NANYANG TECHNOLOGICAL UNIVERSITY
SCHOOL OF ELECTRICAL & ELECTRONIC ENGINEERING
ACADEMIC YEAR 2022-2023
SEMESTER 1

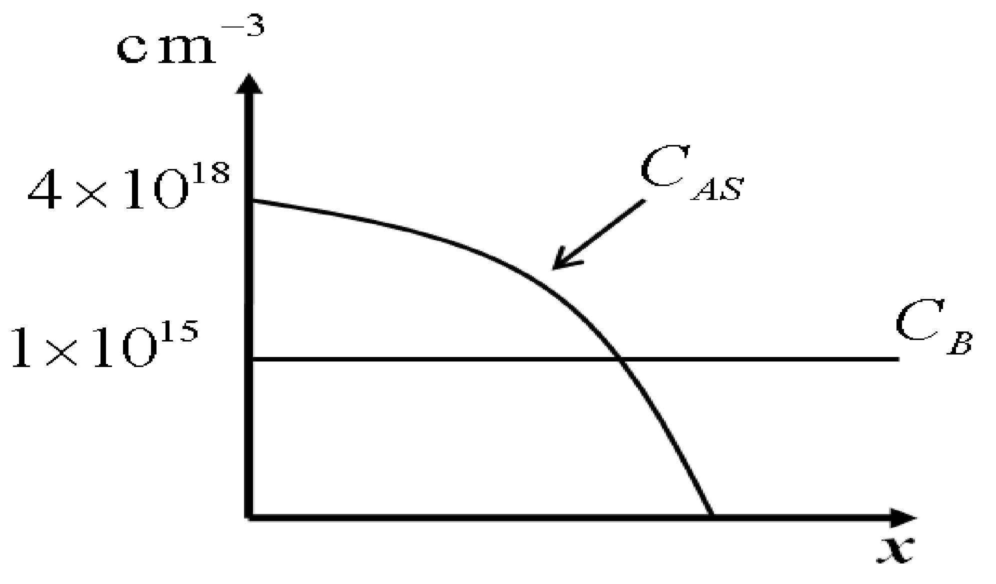
EE3013 SEMINCONDUCTOR DEVICES AND PROCESSING

Diffusion

Q1.

a) If arsenic is diffused into a thick slice of silicon doped with 1×10^{15} boron atoms/ cm^3 at a temperature of 1100°C for 3 hr, what is junction depth if the surface concentration is held constant at 4×10^{18} atoms/cm^{-3} ? $D_{As}=3\times10^{-14}cm^2/s$ at 1100°C.

b) If the diffusion temperature is lowered to 900°C, what is the junction depth? $D_{As}=1\times10^{-16}cm^2/s$ at 900°C.



(a)

$$N_{AS}(x,t) = N_{AS0} \cdot \text{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$\left.\begin{aligned} D &= 3\times10^{-14}\ \text{cm}^2/s \\ t &= 3\times60\times60\ \ s \end{aligned}\right\} \quad \text{when } x = x_j, N_{AS}(x_j,t) = N_B$$

$$\text{Or}\quad 1\times10^{15} = 4\times10^{18}\cdot\text{erfc}\left(\frac{x_j}{3.6\times10^{-5}}\right)$$

$$\text{erfc}(z) = 2.5\times10^{-4} \quad\Rightarrow\quad \text{erf}(z) = 0.99975$$

From table of error function: *z* = 2.595 (can also be from erfc function).

X_j = (3.6x10^{-5})(2.595) cm ➡ $x_j = 0.93\ \mu m$ ([1 cm = 10^4 μm]

b) At a lower diffusion temperature of 900°C

$$\frac{x_j}{2\sqrt{Dt}} = \frac{x_j}{2\sqrt{1\times10^{16}\times3\times60\times60}} = \frac{x_j}{2.078\times10^{-6}} = 2.595$$

or $x_j = 0.054\ \mu m$ ➡ So at lower temperature, junction is shallower

Error Function Table

z	erf(z)	erfc(z)	z	erf(z)	erfc(z)
0.00	0	1	1.3	0.9340079	0.0659921
0.05	0.056372	0.943628	1.4	0.9522851	0.0477149
0.10	0.1124629	0.8875371	1.5	0.9661051	0.0338949
0.15	0.167996	0.832004	1.6	0.9763484	0.0236516
0.20	0.2227026	0.7772974	1.7	0.9837905	0.0162095
0.25	0.2763264	0.7236736	1.8	0.9890905	0.0109095
0.30	0.3286268	0.6713732	1.9	0.9927904	0.0072096
0.35	0.3793821	0.6206179	2.0	0.9953223	0.0046777
0.40	0.4283924	0.5716076	2.1	0.9970205	0.0029795
0.45	0.4754817	0.5245183	2.2	0.9981372	0.0018628
0.50	0.5204999	0.4795001	2.3	0.9988568	0.0011432
0.55	0.5633234	0.4366766	2.4	0.9993115	0.0006885
0.60	0.6038561	0.3961439	2.5	0.999593	0.000407
0.65	0.6420293	0.3579707	2.6	0.999764	0.000236
0.70	0.6778012	0.3221988	2.7	0.9998657	0.0001343
0.75	0.7111556	0.2888444	2.8	0.999925	0.000075
0.80	0.742101	0.257899	2.9	0.9999589	0.0000411
0.85	0.7706681	0.2293319	3.0	0.9999779	0.0000221
0.90	0.7969082	0.2030918	3.1	0.9999884	0.0000116
0.95	0.8208908	0.1791092	3.2	0.999994	0.000006
1.00	0.8427008	0.1572992	3.3	0.9999969	0.0000031
1.20	0.910314	0.089686	3.5	0.9999993	0

Q2. A pn junction with a junction depth of 2μm is formed by diffusing pre-deposited boron atoms into the n-type silicon substrate at 1150^{o}C for 1 hr. The dose for the pre-deposited boron atoms is 3×10^{13} boron atoms/cm^2. Assuming that the diffusion is Gaussian, find the doping of the n-type silicon substrate. Given that $D_B=9.2\times10^{-13}$cm^2/s at 1150^{o}C.

Solution:

Pre-deposited Boron atom concentration

Constant Source diffusion

$$N(x,t) = \frac{Q}{\sqrt{\pi Dt}} e^{-\frac{x^2}{4Dt}},$$

For t = 1 hr, N = $\frac{Q}{\sqrt{\pi Dt}} = \frac{3\times 10^{13}}{\sqrt{\pi \times 9.2\times 10^{-13} \times \underbrace{1\times 60\times 60}_{\text{1 hour}}}}$

$$= 2.94\times 10^{17}\ \mathrm{cm}^{-3}$$

Junction depth = 2μm = 2x10^{-4} cm

$$N(x,t) = N_{\text{backgroud}}$$

$$N_{\text{backgroud}} = 2.94\times 10^{17} \exp[-\frac{(2\times 10^{-4})^2}{(4)(9.2\times 10^{-13})(1\times 60\times 60)}] = 1.44\times 10^{16}\, cm^{-3}$$

Q3. In a diffusion step 2.25×10^{13} boron atoms/cm^2 were deposited on the surface of a silicon slice. The slice was subsequently placed in a diffusion furnace tube at 1145^{o}C for 2 hr. The n-type substrate had an impurity concentration of 1×10^{16}cm^{-3}. Assuming that the diffusion is Gaussian, find the depth of the p-n junction in micrometers. $D_B=9.2\times10^{-13}$cm^2/s at 1145^{o}C.

This is a limited source diffusion:

Surface concentration

$Q=2.25\times10^{13}$ boron atoms/cm^2 were deposited on the surface

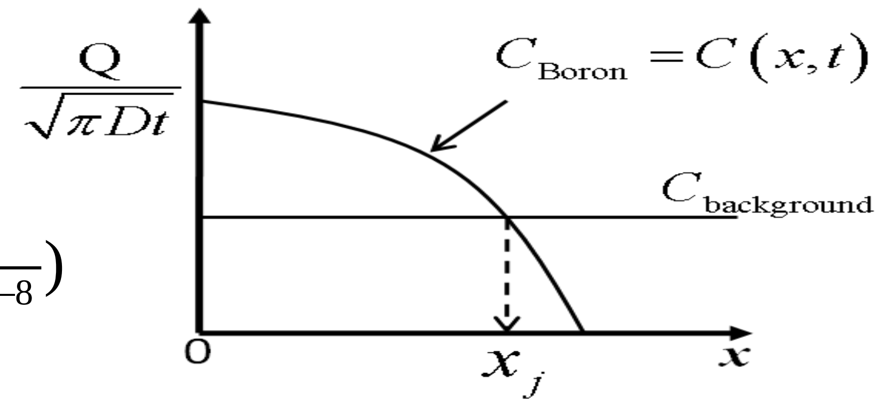
$$N(x,t)=\frac{Q}{\sqrt{\pi Dt}}e^{-\frac{x^2}{4Dt}},$$

$$\frac{Q}{\sqrt{\pi Dt}}=\frac{2.25\times10^{3}}{\sqrt{\pi\times9.2\times10^{-13}\times2\times60\times60}}$$

$$=1.56\times10^{17}\ \text{cm}^{-3}$$

After diffusion, when x = x_j

$$N(x,t)=N_{\text{backgroud}}$$



$$1\times10^{16}=1.56\times10^{17}\exp\left(-\frac{x_j^2}{2.65\times10^{-8}}\right)$$

Solving $x_j=\pm2.7\,\mu m$

Note: X_j = -2.7μm cannot be the solution

Q4. An emitter-base junction is formed by diffusing phosphorous atoms into p-type silicon for 1 hr at 1000^{o}C. The phosphorous concentration at the silicon surface is maintained at the limit of solid solubility. Assuming that the base has a uniform p-type background concentration of 1×10^{17} atoms/cm^{-3}, locate the emitter-base junction.

If the emitter diffusion is performed at 900^{o}C, determine the diffusion time for obtaining the same junction depth. Solid solubility of P in Si is suitably assumed. $D_P = 1 \times 10^{-15}$ cm^2/s at 900^{o}C and 3×10^{-14} cm^2/s at 1000^{o}C.

Since P concentration at surface maintained at solid-solubility limit, the diffusion is constant source

$$N(x,t) = N_s \cdot \mathrm{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)$$

- Solid solubility limit for P in Si at 1000°C =10^{21} cm^{-3} (see lecture notes and also available in most textbooks). So, $N_s = 10^{21}$cm^{-3}

$$x = x_j \quad \Rightarrow N(x_j, t) = 1\times 10^{17};$$

$$1\times 10^{17} = 10^{21}\mathrm{erfc}(Z)$$

$$\mathrm{erfc}(Z) = 0.0001$$

$$\Rightarrow Z = \frac{x_j}{2\sqrt{Dt}} = 2.755;$$

z	erf(z)	erfc(z)
1.3	0.9340079	0.0659921
1.4	0.9522851	0.0477149
1.5	0.9661051	0.0338949
1.6	0.9763484	0.0236516
1.7	0.9837905	0.0162095
1.8	0.9890905	0.0109095
1.9	0.9927904	0.0072096
2.0	0.9953223	0.0046777
2.1	0.9970205	0.0029795
2.2	0.9981372	0.0018628
2.3	0.9988568	0.0011432
2.4	0.9993115	0.0006885
2.5	0.999593	0.000407
2.6	0.999764	0.000236
2.7	0.9998657	0.0001343
2.8	0.999925	0.000075

$$\text{or} \quad x_j = 2\times 2.755 \times \sqrt{3\times 10^{-14} \times 60 \times 60} = 0.573\,\mu\text{m}.$$

- At 900 °C, then solid solubility of P is 5 × 10^{20} cm^{-3} and diffusion coefficient of P is 1×10^{-15} cm^2/s.

To have the same junction depth of 0.575×10^{-4} cm,

$$1\times10^{17} = 5\times10^{20}\,erfc\left(\frac{0.573\times10^{-4}}{2\sqrt{1\times10^{-15}\times t}}\right)$$

$$0.0002 = erfc\left(\frac{0.573\times10^{-4}}{2\sqrt{1\times10^{-15}\times t}}\right)$$

$$\frac{0.575\times10^{-4}}{2\sqrt{1\times10^{-15}\times t}} = 2.63$$

t = 119499 sec = 33.2 hours

z	erf(z)	erfc(z)
1.3	0.9340079	0.0659921
1.4	0.9522851	0.0477149
1.5	0.9661051	0.0338949
1.6	0.9763484	0.0236516
1.7	0.9837905	0.0162095
1.8	0.9890905	0.0109095
1.9	0.9927904	0.0072096
2.0	0.9953223	0.0046777
2.1	0.9970205	0.0029795
2.2	0.9981372	0.0018628
2.3	0.9988568	0.0011432
2.4	0.9993115	0.0006885
2.5	0.999593	0.000407
2.6	0.999764	0.000236
2.7	0.9998657	0.0001343
2.8	0.999925	0.000075