In Practice, the Diffusion of Impurities is a Two-Step Process

① Predeposition (ii) Drive-In

① Predeposition :

Here we perform Constant Source diffusion at Temperature T_1 for time t_1

$$\therefore D_1 = D_1(T_1), \quad N_{O1} = N_O(T_1)$$

$$\therefore N(x, t_1) = N_{O1} \, \mathrm{erfc}\left(\frac{x}{2\sqrt{D_1 t_1}}\right)$$

And after time t_1, the dose of Impurities $Q(t_1)$ at Surface $= 2 N_{O1} \sqrt{\frac{D_1 t_1}{\pi}}$

(ii) After Predeposition step, source of Impurities are stopped. Then the wafers are reintroduced in the furnace at Temperature T_2 for time t_2 this process is continued. This process is called Drive-In.

At T_2, $D_2(T_2) = D_2$, $\therefore$ $Dt = D_2 t_2$

In Drive-In, no new impurities are introduced, but available ones from Predeposition are Re-distributed (Q dose). This is the case of Limited Source Diffusion giving Gaussian Profile:

$$N(x, t_1, t_2) = \frac{Q}{\sqrt{\pi D_2 t_2}} \exp\left(-\frac{x^2}{4 D_2 t_2}\right)$$

or $$N(x, t_1, t_2) = \frac{2 N_{01}}{\pi} \sqrt{\frac{D_1 t_1}{D_2 t_2}} \exp\left(-\frac{x^2}{4 D_2 t_2}\right)$$

Assumption here is

$$D_1 t_1 << D_2 t_2$$

However even if this condition is not met, we can still evaluate Profile, using Smith's Integral.

We define $\alpha = \sqrt{\dfrac{D_1 t_1}{D_2 t_2}}$ and $\beta = \dfrac{x^2}{4(D_1 t_1 + D_2 t_2)}$

If $D_1 t_1 \simeq D_2 t_2$, then

$$N(x, t_1, t_2) = \frac{2 N_{01}}{\pi} \int_{\sqrt{\beta}}^{\infty} e^{-y^2} \operatorname{erf}(\alpha y)\, dy$$

By Simplification

$$N(x, t_1, t_2) = \frac{2 N_{01}}{\pi} \int_0^{\alpha} \frac{e^{-\beta(1+\alpha^2)}}{1+\alpha^2}\, d\alpha$$

Now surface conc (at $x=0$) N_s is given by

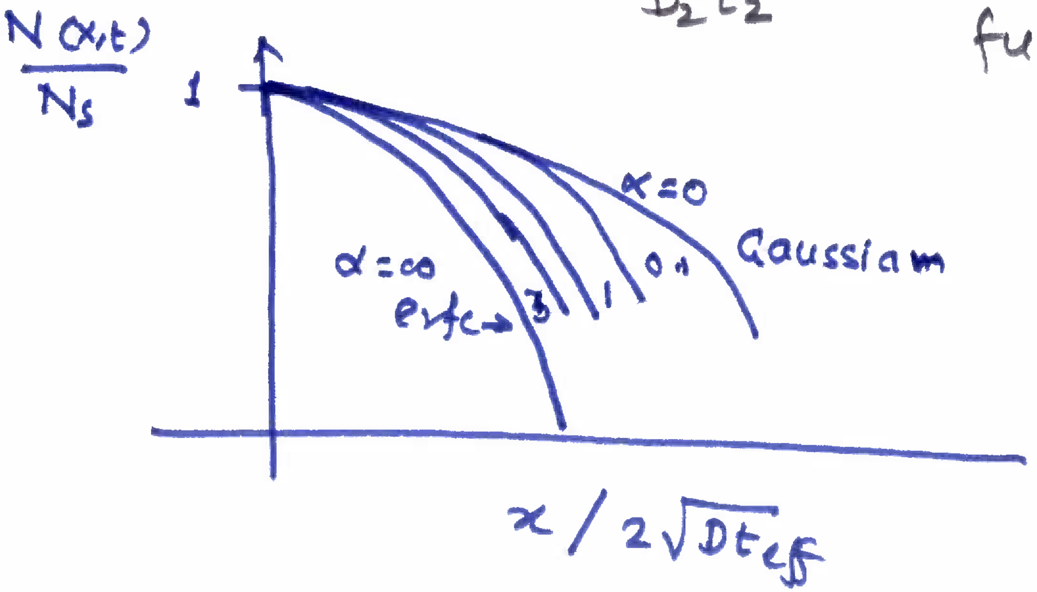
$$N_s = \frac{2N_{01}}{\pi}\tan^{-1}\alpha$$

If α is Small and $<< 1 \Rightarrow D_1t_1 << D_2t_2$

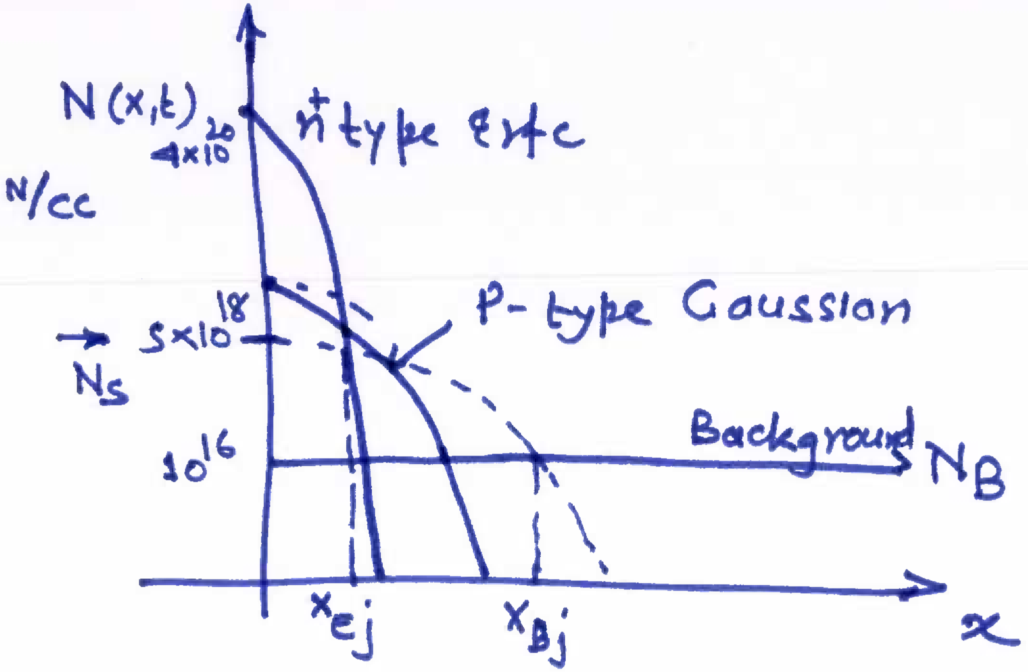
Then $\tan^{-1}\alpha = \alpha$

$$\therefore \quad N_s = \frac{2N_{01}}{\pi}\sqrt{\frac{D_1t_1}{D_2t_2}}$$

Same as Standard Two step function.



Successive Diffusion



$$(Dt)_{eff} = \Sigma D_1t_1 + D_2t_2 + D_3t_3 + \dots$$

① Substrate n-type = 10^{16}/cc

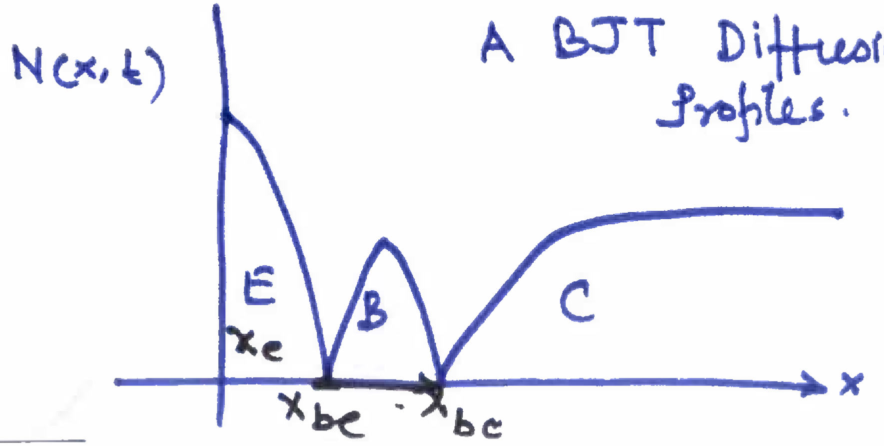
② Base Diffusion

Predeposition → D_1t_1
Drive-In → D_2t_2

③ Emitter Diffusion

Only Predeposition → D_3t_3

∴ Base Diffusion $Dt_{eff} = D_1t_1 + D_2t_2 + D_3t_3$



A BJT Diffusion profiles.

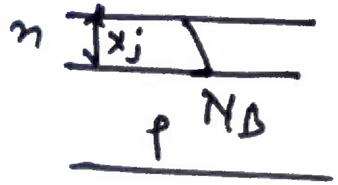
Junction Formation in Two Step Diffusion

We have

$$N(x, t_1, t_2 ..) = \frac{2 N_{01}}{\pi}\sqrt{\frac{D_1 t_1}{(Dt)_{eff}}}\, \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$

At $x = 0$ $\quad N(x, t_1, t_2 \cdot\cdot) = N_S$ Surface Conc.

or $$N_S = \frac{2 N_{01}}{\pi}\sqrt{\frac{D_1 t_1}{(Dt)_{eff}}}$$



or $$N(x, t_1, ..) = N_S \exp\left(-\frac{x^2}{4\, Dt_{eff}}\right)$$

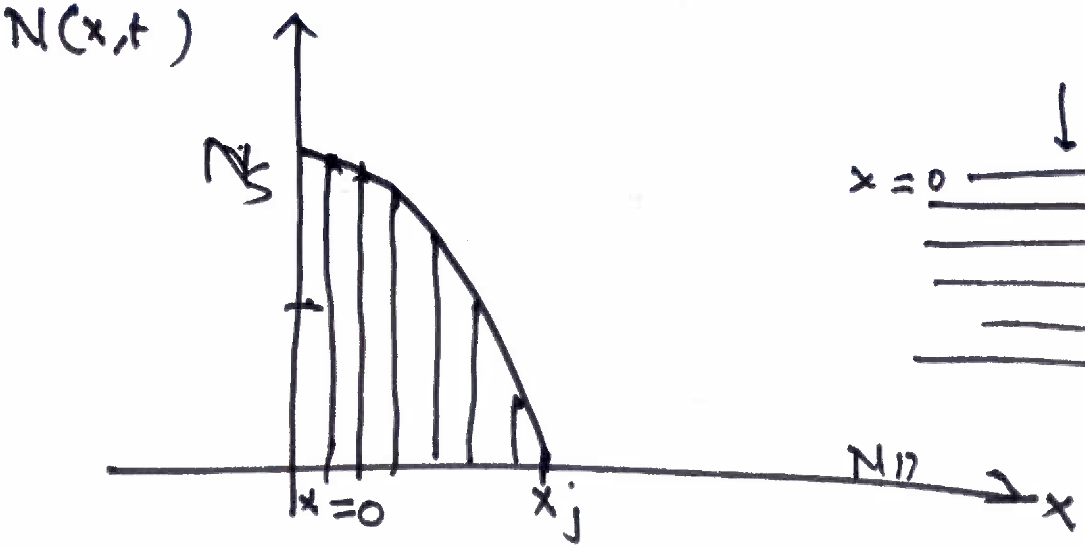
At Junction of B-C (as shown) in Fig

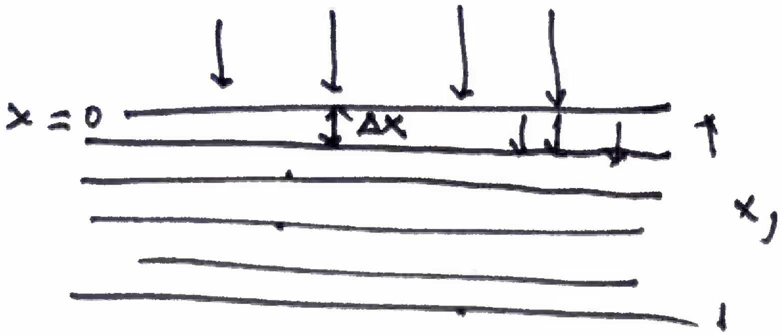
$$N(x_j, t_1, t_2) = N_B$$

$$\therefore \; N_B = N_S \exp\left(-\frac{x_j^2}{4\, Dt_{eff}}\right)$$

or $$x_j^2 = 4(Dt)_{eff} \ln\left(\frac{N_s}{N_B}\right)$$

or $$x_{jBC} = 2\sqrt{(Dt)_{eff}}\,\sqrt{\ln\left(\frac{N_s}{N_B}\right)}$$





Earlier we had defined Sheet Resistance R_s for uniformely doped Semiconductor bar with dimension $L \times W \times t$ as

$$R_s = \frac{\rho}{t} \quad \& \quad \rho = \frac{1}{q\mu_n n} \quad \text{(n-type)}$$

$$N(x,t) = n(x)$$

$$\therefore \quad R = R_s \left(\frac{L}{W}\right)$$

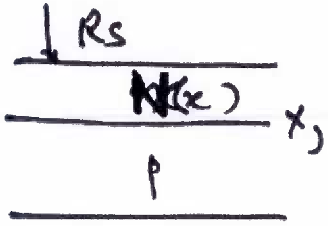
In a graded semiconductor with carrier conc profile of $n(x)$ or $p(x)$, we can get R_s, knowing x_j.

$$R_s = \frac{1}{\int_0^{x_j} \sigma(x)\,dx} \qquad \text{where } \sigma(x) = q\mu\,(N(x) - N_B)$$

$$R_s x_j = \frac{x_j}{\int_0^{x_j} q\mu\,[N(x) - N_B]\,dx}$$

$$\text{or} \quad \frac{1}{R_S x_j} = q\mu(n/p)\,\frac{1}{x_j}\int_0^{x_j} [N(x) - N_B]\,dx$$

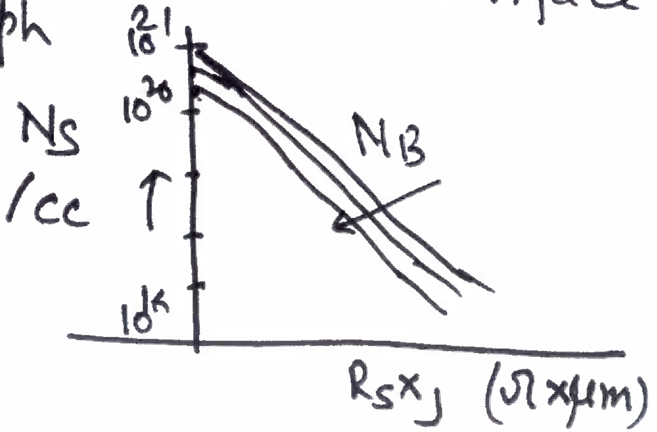
Hence we can plot $(R_S x_j)$ versus $N(x)$



We can monitor R_s at the surface and also can get value of x_j by Angle Lapping technique.

$$\text{Then } (R_{so} x_j)^{-1} = \frac{1}{x_j}\, q\mu \int^{x_j} [N(x=0) - N_B]\,dx$$

But N(x) at $x = 0$ → N_s surface conc. Hence we can have graph



Example

For a case of Const. Source Diffusion

$$N(x) = N_s \,\mathrm{erfc}\left(\frac{x}{2\sqrt{Dt}}\right) \quad \text{where } N_s = N_0$$

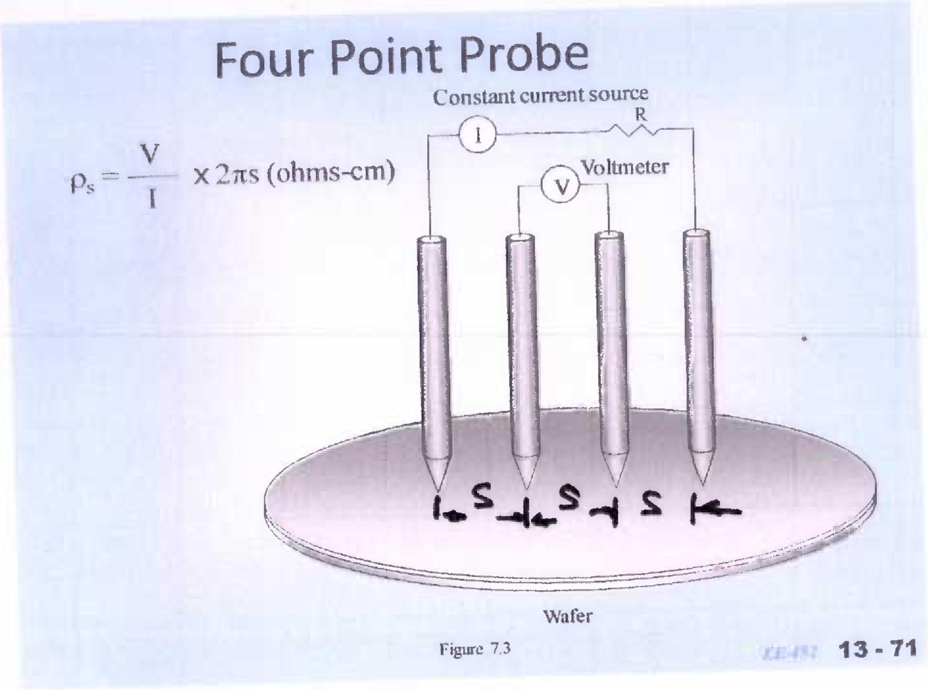
While for a case of Limited Source Diffusion

$$N(x) = 2N_0 \sqrt{\frac{D_1 t_1}{D_2 t_2}} \exp\left(-\frac{x^2}{4 D_2 t_2}\right)$$

Where $N_s = 2N_0 \sqrt{\frac{D_1 t_1}{D_2 t_2}}$

Hence by knowing R_s and x_j at the surface after Diffusion, we can get N_s for given substrate conc.

Measurement of R_s



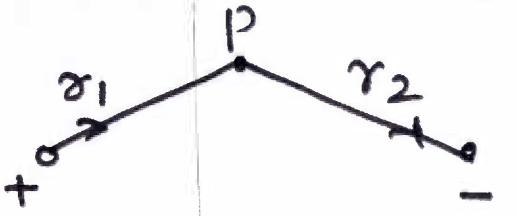
Four Point Probe

$\rho_s = \frac{V}{I} \times 2\pi s$ (ohms-cm)

Figure 7.3

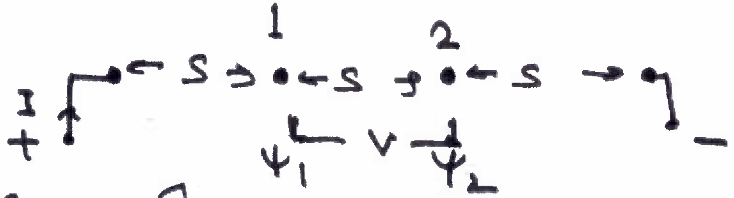
Analysis:

We take a case of 3 Points separated by distance r_1 & r_2



$$\therefore \psi_p = \frac{IR_s}{2\pi} \ln \frac{r_2}{r_1} + A$$

In Four Point probe case, Probes are separated by distance s.



$$\therefore \psi_1 = \frac{IR_s}{2\pi} \ln \frac{s}{2s} + A$$

$$\psi_2 = \frac{IR_s}{2\pi} \ln \frac{2s}{s} + A$$

$$\therefore V = \psi_1 - \psi_2 = \frac{IR_s}{\pi} \ln 2$$

$$\therefore R_s = \frac{\pi}{\ln 2} \cdot \frac{V}{I}$$