then iterate).

This approach is also flawed by assuming that the solution can be arrived at analytically, even if you chose the diffusion constant at the background dopant concentration. Clearly, the greater diffusion rate closer to the surface, where the impurity concentration is greater, would square-up the diffusion profile (see sketch, dotted line) and accelerate the diffusion at greater depth, moving the estimated junction deeper, or the time to achieve a given depth, overestimated.



Problem 5

a) At 40 keV, boron from Fig. 8-3, $R_p \approx 145$ nm and $\Delta R_p \approx 58$ nm.

b) Given $Q = 10^{12}$ cm^{-2} and ΔR_p above, $Q = (2\pi)^{1/2} \Delta R_p c_p$ gives $c_p = 6.88 \times 10^{16}$ cm^{-3}.

c) $c(x) = c_p \exp\left(-\frac{(x - R_p)^2}{2\Delta R_p^2}\right)$ at $x = 300$ nm gives $c(300) = 1.53 \times 10^{15}$ cm^{-3}.

Problem 6

Given $R_p = 0.2$ μm (200 nm) demands an implant of boron at about 60 keV (Fig. 8-3). At this energy $\Delta R_p \approx 52.5$ nm, so the dose giving a peak concentration of 10^{17} cm^{-3} is easily calculated from $Q = (2\pi)^{1/2} \Delta R_p c_p$ to be 1.3×10^{12} cm^{-2}. For a background doping of 10^{15} cm^{-3}, the junction depth before diffusion is given by inverting $c(x) = c_p \exp\left(-\frac{(x - R_p)^2}{2\Delta R_p^2}\right)$ to get two junctions, one at $x_{jct} = 40.7$ nm the other at 359 nm.