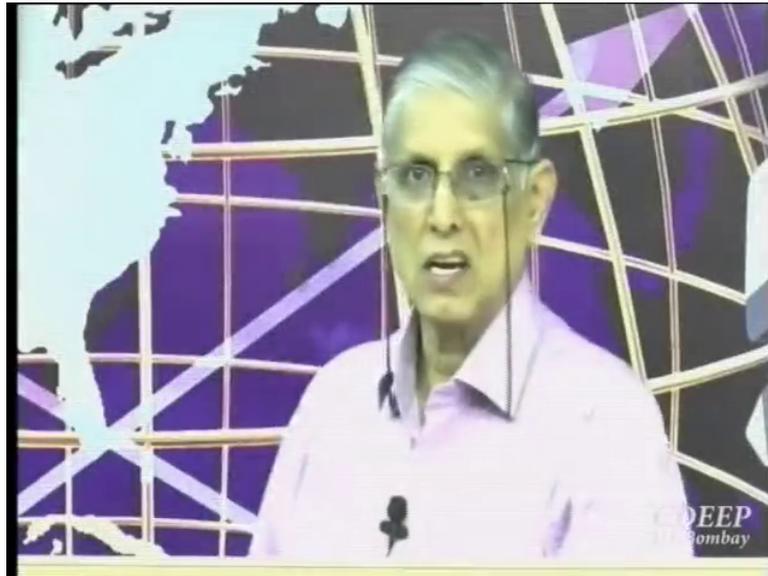


**Fabrication of Silicon VLSI Circuits Using the MOS Technology**  
**Professor. A. N. Chandorkar**  
**Department of Electrical Engineering**  
**Indian Institute of Technology Bombay**  
**Lecture No 09**  
**Solid State Diffusion**

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Ok here we start. Last time

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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  $t_1$

$\therefore D_1 = D_1(T_1)$ ,  $N_{o1} = N_o(T_1)$

$\therefore N(x, t_1) = N_{o1} \operatorname{erfc}\left(\frac{x}{2\sqrt{D_1 t_1}}\right)$

And after time  $t_1$ , the dose of Impurities  $Q(t_1)$  at Surface

$$= 2 N_{o1} \sqrt{\frac{D_1 t_1}{\pi}}$$

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we were looking for diffusion of any impurity in other kind of wafers and we suggested that in practice, the diffusion of impurities is a two step process. And this is particularly true for solid state diffusion. Even in implant, actually there is a step by step implant which we say; implant itself is a pre-diffusion step. And there is a drive-in there as well.

So basically you somehow put impurities first and then push them inside, Ok. That is the method of any impurity incorporation.

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So we did look into the feature that in pre-deposition we perform

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

(i) Predeposition (ii) Drive-In

(i) Predeposition:

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

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And after time  $t_1$ , the dose of Impurities  $Q(t_1)$   
at Surface =  $2 N_{o1} \sqrt{\frac{D_1 t_1}{\pi}}$

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normally in the case of solid state diffusions processes, a constant source diffusion at temperature  $T_1$  for time  $t_1$  and for time  $t_1$ , say  $D_1$  is the diffusion coefficient for temperature  $T_1$  for an impurity which is going to be incorporated in the bulk of another surf/surface, of another type,  $N_{o1}$  is the solid solubility or the active solid solubility at temperature  $T_1$ , and then we say  $N(x, t_1)$  is equal to  $N_{o1}$  error function, complement error function  $x$  upon  $2 \text{ root } d D_1 t_1$  and after a time  $t_1$  the net amount calculated is per unit area which 0:01:43.4 question was  $2 N_{o1} \text{ under root of } D_1 t_1 \text{ by } \pi$ .

This we did, I am just trying to recollect what we did. We had a gap of so many days, so suddenly people also are not aware what we were doing; so maybe, just for the recapitulations.

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(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:

$$N(x, t_1, t_2) = \frac{Q}{\sqrt{\pi D_2 t_2}} \exp\left(-\frac{x^2}{4 D_2 t_2}\right)$$
$$\approx N(x, t_1, t_2) = \frac{2 N_0 s_1 \sqrt{D_1 t_1}}{\pi \sqrt{D_2 t_2}} \exp\left(-\frac{x^2}{4 D_2 t_2}\right)$$

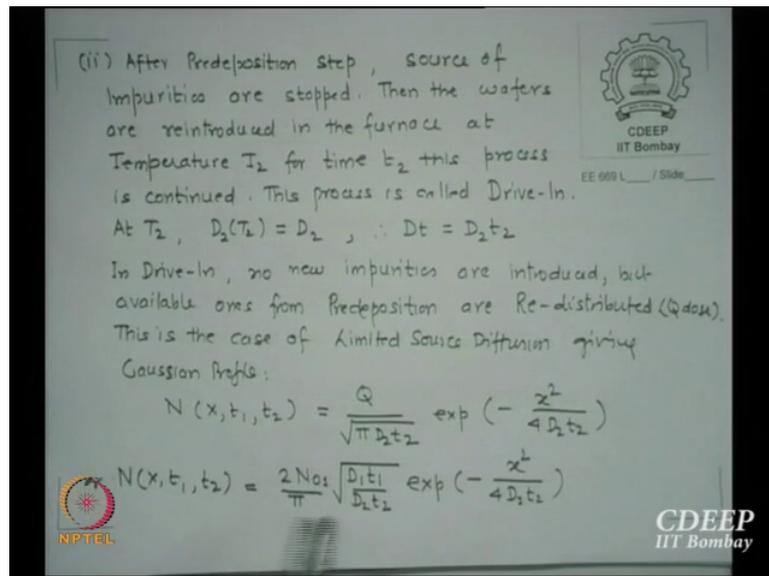
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We also said that after predeposition step, the source is stopped. Then, the source is stopped and then the wafers are reintroduced in the furnace at temperature  $T_2$  for time  $t_2$  and this process is called drive-in.

Impurities are driven inside the silicon wafer. At time  $t_2$ , at temperature  $T_2$  the diffusion coefficient of impurities in bulk is  $D_2$  and  $D t$  product is now  $D_2 t_2$  and since the impurities are already fixed by us during predepositions, they only get redistributed during the drive-in cycle. And the new profile is a Gaussian in nature.

And if you solve that from the diffusion equation, the solution turns out to be  $N(x, t_1, t_2) = \frac{2 N_0 s_1 \sqrt{D_1 t_1}}{\pi \sqrt{D_2 t_2}} \exp\left(-\frac{x^2}{4 D_2 t_2}\right)$

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

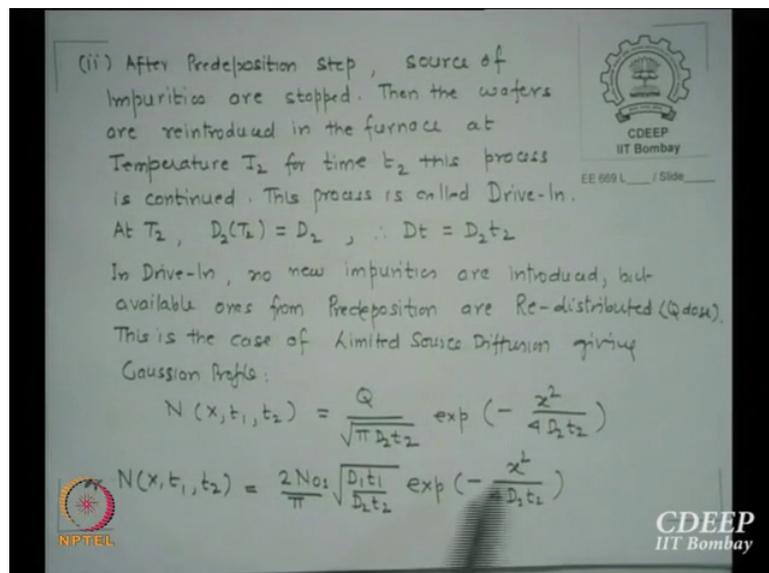
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$$N(x, t_1, t_2) = \frac{Q}{\sqrt{\pi D_2 t_2}} \exp\left(-\frac{x^2}{4 D_2 t_2}\right)$$
$$N(x, t_1, t_2) = \frac{2 N_0 s_1 \sqrt{D_1 t_1}}{\pi \sqrt{D_2 t_2}} \exp\left(-\frac{x^2}{4 D_2 t_2}\right)$$

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of  $D_1 t_1 + D_2 t_2$  and

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

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exponential minus  $x^2$  upon  $4 D$ . This is what we did last time. And we did say, at  $x$  equal to zero,

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(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:

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

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if I make x is equal to zero, this concentration

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

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is essentially

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

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

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

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$2 N_0 s \sqrt{D_1 t_1} / \pi \sqrt{D_2 t_2}$  under root, which is called the surface concentration for the profile. At the maximum concentration occurs at  $x$  is equal to zero

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and that is called  $N_s$ ,  $N_s$  Surface.

To calculate the junction depth we last time did, but we may do again. But,

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(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  $T_2$ ,  $D_2(T_2) = D_2$ ,  $\therefore Dt = D_2 t_2$   
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$$N(x, t_1, t_2) = \frac{Q}{\sqrt{\pi D_2 t_2}} \exp\left(-\frac{x^2}{4 D_2 t_2}\right)$$
  
$$N(x, t_1, t_2) = \frac{2N_0 \sqrt{D_1 t_1}}{\pi \sqrt{D_1 t_2}} \exp\left(-\frac{x^2}{4 D_2 t_2}\right)$$

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so this is the two step diffusion process. However in this or doing this we assume that the sheet charge across junction is valid and we did say that  $D_1 t_1$  is much smaller than

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Video frame showing a speaker. Logos: NPTEL, CDEEP IIT Bombay

$D_2 t_2$  and therefore that thin sheet of charge is possible.

However this assumption is only an assumption and can be taken care. This was the

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Assumption here is  
 $D_1 t_1 \ll D_2 t_2$

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

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

If  $D_1 t_1 \ll D_2 t_2$ , then

$$N(x, t_1, t_2) = \frac{2N_0}{\sqrt{\pi}} \int_0^{\infty} e^{-y^2} \operatorname{erf}(\alpha y) dy$$

By simplification

$$N(x, t_1, t_2) = \frac{2N_0}{\pi} \int_0^{\sqrt{\beta}} \frac{e^{-\alpha^2 - \beta(1+\alpha^2)}}{1+\alpha^2} d\alpha$$

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last time. So now we start today something more. Our assumption in two step diffusion was that  $D_1 t_1$  is much smaller in  $D_2 t_2$ . However, even if this condition is not met, we can still evaluate the profile.

And the method is called using Smith's Integral. Those who are very keen to know, some old books on diffusion theory are available in the literature. You can Google them. But I just give the final answer.

We define two

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Assumption here is  $D_1 t_1 \ll D_2 t_2$

However even if this condition is not met, we can still evaluate  $\rho(x)$ , using Smith's Integral.

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

If  $D_1 t_1 \ll D_2 t_2$ , then

$$N(x, t_1, t_2) = \frac{2N_0 l}{\sqrt{\pi}} \int_0^{\infty} e^{-y^2} \operatorname{erf}(\alpha y) dy$$

By simplification

$$N(x, t_1, t_2) = \frac{2N_0 l}{\sqrt{\pi}} \int_0^{\sqrt{\beta}} e^{-\alpha^2(1+\alpha^2)} \frac{d\alpha}{1+\alpha^2}$$

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terms, alpha is under root  $D_1 t_1$  by  $D_2 t_2$  and beta is

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Assumption here is  $D_1 t_1 \ll D_2 t_2$

However even if this condition is not met, we can still evaluate  $\rho(x)$ , using Smith's Integral.

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

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$$N(x, t_1, t_2) = \frac{2N_0 l}{\sqrt{\pi}} \int_0^{\infty} e^{-y^2} \operatorname{erf}(\alpha y) dy$$

By simplification

$$N(x, t_1, t_2) = \frac{2N_0 l}{\sqrt{\pi}} \int_0^{\sqrt{\beta}} e^{-\alpha^2(1+\alpha^2)} \frac{d\alpha}{1+\alpha^2}$$

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$x^2$  square upon 4 times  $D_1 t_1$  plus  $D_2 t_2$ . Then

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Assumption here is  $D_1 t_1 \ll D_2 t_2$

However even if this condition is not met, we can still evaluate  $\rho(x)$ , using Smith's Integral.

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

If  $D_1 t_1 \ll D_2 t_2$ , then

$$N(x, t_1, t_2) = \frac{2N_0 l}{\sqrt{\pi}} \int_0^{\infty} e^{-y^2} \operatorname{erf}(\alpha y) dy$$

by simplification

$$N(x, t_1, t_2) = \frac{2N_0 l}{\sqrt{\pi}} \int_0^{\sqrt{\beta}} \frac{e^{-\alpha^2(1+x^2)}}{1+\alpha^2} d\alpha$$

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just take a case.  $D_1 t_1$  is very close to  $D_2 t_2$ , that is not much larger but closer to  $D_2 t_2$ .

Then

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Assumption here is  $D_1 t_1 \ll D_2 t_2$

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

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

If  $D_1 t_1 \ll D_2 t_2$ , then

$$N(x, t_1, t_2) = \frac{2N_0}{\sqrt{\pi}} \int_0^{\infty} e^{-y^2} \operatorname{erf}(\alpha y) dy$$

By simplification

$$N(x, t_1, t_2) = \frac{2N_0}{\sqrt{\pi}} \int_0^{\sqrt{\beta}} \frac{e^{-\beta(1+\alpha^2)}}{1+\alpha^2} d\alpha$$

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$N(x, t_1, t_2)$  is

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Assumption here is  $D_1 t_1 \ll D_2 t_2$

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

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

If  $D_1 t_1 \ll D_2 t_2$ , then

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By simplification

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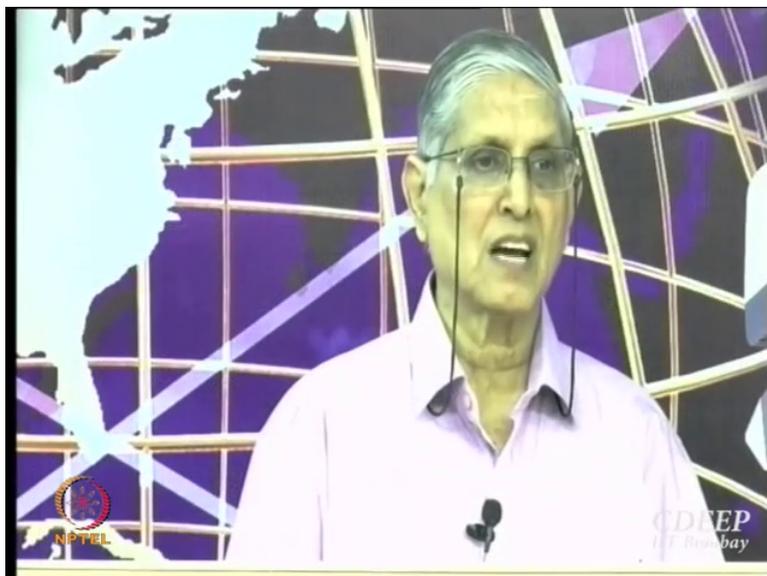
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$\frac{2N_0}{\sqrt{\pi}} \int_0^{\infty} e^{-y^2} \operatorname{erf}(\alpha y) dy$ , this is called Smith's integral.

Simplification, as I said this is the theory of diffusion and this has nothing to do with devices or semiconductors. This you can read from Smith charts or Smith integrals. Otherwise I will suggest you some book on diffusions.

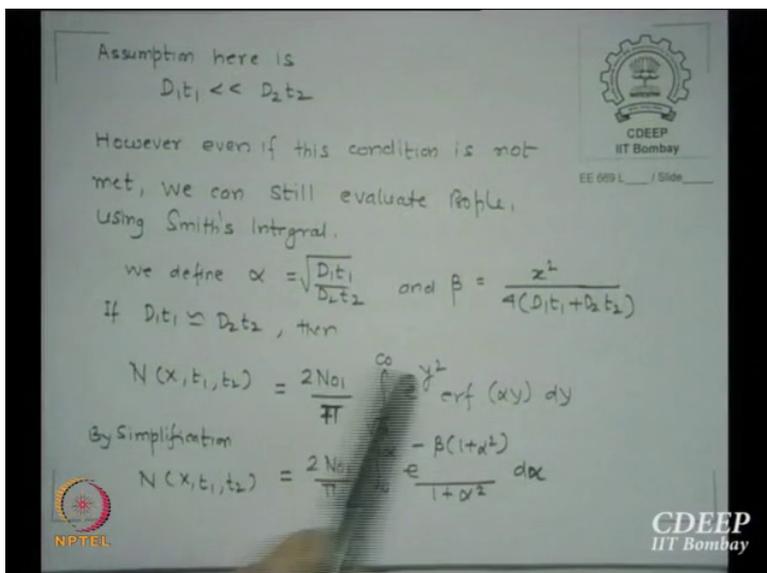
Since I am rarely going to use this, however I may use it. I am not

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I will never use this. And so I will actually have this simplified

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version of this is

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Assumption here is  $D_1 t_1 \ll D_2 t_2$

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

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

If  $D_1 t_1 \ll D_2 t_2$ , then

$$N(x, t_1, t_2) = \frac{2N_0}{\sqrt{\pi}} \int_0^{\infty} e^{-y^2} \operatorname{erf}(\alpha y) dy$$

By simplification

$$N(x, t_1, t_2) = \frac{2N_0}{\pi} \int_0^{\sqrt{\beta}} \frac{e^{-\beta(1+\alpha^2)}}{1+\alpha^2} d\alpha$$

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$\frac{2 N_0}{\pi} \int_0^{\sqrt{\beta}} \frac{e^{-\beta(1+\alpha^2)}}{1+\alpha^2} d\alpha$ . This is essentially known as Smith Integral. Ok. So the condition is

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Speaker: A man with glasses wearing a light purple shirt.

Background: A world map with a grid overlay.

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$D_1 t_1$  is very close to  $D_2 t_2$ .

The first case we discussed was when  $D_1 t_1$  was much smaller than  $D_2 t_2$ . So we say predeposition step is for shorter temperature, shorter time for a smaller temperature. Drive-ins are for larger temperatures and larger times.

Now this method as I say will lead to a solution which, once you write down I will just show you. So I have a integral which,

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Assumption here is  $D_1 t_1 \ll D_2 t_2$

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

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

If  $D_1 t_1 \leq D_2 t_2$ , then

$$N(x, t_1, t_2) = \frac{2N_{01}}{\sqrt{\pi}} \int_0^{\infty} e^{-y^2} \operatorname{erf}(\alpha y) dy$$

By simplification

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

if you have noted down, I will show what is the way Smith Integral is

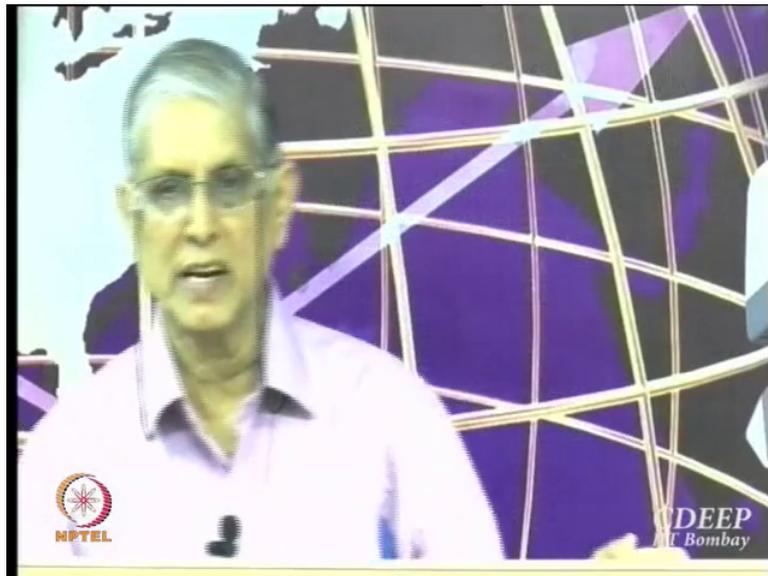
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given. Since I have used alpha, the table is from Smith himself, this has a alpha, instead they have a variable called u, the only difference between mine and theirs. Ok.

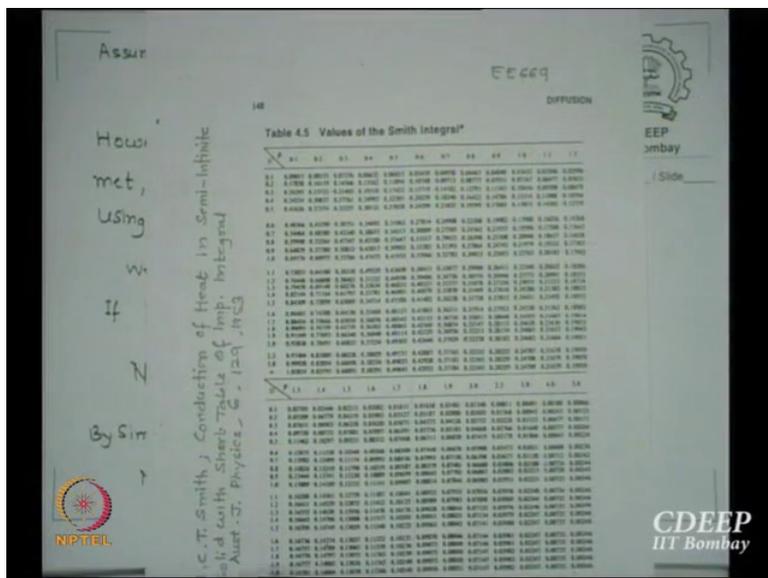


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obtained from knowing alpha and beta. Please remember alpha is u in this table because Smith uses the term u. We have been using alpha. So that is the major difference between their terms and my term.

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The reference is already given. This is from a heat equation semi infinite solid, short table of bottom integral. This appeared way back in 1953 in Australian Journal of Physics by Arthur D. Smith whose integral is, name is given to this name.

So this



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Assumption here is  $D_1 t_1 \ll D_2 t_2$

However even if this condition is not met, we can still evaluate  $\rho(x, t)$  using Smith's Integral.

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

If  $D_1 t_1 \ll D_2 t_2$ , then

$$N(x, t_1, t_2) = \frac{2N_0 l}{\sqrt{\pi}} \int_0^{\infty} e^{-y^2} \operatorname{erf}(\alpha y) dy$$

By simplification

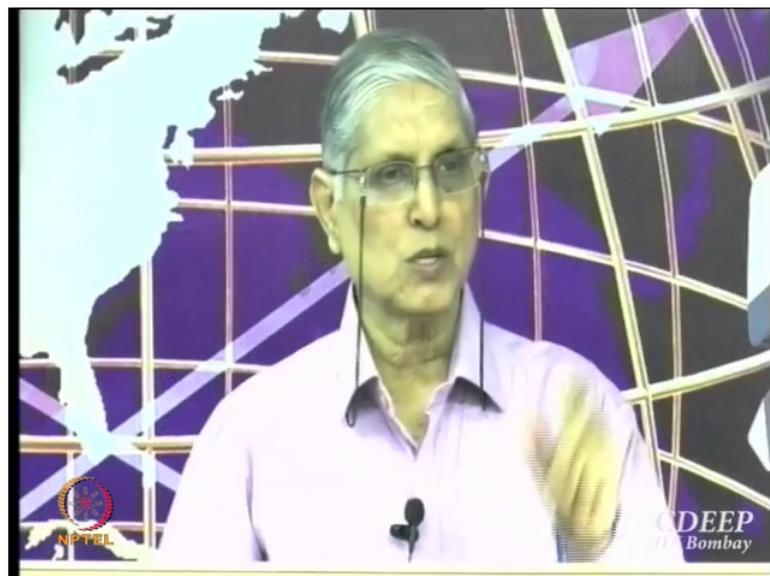
$$N(x, t_1, t_2) = \frac{2N_0 l}{\pi} \int_0^{\sqrt{\beta}} \frac{e^{-\alpha^2 - \beta(1+\alpha^2)}}{1+\alpha^2} d\alpha$$

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know  $D_1$ , I know  $t_1$ , I know  $D_2$ , I know  $t_2$ . Since I know almost this all from two step diffusion process, so I know  $\alpha$   $\beta$  and the value of integral can always be obtained. Is that clear?

So in case  $D_1 t_1$  is

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close to  $D_2 t_2$ , please do not use the earlier expression. And there is an example I will show you. Now surface concentration at  $x$  is equal to zero is  $2 N_0 / \pi \tan^{-1} \alpha$  and if you say  $\alpha$  is small,  $\alpha$

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

$$N_s = \frac{2N_0}{\pi} \tan^{-1} \alpha$$

If  $\alpha$  is small and  $\ll 1 \Rightarrow D_1 t_1 \ll D_2 t_2$

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

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

Same as Standard Two-step function.

Graph showing  $\frac{N(x,t)}{N_0}$  vs  $x / \sqrt{D_1 t_1}$ . Curves are labeled  $\alpha=0$ ,  $\alpha=1$ ,  $\alpha=2$ ,  $\alpha=3$ ,  $\alpha=4$ ,  $\alpha=5$ ,  $\alpha=6$ ,  $\alpha=7$ ,  $\alpha=8$ ,  $\alpha=9$ ,  $\alpha=10$ . The curve for  $\alpha=0$  is labeled "Gaussian".

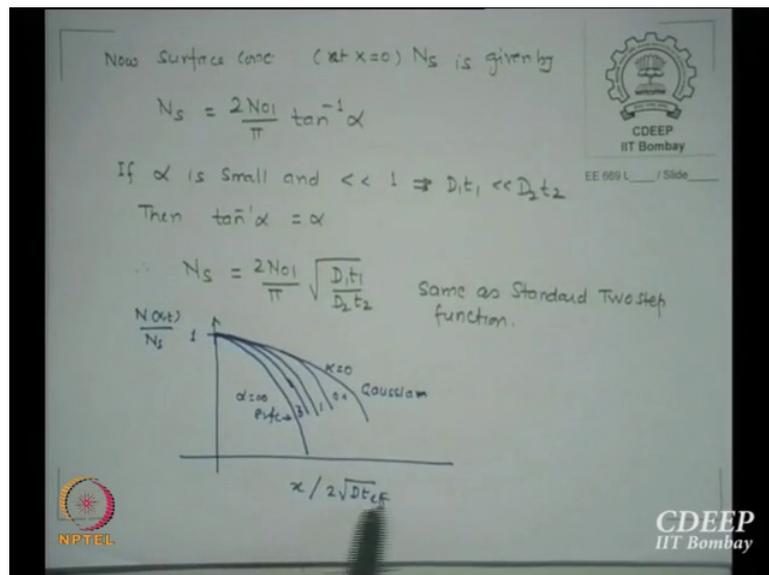
Logos: NPTEL, CDEEP IIT Bombay

is under root  $D_1 t_1$  by  $D_2 t_2$ , so what does that mean?

$D_1 t_1$  is smaller than  $D_2 t_2$  means  $\alpha$  is small, Ok.  $\tan^{-1} \alpha$  is  $\alpha$  when  $\alpha$  is small. So if I substitute them here  $N_s$  is  $2 N_0 / \pi$  under root  $D_1 t_1$  by  $D_2 t_2$  you return back to a case when  $D_1 t_1$  is smaller than  $D_2 t_2$ .

In case it is equal to  $D_2 t_2$  you should use Smith's Integral and then use surface concentration as this value, Ok. I have plotted normalized  $N(x,t)$  function with surface concentration of this for various values of normalized distance

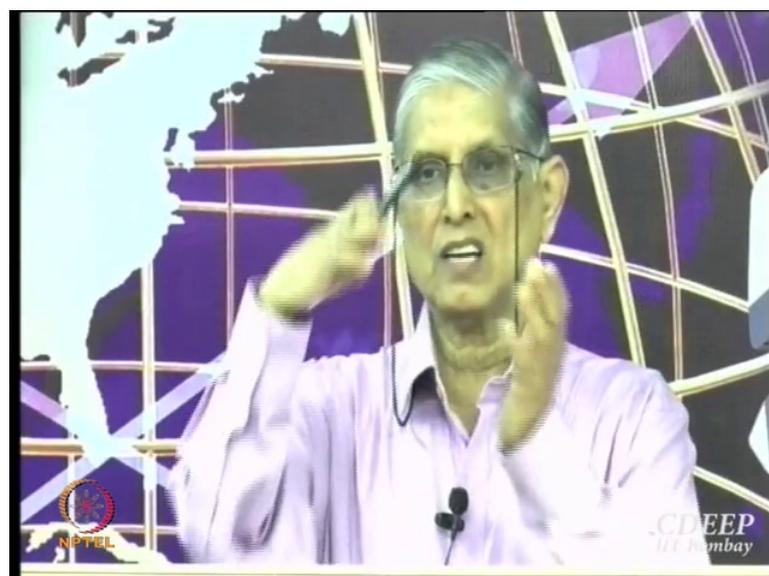
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with  $D t$  effective. And we find  $\alpha$  is zero is Gaussian.  $\alpha$  infinite complementary function and in between is the value.

So this is the graph which essentially, I have plotted roughly but this may not be accurate. We have, that means the upper bound and lower bound is Gaussian profile and complementary profiles. Ok. Why I said this, because in complementary functions we have said  $D_1 t_1$  is smaller, in the other case we say  $D_1 t_1$  can be as much as  $D_2 t_2$ , so upper bounds.  $\alpha$  zero and  $\alpha$  infinite or large values. So complement error to Gaussian

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will actually be N x profile will appear. Ok.

However as I say 99 cases this may not occur.  $D_1 t_1$  will be always used less than  $D_2 t_2$ . But do not take it my word because I may intentionally set a problem in which  $D_1 t_1$  may be comparable (laugh). So do not just go by it and see whether it is equal and then go for Smith's Integral. Ok.

Ok so this is what I say.

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

$$N_s = \frac{2N_0l}{\pi} \tan^{-1} \alpha$$

If  $\alpha$  is small and  $\ll 1 \Rightarrow D_1 t_1 \ll D_2 t_2$

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

$$\therefore N_s = \frac{2N_0l}{\pi} \sqrt{\frac{D_1 t_1}{D_2 t_2}}$$

Same as Standard Twostep function.

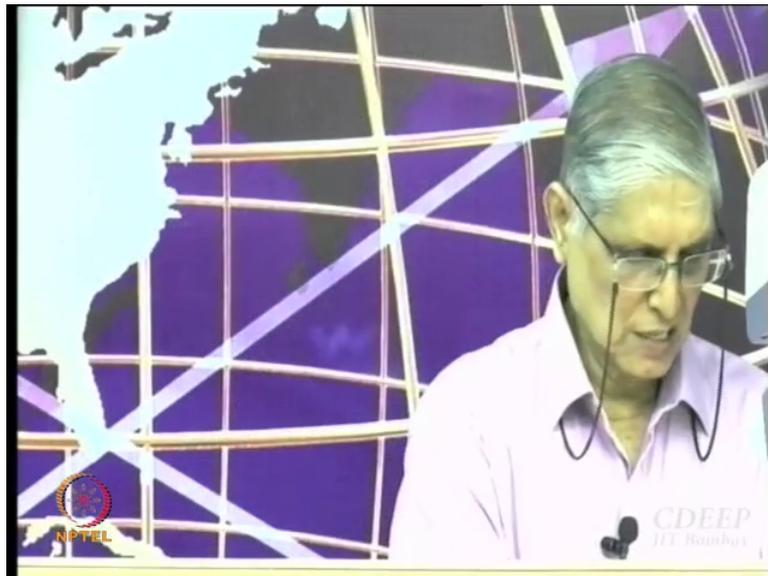
Graph showing  $\frac{N(x,t)}{N_s}$  vs  $\frac{x}{2\sqrt{D_1 t_1}}$  for  $\alpha = 0$  (Gaussian) and  $\alpha = \infty$  (Step function).

Logos: NPTEL, CDEEP IIT Bombay

In case there is a situation in which  $D_1 t_1$  is larger than  $D_2 t_2$  or equal to  $D_2 t_2$ , Smith's solutions can be used. Alternatively if  $D_1 t_1$  is smaller than  $D_2 t_2$ , then normal predeposition will give me a Gaussian profile as we discussed.

There is another problem which comes. Please remember which I did not say so obviously but maybe I go back in my sheets.

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If you have written down this. Ok. I said after the predeposition step, we go for; we remove the wafer from the furnace. We will see what are the kinds of furnace we use. And impurity

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(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:

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

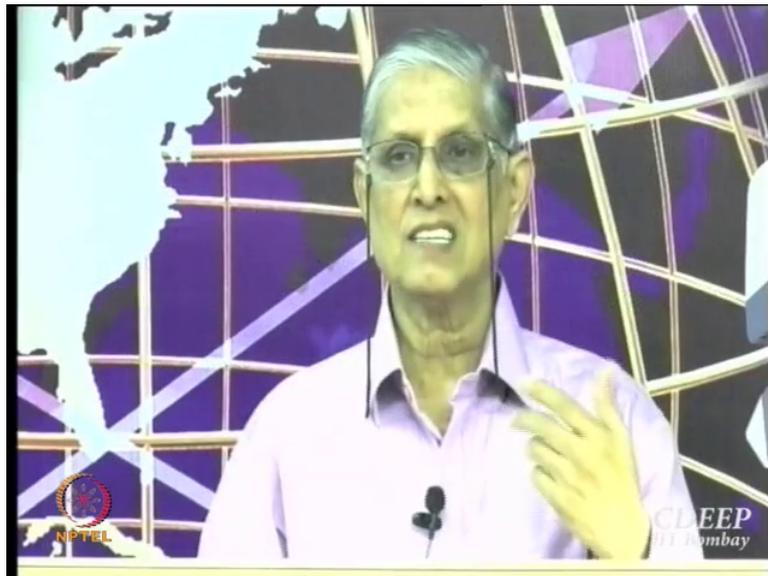
source is stopped and then wafers are removed.

And in fact what we do is, what we say there is a small glass of phosphorus silicate sitting on the wafer, because phosphorus or, not phosphorus silicate, impurity silicate. It may be arsenic silicate, it may be boron silicate or it can be phosphorus silicate, glass is sitting on the, glass means 0.3 of that, Ok.

So phosphorus silicate glass is sitting there, then first we etch that glass, Ok. First we etch the glass. Why? Because if we keep that glass, impurities are within that glass. So that glass is returned it is just constant source diffusion because then impurities will keep coming.

So the first thing we do for drive-in is to remove that upper layer of glass. Glass

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is oxide and therefore we know silicon dioxide etches in H F whereas silicon does not. So we just put it into H F disk and remove the glass. So that any source of impurities then are removed from the surface.

Then there is a constant, because source is removed so it becomes then a fixed charge kind of impurities inside semiconductor at the surface and they then are driven in. But other day I said also impurities can come out. Ok. I mean there is isotropic situation. At high heat temperature both sides impurities will go. Ok, random. So we must stop impurities going out.

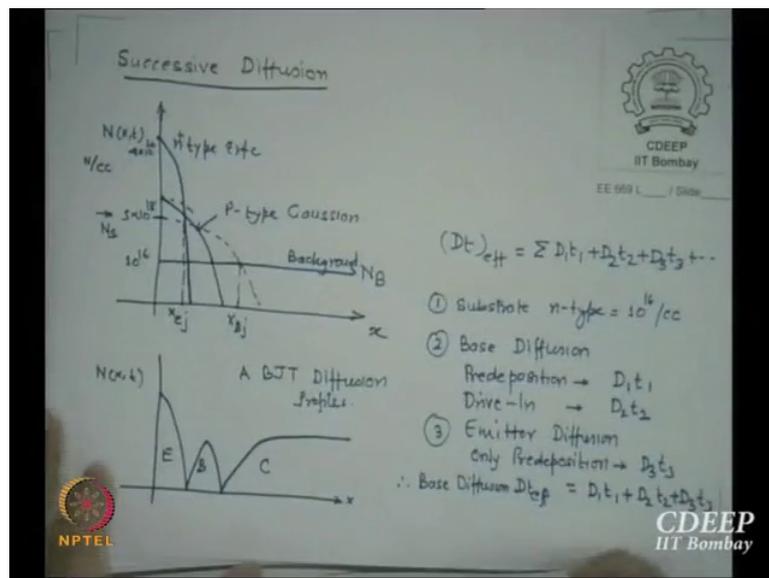
So first thing what we do is we start the drive-in process in oxygen ambient. We push the wafer in furnace at a given temperature  $T_2$  and start oxygen inside furnace. So start oxidizing the silicon surface and silicon dioxide is a mask for impurities to come out. Ok it does not allow. So this step is very important that we create another glass which is not that glass but silicon dioxide layer and then as the time proceeds impurities will go down as the time you want to do for, Ok.

So this step, that first you remove the glass is very crucial, phosphosilicate glass or borosilicate glass because that will remove the impurity source from the surface, Ok which is not very clearly studied by many. You say Ok, you do predip and drive, no then it will be pseudo situation because some impurities will keep coming from the glass itself. Ok during the drive-in cycle.

Then that Smith Integral, why I showed you this, because then that Smith Integral situation may appear because we are also having a source and also driving in, Ok so it may have a situation in which  $D_1 t_1$  can be as close to  $D_2 t_2$  and therefore this is a situation which you should normally avoid, you remove the glass immediately. Ok.

Ok what we do is in a real

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process cycles implant or diffusion may be done, may be fourth, third or fourth step or fifth step, even for the channel also it may be the second step. Since there are too many diffusion, after every diffusion cycle there is a oxidation but there are number of such temperature cycles before the wafer is completed for the I C. It goes through a large number of temperature time cycles.

As many steps you go through in process that many  $D t$  products are actually appearing. Every new step you create, you have a  $D t$  for that process. So the first one which you did, it is not only seeing  $D_1 t_1$

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but also seeing  $D^2 t^2$ ,  $D^3 t^3$ ,  $D^4$ , as many  $D t$  products it sees it keeps on adding additional  $D t$  to the earlier one, this is called  $D t$  effective.

So as many process steps you go through, temperature cycle time cycle, those many  $D t$  products should get added to the first one. For the second one, third, fourth should be added. For the third one, fourth, fifth, whatever number of cycles you have gone through. So every temperature time cycle adds to the first diffusion some kind of  $D^2 t^2$  product gets modified which is called  $D t$  effective, Ok.

So here is a some kind of example shown here. It is a, I am making an n p n transistor. For example we have a diagram, concentration of N for example which is  $10^{16}$  per c c. And then we are going to do a base diffusion

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**Successive Diffusion**

$N(x,t)$  vs  $x$  graph showing n-type and p-type Gaussian profiles. Background  $N_B$  is indicated. Key points  $x_{ej}$  and  $x_{bj}$  are marked.

**A BJT Diffusion Profiles** graph showing Emitter (E), Base (B), and Collector (C) profiles.

**Diffusion Steps:**

- Substrate n-type =  $10^{16}/cc$
- Base Diffusion
  - Predeposition  $\rightarrow D_1 t_1$
  - Drive-In  $\rightarrow D_2 t_2$
- Emitter Diffusion
  - Only Predeposition  $\rightarrow D_3 t_3$

$\therefore$  Base Diffusion  $D_{teq} = D_1 t_1 + D_2 t_2 + D_3 t_3$

$(Dt)_{eff} = \sum D_i t_i + D_2 t_2 + D_3 t_3 + \dots$

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which I did at, which has a predeposition drive-in cycle done at  $D_1 t_1$   $D_2 t_2$ . This

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**Successive Diffusion**

$N(x,t)$  vs  $x$  graph showing n-type and p-type Gaussian profiles. Background  $N_B$  is indicated. Key points  $x_{ej}$  and  $x_{bj}$  are marked.

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$(Dt)_{eff} = \sum D_i t_i + D_2 t_2 + D_3 t_3 + \dots$

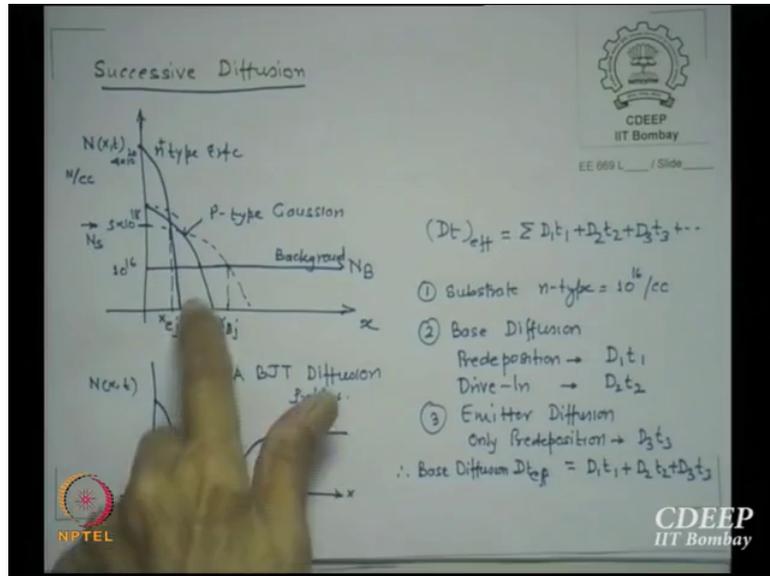
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p type diffusion which is I am performing, sorry, yeah this is the diffusion I did.

However nothing happens to base because base is a constant uniformly doped wafer, so no concentration gradient. So it does not change. However when I want to do emitter diffusions which is this, which may be on the error function profile it sees another  $D t$  product. This

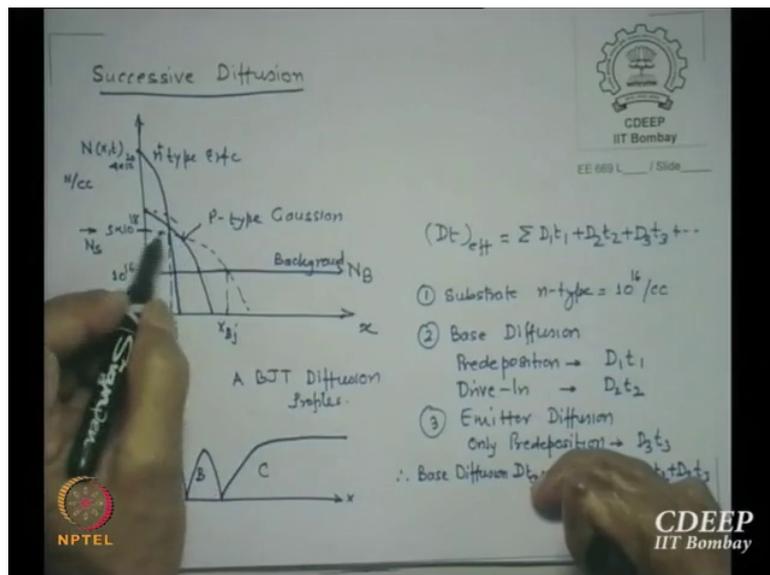
base diffusion has additional  $Dt$  coming from error function timing. Ok. That must get added to this second profile.

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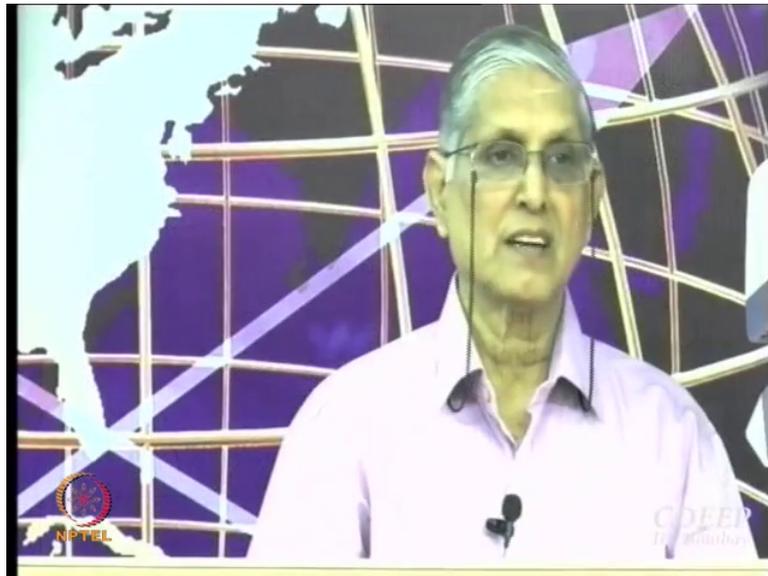
So what will happen? This profile will get modified by this profile. If I have not done it, the junction which was here

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actually is not here but since the profile has changed, it has changed to slightly higher values now. So please remember since the profile actually is going deeper now, the junction depth changes. The base width is different.

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Emitter widths are different and therefore it has to be understood that any time temperature cycle will push the next, earlier cycle further ahead inside that will change the junction depth. Ok. If it changes the junction depth, what will also will change? The surface concentration for that area.

And therefore in your evaluation of device parameters we will have to know what exactly was the base width, what exactly was the junction's doping on the surfaces and that is a very crucial issue in getting a beta of a transistor, particularly in N P N; beta is decided by the base width. Larger is the base width, smaller is the beta. So we are trying to control this. So what does it means?

For given beta, I should exactly know how many thermal cycles I am going to go through and for that value of final I must get my  $I_{0:17:19.8}$  or the base width correspondingly so that I will get a beta of my choice. So this has to be a priori decided how much initial I should do, second time when it pushes it how much it will go and is that base width is sufficient for my beta which I am designing.

So process design also is related to device parameters. And therefore very crucial because you do not take care of second diffusion, third diffusions, your base width will keep changing. And larger the base width, larger, smaller is the beta. And all, whether it is digital or analog, we prefer beta larger. Analog of course is a gain function. Why digital we need larger betas?

(Professor – student conversation starts)

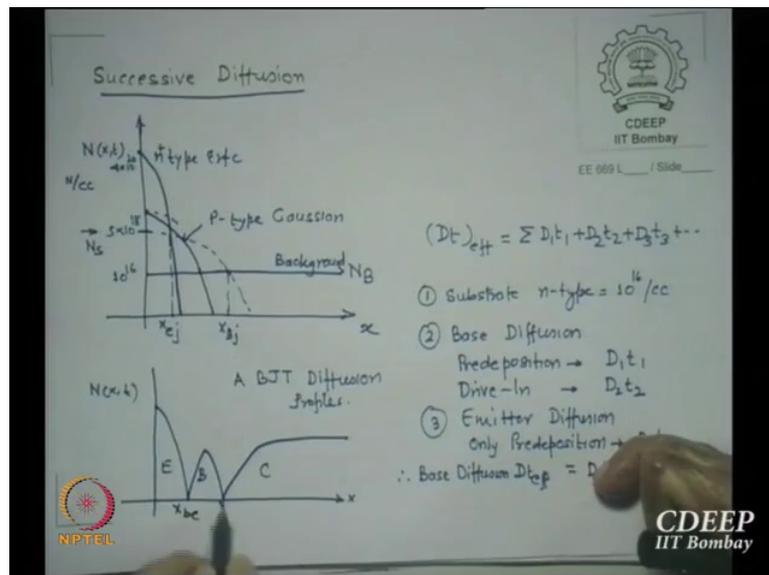
Student: 0:18:04.6

Professor: It is a delay time. Larger current at the same base so it will give a smaller delay. Ok or for speed, so larger beta is the requirement for most cases. Of course in some current processes it may not be but otherwise we will prefer to have larger beta.

(Professor – student conversation ends)

So typically it may look like emitter base collector, this is the junction, this is my x b e,

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and this is my x b c.

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**Successive Diffusion**

$N(x,t)$  vs  $x$  graph showing n-type Etc, P-type Gaussian, and Background  $N_B$ . Y-axis labels:  $10^{16}/cc$ ,  $5 \times 10^{15}$ ,  $10^{16}$ . X-axis labels:  $x_{ej}$ ,  $x_{bj}$ .

**A BJT Diffusion Profiles.** Graph showing Emitter (E), Base (B), and Collector (C) profiles. X-axis labels:  $x_{be}$ ,  $x_{bc}$ .

**Equation:**  $(Dt)_{eff} = \sum D_1 t_1 + D_2 t_2 + D_3 t_3 + \dots$

- Substrate n-type =  $10^{16}/cc$
- Base Diffusion  
Predeposition  $\rightarrow D_1 t_1$   
Drive-In  $\rightarrow D_2 t_2$
- Emitter Diffusion  
Only Predeposition  $\rightarrow D_3 t_3$

$\therefore$  Base Diffusion  $Dt_{top} = D_1 t_1 + D_2 t_2 + D_3 t_3$

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This is my base width,

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**Successive Diffusion**

$N(x,t)$  vs  $x$  graph showing n-type Etc, P-type Gaussian, and Background  $N_B$ . Y-axis labels:  $10^{16}/cc$ ,  $5 \times 10^{15}$ ,  $10^{16}$ . X-axis labels:  $x_{ej}$ ,  $x_{bj}$ .

**A BJT Diffusion Profiles.** Graph showing Emitter (E), Base (B), and Collector (C) profiles. X-axis labels:  $x_{be}$ ,  $x_{bc}$ .

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- Emitter Diffusion  
Only Predeposition  $\rightarrow D_3 t_3$

$\therefore$  Base Diffusion  $Dt_{top} = D_1 t_1 + D_2 t_2 + D_3 t_3$

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and this is of course collector and this is my  $x_e$  in case we need because

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**Successive Diffusion**

$N(x,t)$  vs  $x$  graph showing n-type Etc, P-type Gaussian, and Background  $N_B$ . Parameters include  $N_s$ ,  $10^{16}$ ,  $x_{ej}$ , and  $x_{bj}$ .

**A BJT Diffusion Profiles** graph showing Emitter (E), Base (B), and Collector (C) regions with junctions  $x_{je}$  and  $x_{bc}$ .

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

- Substrate n-type =  $10^{16}/cc$
- Base Diffusion  
Predeposition  $\rightarrow D_1t_1$   
Drive-in  $\rightarrow D_2t_2$
- Emitter Diffusion  
only Predeposition  $\rightarrow D_3t_3$   
 $\therefore$  Base Diffusion  $D_{top} = D_1t_1 + D_2t_2 + D_3t_3$

and this has to be heavily doped because N plus emitters are doped. So you can see, why therefore error functions is to be used.

First the emitter should be shallow. This is necessity for some reason which we will see later, and

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**Successive Diffusion**

$N(x,t)$  vs  $x$  graph showing n-type Etc, P-type Gaussian, and Background  $N_B$ . Parameters include  $N_s$ ,  $10^{16}$ ,  $x_{ej}$ , and  $x_{bj}$ .

**A BJT Diffusion Profiles** graph showing Emitter (E), Base (B), and Collector (C) regions with junctions  $x_{je}$  and  $x_{bc}$ .

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

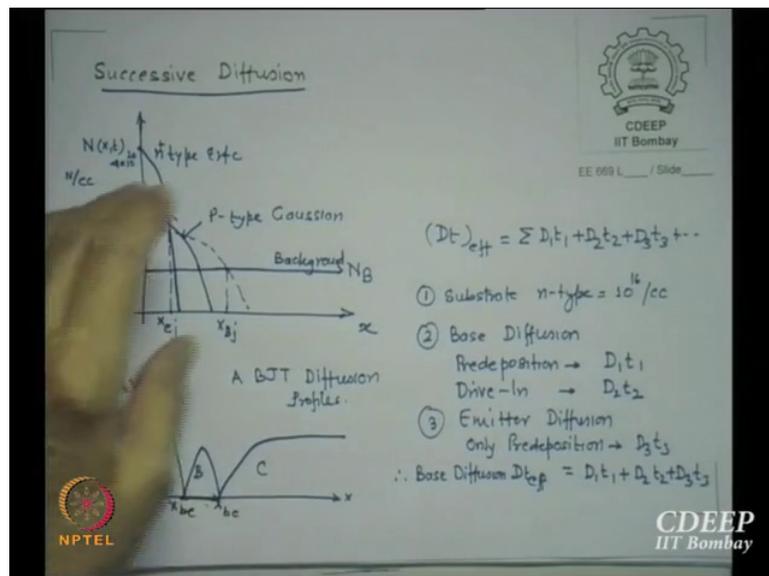
- Substrate n-type =  $10^{16}/cc$
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Predeposition  $\rightarrow D_1t_1$   
Drive-in  $\rightarrow D_2t_2$
- Emitter Diffusion  
only Predeposition  $\rightarrow D_3t_3$   
 $\therefore$  Base Diffusion  $D_{top} = D_1t_1 + D_2t_2 + D_3t_3$

secondly its concentration has to be  $N$  plus, higher because if we put in second drive-in cycle what will happen? It will reduce this  $N$   $S$  further. So I want largest  $N$   $S$  available for the emitter.

So actually I will have a shallow diffusion with high solid solubility. So it is actually performing at a little higher temperatures so that solid solubility is higher here, Ok and for very short durations.

Same thing can be achieved in case of implants and we will see that when we look for implant process. We will see that nothing much is changing. Normally,

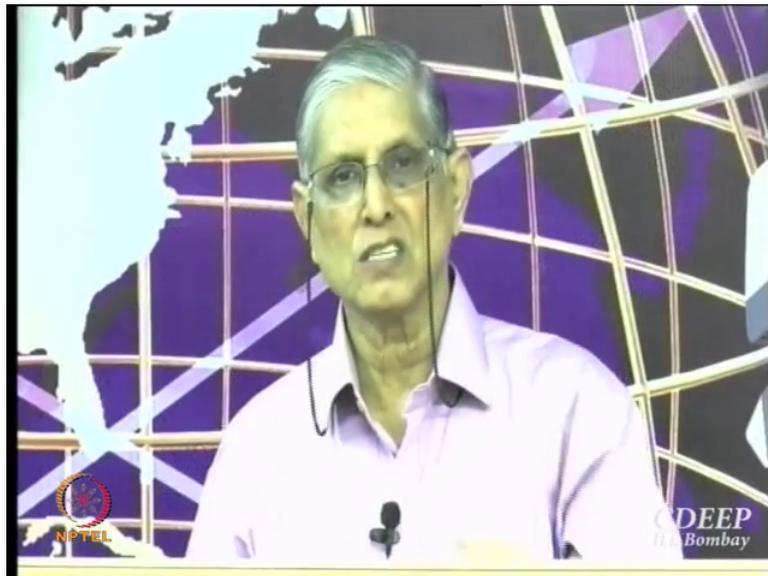
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same profiles, Gaussian profiles would be obtained.

In the case of implant there is no error function profile. It is a naturally Gaussian

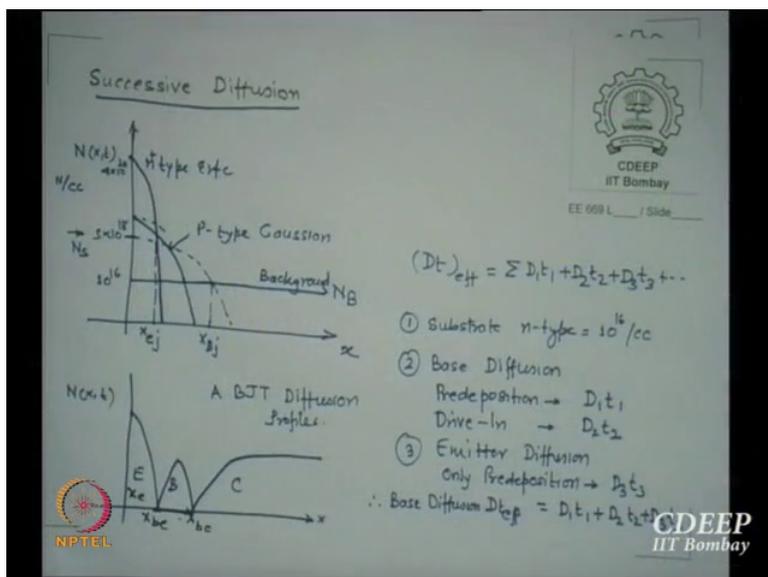
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system. And therefore the only difference will be Gaussian system. But otherwise, profiling will be identical to what it is. There you will see how much there impurity should go or why not there should be here or there, how to control them, all these issues we will look into it, Ok.

So I just gave an example so please remember

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the subsequent time temperature cycle must get added to the drive-in times of these, these because they will keep adding to that earlier value. In the case of, I already showed you, to calculate the junction depth in a two step process; we say this is my

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Junction Formation in Two Step Diffusion  
 We have  

$$N(x, t_1, t_2) = \frac{2 N_{o1}}{\pi} \sqrt{\frac{D_1 t_1}{(D_1 t_1)_{eff}}} \exp\left(-\frac{x^2}{4(D_1 t_1)_{eff}}\right)$$
  
 At  $x=0$ ,  $N(x, t_1, t_2, \dots) = N_s$  Surface Conc.  
 or  $N_s = \frac{2 N_{o1}}{\pi} \sqrt{\frac{D_1 t_1}{(D_1 t_1)_{eff}}}$   

$$= N_s \exp\left(-\frac{x^2}{4(D_1 t_1)_{eff}}\right)$$
  
 A (as shown) in Fig  

$$N_s \exp\left(-\frac{x^2}{4(D_1 t_1)_{eff}}\right)$$

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surface concentration. x is equal to

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Junction Formation in Two Step Diffusion  
 We have  

$$N(x, t_1, t_2) = \frac{2 N_{o1}}{\pi} \sqrt{\frac{D_1 t_1}{(D_1 t_1)_{eff}}} \exp\left(-\frac{x^2}{4(D_1 t_1)_{eff}}\right)$$
  
 At  $x=0$ ,  $N(x, t_1, t_2, \dots) = N_s$  Surface Conc.  
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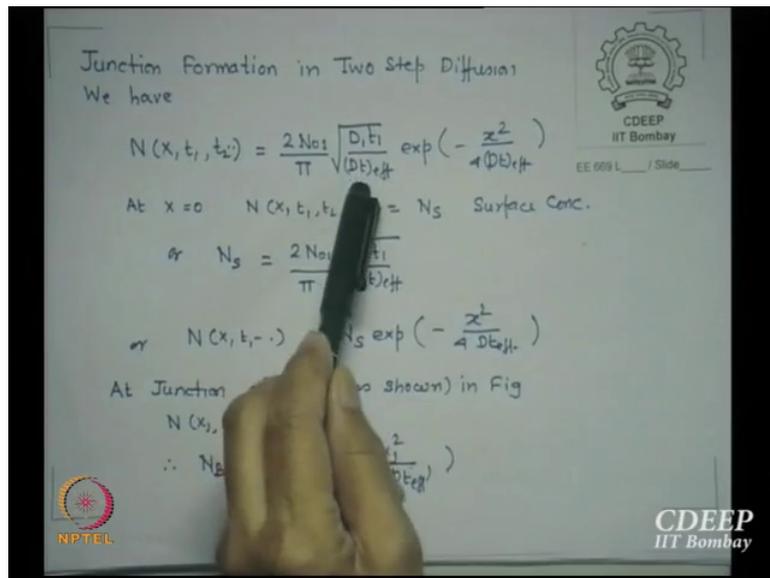
$$N(x, t_1, \dots) = N_s \exp\left(-\frac{x^2}{4(D_1 t_1)_{eff}}\right)$$
  
 in of B-C (as shown) in Fig  

$$N(x, t_2) = N_s \exp\left(-\frac{x^2}{4(D_1 t_2)_{eff}}\right)$$

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zero, this is my surface concentration  $2 N_{o1}$  by  $\pi$  root  $D_1 t_1$  by, now look at it.

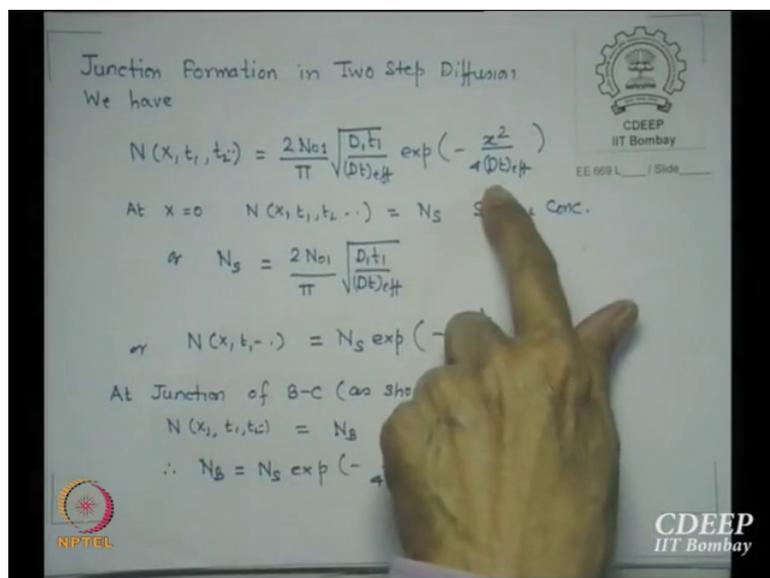
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I made it D t effective.

How many temperature time cycles it has gone through, it is D t effective.

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Same here  $D t_2$  should be replaced by  $4 D t$  effective. Well this is my

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Junction Formation in Two Step Diffusion  
 We have

$$N(x, t_1, t_2) = \frac{2N_0s_1}{\pi} \sqrt{\frac{D_1t_1}{(Dt)_{eff}}} \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$

At  $x=0$   $N(x, t_1, t_2 \dots) = N_s$  Surface Conc.

$$\text{or } N_s = \frac{2N_0s_1}{\pi} \sqrt{\frac{D_1t_1}{(Dt)_{eff}}}$$

$$\text{or } N(x, t_1 \dots) = N_s \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$

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

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

$$\therefore N_B = N_s \exp\left(-\frac{x_s^2}{4(Dt)_{eff}}\right)$$

N S. And what is the junction definition? That at junction the concentration

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Junction Formation in Two Step Diffusion  
 We have

$$N(x, t_1, t_2) = \frac{2N_0s_1}{\pi} \sqrt{\frac{D_1t_1}{(Dt)_{eff}}} \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$

At  $x=0$   $N(x, t_1, t_2 \dots) = N_s$  Surface Conc.

$$\text{or } N_s = \frac{2N_0s_1}{\pi} \sqrt{\frac{D_1t_1}{(Dt)_{eff}}}$$

$$\text{or } N(x, t_1 \dots) = N_s \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$

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

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

$$N_B = N_s \exp\left(-\frac{x_s^2}{4(Dt)_{eff}}\right)$$

of the wafer at  $x$  is equal to zero should be same as, at  $x$  is equal to  $x_j$  must be the same as the bulk concentration or base concentration. So  $N_B$  is  $N_s$ . Exponential

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Junction Formation in Two Step Diffusion  
 We have

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

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

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

$$\text{or } N(x, t_1 \dots) = N_S \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$

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

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

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

minus  $x_j^2 / 4 D t$  effective. Is that clear?

At junction, where is the junction occurring? If this is your diffusion profile, let us say I am making P N, so this is my  $x_j$ . Below is  $N_B$  and there

(Refer Slide Time: 21:19)

Junction Formation in Two Step Diffusion  
 We have

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

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

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

$$\text{or } N(x, t_1 \dots) = N_S \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$

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

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

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

is a profile here. So this concentration at  $x$  is equal to  $x_j$  is equal to the base concentration, there, where the net impurity concentration is zero and junction occurs.

And therefore I substitute  $N \times t$  this is  $N_B$  equal to  $N_S$ , this function.

(Refer Slide Time: 21:32)

Junction Formation in Two Step Diffusion  
 We have  

$$N(x, t_1, t_2) = \frac{2N_{01}}{\pi} \sqrt{\frac{D_1 t_1}{(Dt)_{eff}}} \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$
  
 At  $x=0$   $N(x, t_1, t_2 \dots) = N_S$  Surface Conc.  
 or 
$$N_S = \frac{2N_{01}}{\pi} \sqrt{\frac{D_1 t_1}{(Dt)_{eff}}}$$
  
 or 
$$N(x, t_1, \dots) = N_S \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$
  
 At Junction of B-C (as shown) in Fig  

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

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

$N_B$  is known.  $N_S$  is known. How  $N_S$  is known?

(Refer Slide Time: 21:37)

Junction Formation in Two Step Diffusion  
 We have  

$$N(x, t_1, t_2) = \frac{2N_{01}}{\pi} \sqrt{\frac{D_1 t_1}{(Dt)_{eff}}} \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$
  
 At  $x=0$   $N(x, t_1, t_2 \dots) = N_S$  Surface Conc.  
 or 
$$N_S = \frac{2N_{01}}{\pi} \sqrt{\frac{D_1 t_1}{(Dt)_{eff}}}$$
  
 or 
$$N(x, t_1, \dots) = N_S \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$
  
 At Junction of B-C (as shown) in Fig  

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

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

$D_1 t_1$  is known.  $D t$  effective is known.  $N_{01}$  is known,  $\pi$  is known, therefore  $N_S$  is known.

(Refer Slide Time: 21:44)

Junction Formation in Two Step Diffusion  
 We have  

$$N(x, t_1, t_2) = \frac{2N_{o1}}{\pi} \sqrt{\frac{D_1 t_1}{(Dt)_{eff}}} \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$
  
 At  $x=0$   $N(x, t_1, t_2 \dots) = N_S$  Surface Conc.  
 or  $N_S = \frac{2N_{o1}}{\pi} \sqrt{\frac{D_1 t_1}{(Dt)_{eff}}}$   
 or  $N(x, t_1 \dots) = N_S \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$   
 At Junction of B-C (as shown) in Fig  
 $N(x_j, t_1, t_2) = N_B$   
 $\therefore N_B = N_S \exp\left(-\frac{x_j^2}{4(Dt)_{eff}}\right)$

$D t$  effective is known. So what we can calculate?  $x_j$  at the junction base evaluation can be done.

I repeat, this is the surface concentration.  $N_S$

(Refer Slide Time: 21:56)

Junction Formation in Two Step Diffusion  
 We have  

$$N(x, t_1, t_2) = \frac{2N_{o1}}{\pi} \sqrt{\frac{D_1 t_1}{(Dt)_{eff}}} \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$$
  
 At  $x=0$   $N(x, t_1, t_2 \dots) = N_S$  Surface Conc.  
 or  $N_S = \frac{2N_{o1}}{\pi} \sqrt{\frac{D_1 t_1}{(Dt)_{eff}}}$   
 or  $N(x, t_1 \dots) = N_S \exp\left(-\frac{x^2}{4(Dt)_{eff}}\right)$   
 At Junction of B-C (as shown) in Fig  
 $N(x_j, t_1, t_2) = N_B$   
 $\therefore N_B = N_S \exp\left(-\frac{x_j^2}{4(Dt)_{eff}}\right)$

is  $2 N_{o1}$  by  $\pi$ . What is surface concentration? At  $x$  is equal to zero, whatever is the concentration is the surface, at the surface. So this is surface concentration. I know everything of it.

Predeposition temperature therefore  $D_1$ ,

(Refer Slide Time: 22:12)

Junction Formation in Two Step Diffusion  
 We have  

$$N(x, t_1, t_2) = \frac{2N_{01}}{\pi} \frac{\sqrt{D_1 t_1}}{\sqrt{D_1 t_1 + D_2 t_2}} \exp\left(-\frac{x^2}{4(D_1 t_1 + D_2 t_2)}\right)$$
  
 At  $x=0$   $N(x, t_1, t_2 \dots) = N_s$  Surface Conc.  
 or  $N_s = \frac{2N_{01}}{\pi} \frac{\sqrt{D_1 t_1}}{\sqrt{D_1 t_1 + D_2 t_2}}$   
 or  $N(x, t_1, \dots) = N_s \exp\left(-\frac{x^2}{4(D_1 t_1 + D_2 t_2)}\right)$   
 At Junction of B-C (as shown) in Fig  

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

$$\therefore N_B = N_s \exp\left(-\frac{x_j^2}{4(D_1 t_1 + D_2 t_2)}\right)$$

predeposition time so  $t_1$ , any thermal cycle of drive-in it is  $D_2 t_2 + D_3 t_3 + D_4 t_4$ , whatever cycles it has, might have gone through. So this is my surface concentration.

Then the profile is written as  $N_s \exp(-x^2 / (4(D_1 t_1 + D_2 t_2)))$  at  $x$  equal to  $x_j$ , for example in the case of base collector I have shown there, the concentration at that point is the base concentration where the net impurity concentration becomes zero. When this is equal to zero, this concentration is zero, this minus this is zero. That is what it essentially means junction. If that happens,

(Refer Slide Time: 22:52)

Junction Formation in Two Step Diffusion

We have

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

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

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

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

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

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

$N_B$  is  $N_S$  exponential minus this, and now from there what do you think  $x_j$  will be from here quickly some  $\ln$  term will appear,  $\ln$  term, exponential. Is that noted down? Of course these, these are not specific to any book. Any book gives this. So there is nothing great about this. Or you can yourself solve it. It is not very difficult maths

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

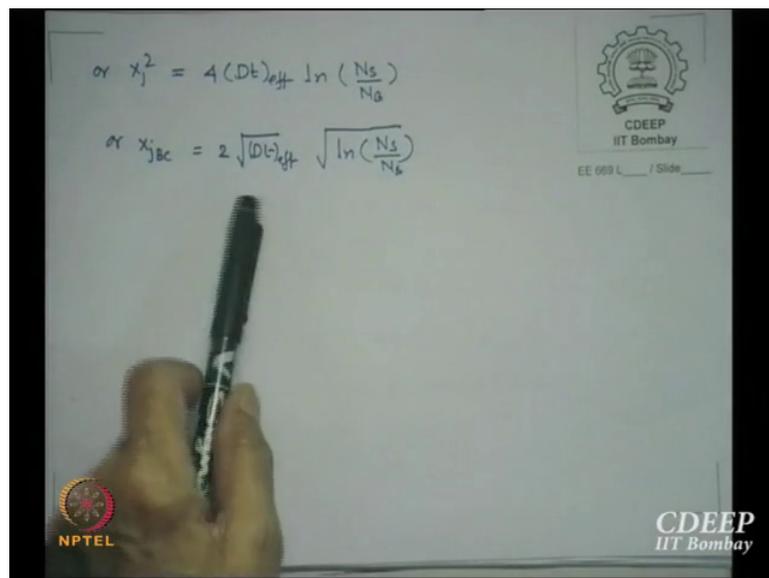
$$\text{or } x_{jbc} = 2\sqrt{(Dt)_{eff}} \sqrt{\ln\left(\frac{N_S}{N_B}\right)}$$

going on.

So  $x_j$  square is  $4 D t$  effective  $\ln N_S$  by  $N_B$ . Please remember  $N_S$  is much larger than  $N_B$ . So this will be a positive number. And  $D t$  effective is also a positive number. So  $x_j$  will be a positive number. It will not be minus kind of things anywhere.

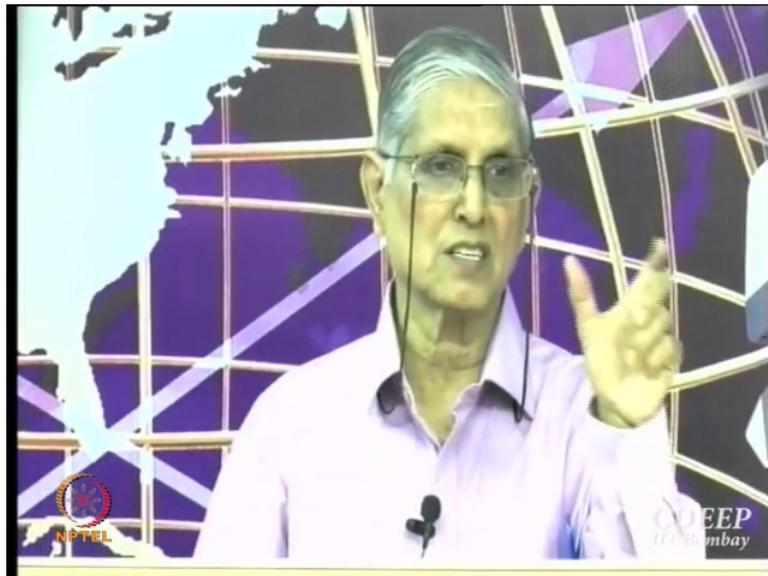
So let us find in the case of base collector junction we said,

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$2 D t$  effective  $\ln N_S$  by  $N_B$  is the junction depth for base collector. At base collector junction,

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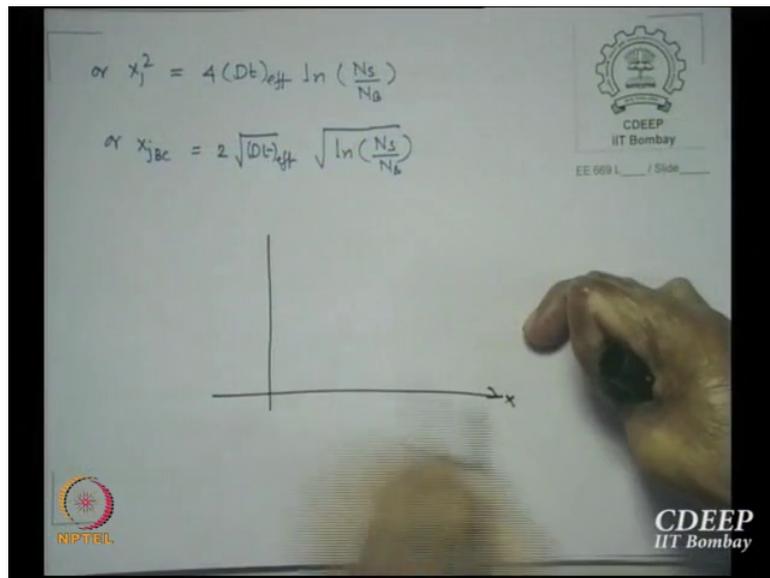


this much base width, actually we have to subtract  $x_e$  from here so I you get the base widths, I.

So I can always evaluate junction depths. Is I clear to you? I can always evaluate the junction depth if I know the temperature time cycle through which the wafer has gone through during in predeposition, drive-in and any other temperature time cycle with no source. If there is a source in between then I will be a Smith's case, I. You will have to recalculate most of it then, I?

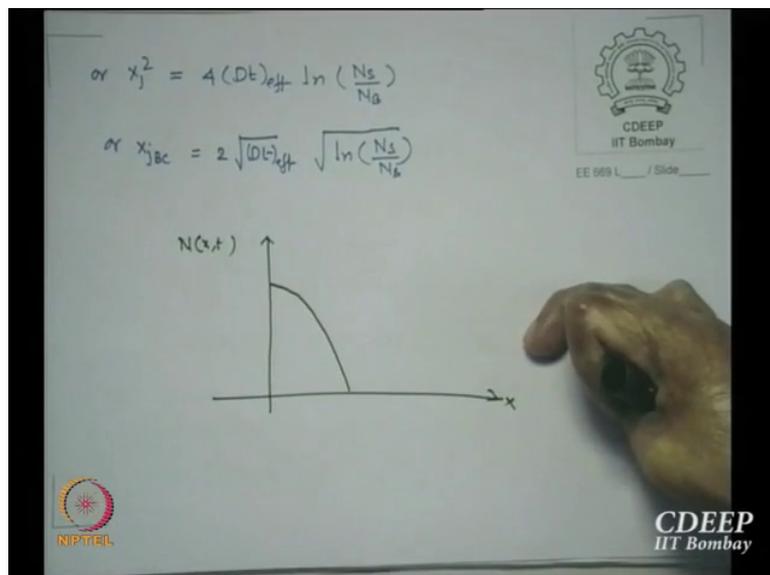
I. Now then I go, I do this, how do I monitor in the lab what has happened? I. Firstly I am interested to know for a given time temperature cycle, the profile itself. But getting a profile is not very easy. I. The way we do, for example, normally I will just show you.

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If my, this is my profile, let it is a Gaussian for some reason, two step or something.

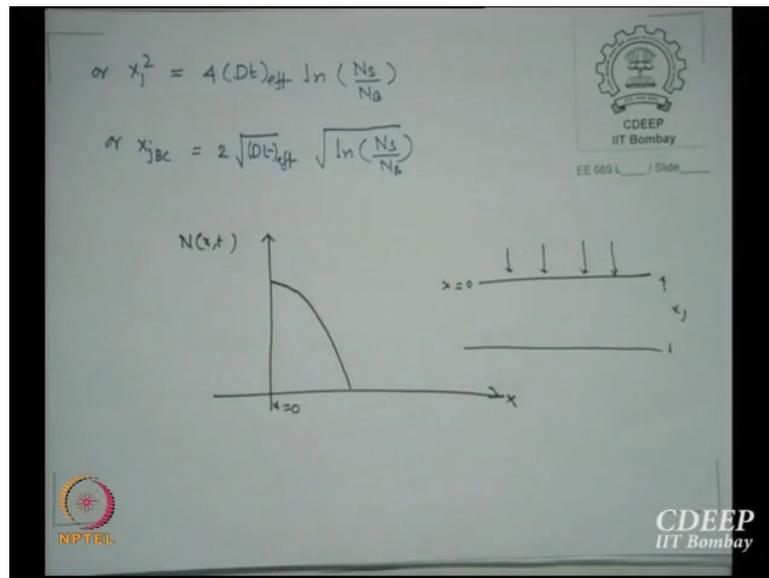
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So what I do is I first, so first let us take this step. This is only junction depth I have shown you. The substrate I am not showing.

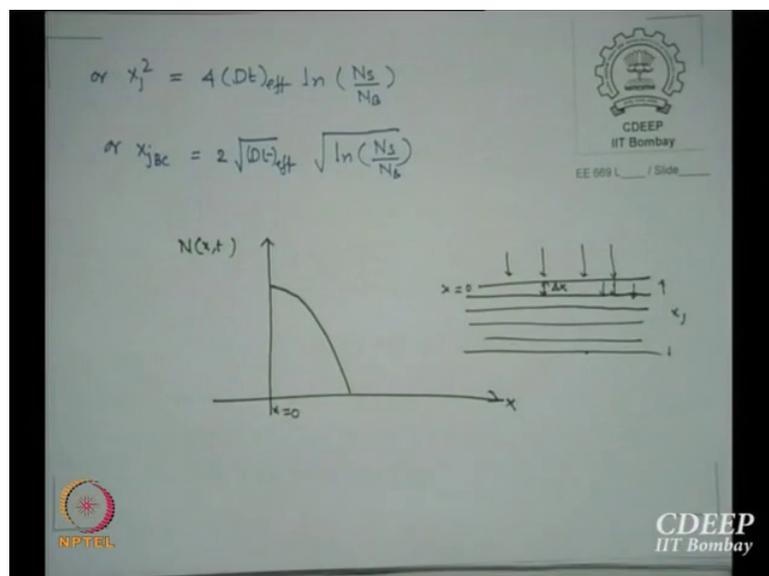
So first I monitor something on this surface at  $x$ , this is my  $x$  is equal to zero, Ok.

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Then so surface concentration is here. Then I etch the surface by some amount which is known to me, delta x. I etch that top layer by amount delta x. Then on this, I do now new measurement, Ok. I keep doing this by step and reach junction,

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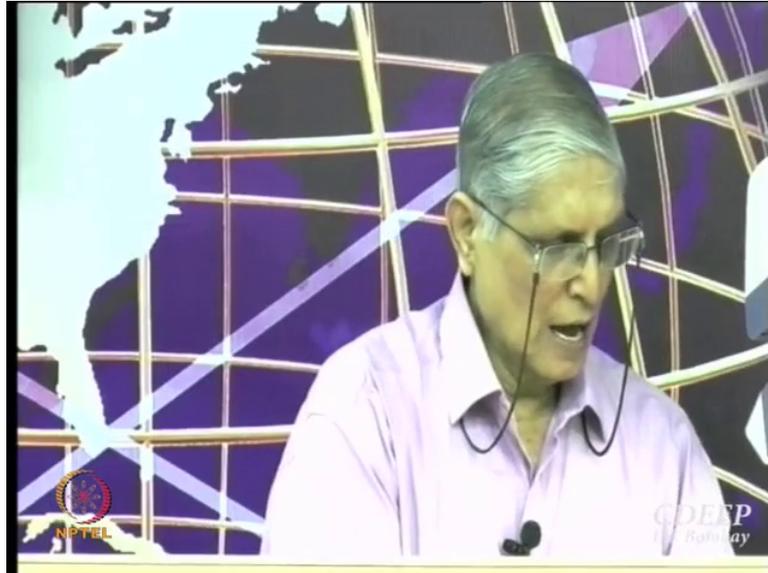


is that clear?

Every time I get a surface, I have top surface, I removed it, new surface. I removed it, new surface and I will keep getting some measurement value at every surface and the

measurement quantity which I monitor is the sheet resistance, Ok. What I am going to monitor at every etched area is the sheet resistance.

(Refer Slide Time: 26:04)



So I, please remember so essentially what I am doing is, discretizing it as if, and I am creating new surfaces and keep monitoring. See if I know my profile at this point, this point, this point, this point, this point, this point then I can plot the profile. Is that clear?

Since I will find out this concentration for this surface measurement,

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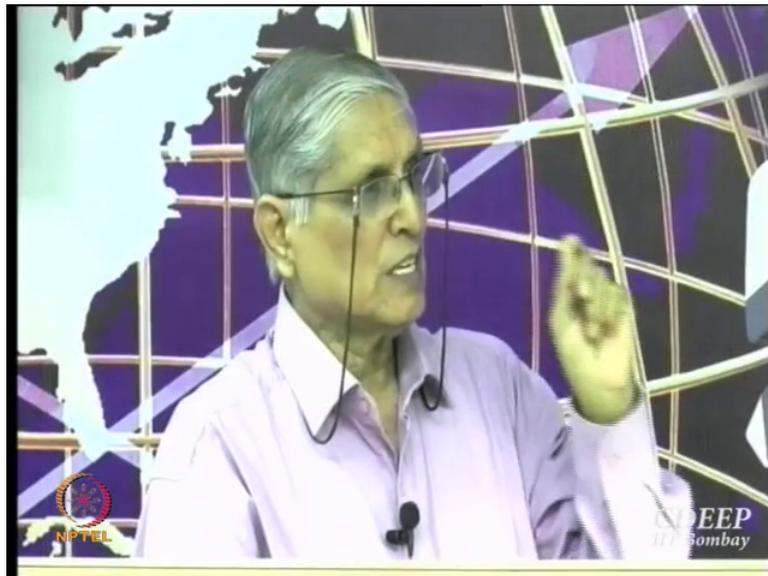
- Equation 1:  $\text{or } x_j^2 = 4(Dt)_{\text{eff}} \ln\left(\frac{N_s}{N_b}\right)$
- Equation 2:  $\text{or } x_{jbc} = 2\sqrt{(Dt)_{\text{eff}}} \sqrt{\ln\left(\frac{N_s}{N_b}\right)}$
- A graph of  $N(x,t)$  versus  $x$  showing a curve that starts at a maximum value at  $x=0$  and decays towards zero as  $x$  increases. The origin is marked  $x=0$ .
- A diagram of a layered material with a surface at  $x=0$ . Arrows indicate etching steps of thickness  $\Delta x$  at various depths  $x_j$ .
- Logos for NPTEL and CDEEP IIT Bombay are visible at the bottom.

profile at that point, so at every time set I will get  $N \times x$ . Ok every etch steps. So I keep plotting  $N \times 1$ ,  $N \times 2$ ,  $N \times 3$ ,  $N \times 4$ ,  $N \times 5$  and once I get, I get the profile. This is called step profile, I mean this is called the etch profiles. We can always get the  $N \times t$  in real life.

There are other techniques of profiling. Etching is done in what we call as secondary ion mass, secondary ion spectroscopy. SIMS as it is called. And the SIMS also basically, maybe on some other day, secondary...all spectroscopy in one day I will tell you what, basically they do same thing in the different, Raman spectra, this spectra is basically same process. Different sources, different outputs, Ok. So is that clear?

To get the profile, you have to start from the surface. And start, the only thing is what is the guarantee you should have? That your

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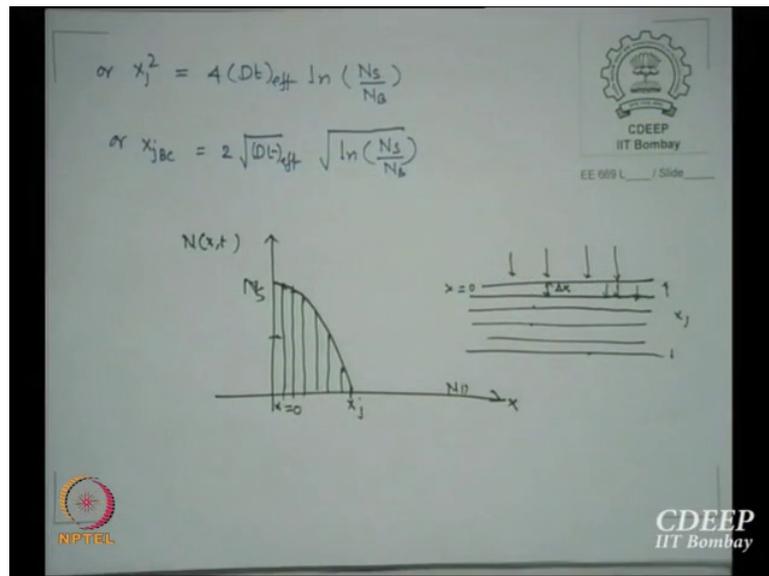


etching should have uniform etch rate. For a given time you will etch, Ok so you should be assured that  $\Delta x$  is same for all the steps that you have gone through, Ok. That time step has to be such that it exactly gives  $\Delta x$  every time.

Otherwise you know, you put this to etch and you do not know how much, then you have problems. So in normal sense this is also an issue in real life, people do not want to use new solution every now and then, so if dip it in the same solution next time, already the p H value of that solution has changed, Ok. So the etch rate of the next for the same time is not same, so there are catches, catch words and how do we do it, some other day when technology starts, Ok. So it that clear how to profile?

So to get a, our ultimate aim is to get a profile, let us say, Ok. And in many cases I do not need even a profile. What I need is, sorry N S and let us say if this is my N B value itself, this junction.

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I am only interested in the surface concentration. That profile whatever I got, that only I see. I am satisfied most derivations I need for my real life situations.

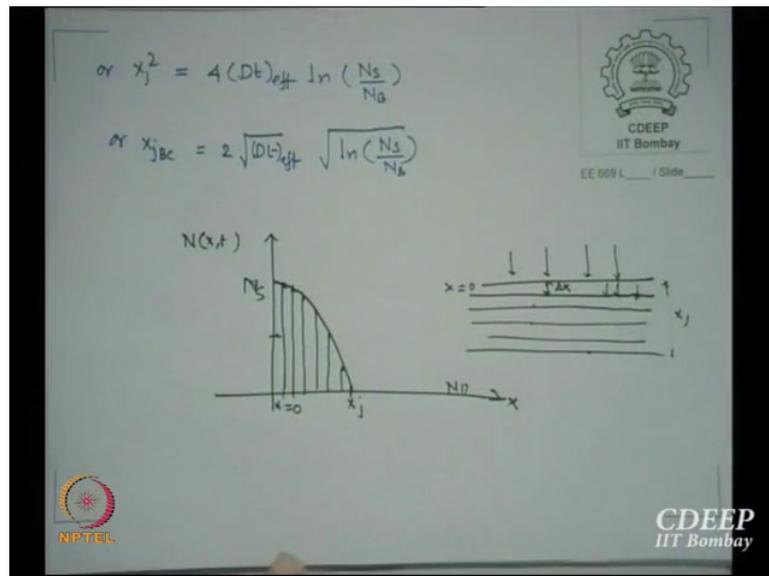
But

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in case you need this profile, there is a technique. Of course there is an optical technique, they are Raman spectra, many techniques in which profiling can be done. This is the easiest one you can do

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by etch method. The only catchword here is ... even there ...etching is done by some kind of sputters which also does not have constant rates.

So whichever technique you do, this guarantee that etch rates are constant, are not very good. So some mischief is always there in the actual profile to the measured profile. Ok. Ok is that point clear how to monitor profiles?

Every surface steps you find R S values. What is this R S, we have already done earlier.

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

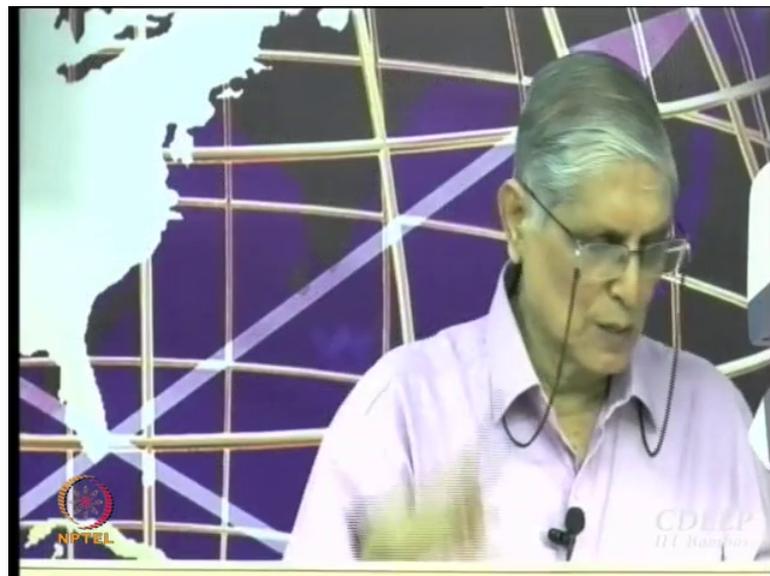
$$R_s = \frac{\rho}{t} \quad \& \quad \rho = \frac{1}{q \mu_n n} \quad (\text{n-type})$$
$$\therefore R = R_s \left( \frac{L}{W} \right)$$

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

$$R_s = \frac{1}{\int_0^{x_j} \sigma(x) dx} \quad \text{where } \sigma(x) = q \mu (N(x) - N_b)$$
$$R_s x_j = \frac{x_j}{\int_0^{x_j} q \mu [N(x) - N_b] dx}$$

But let me repeat again. We have defined sheet resistance for uniformly

(Refer Slide Time: 29:27)



doped semiconductor. We say  $R$  is equal to  $R_s$  times  $L$  by  $W$  where

(Refer Slide Time: 29:34)

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

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$$R = R_s \left( \frac{L}{w} \right)$$

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

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

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

CDEEP IIT Bombay  
NPTEL  
EE 559 L / Slide

$R_s$  is defined by  $\rho$  by  $t$  and  $\rho$  is defined by, for n type impurities, it is  $q \mu n$ .  $n$  is  $N_B$ . This ionized donors; which is  $n$ .

(Refer Slide Time: 29:46)

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

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

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

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

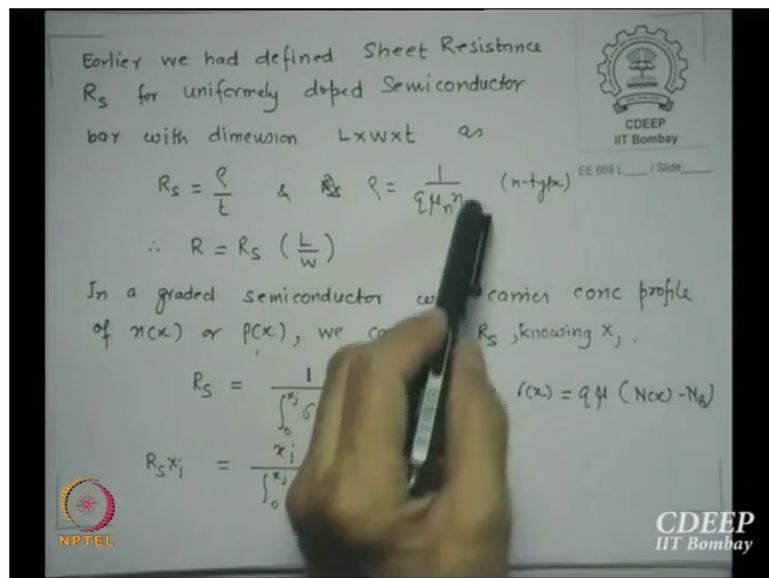
$$R_s = \frac{1}{\int_0^{x_j} \sigma(x) dx} \quad \text{where } \sigma(x) = q \mu [N(x) - N_B]$$

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

CDEEP IIT Bombay  
NPTEL

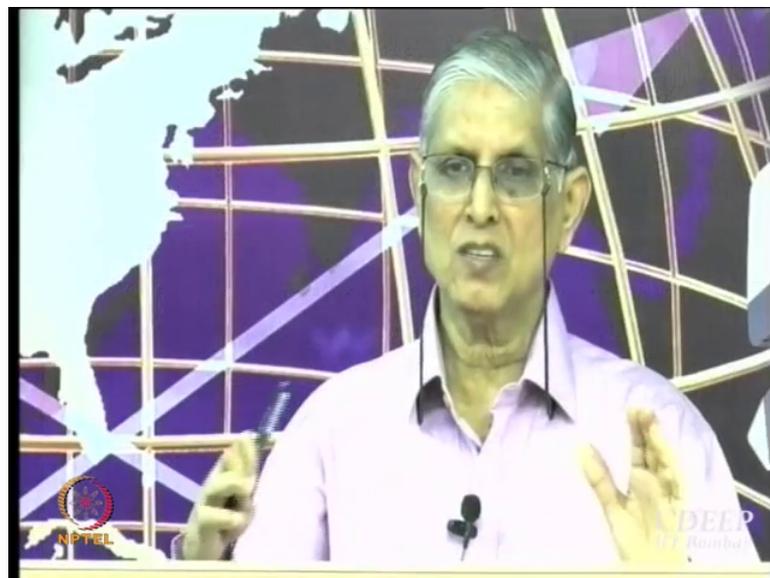
Since if I know my aspect ratio length to width for semiconductor bar, then I know, knowing others, I can find the resistance. But in real life, I am not interested to find even right now resistance. What I am interested is to know only  $R_s$ . So what is the problem with  $\rho$  by  $t$ ?

(Refer Slide Time: 30:09)



Assumption is this  $n$  is constant,  $\mu$  is constant. So  $\rho$  is constant. When this will occur? During crystal growth you may get uniformly doped materials, Ok

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where  $n$  is constant. And therefore  $\mu$  is also constant. So there  $\rho$  is fixed. Whatever doping you have done, that much  $0:30:30$  is used. But when I diffuse, this  $n$  is not constant.  $n$  is a profile of donors or acceptors  $n(x)$ . This  $N(x)t$  whatever you are doing is essentially like this.

(Refer Slide Time: 30:47)

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

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

$$\therefore R = R_s \left( \frac{L}{w} \right) \quad N(x,t) = n(x)$$

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

$$R_s = \frac{1}{\int_0^{x_j} \sigma(x) dx} \quad \text{where } \sigma(x) = q\mu [N(x) - N_A]$$

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

Logos: NPTEL, CDEEP IIT Bombay

The profile of carrier concentration is same as doping concentration. So this profile, since it is

(Refer Slide Time: 30:54)

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

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

Logos: NPTEL, CDEEP IIT Bombay

a profile, it is not a constant value, this is a varying function and if it is a varying function, I must get some average value.

(Refer Slide Time: 31:04)

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

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$$\therefore R = R_s \left( \frac{L}{w} \right) \quad N(x,t) = n(x)$$

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

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

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

Logos: NPTEL, CDEEP IIT Bombay, EE 669 L / Slide

So I say  $R_s$  is then equal to  $1$  upon  $\int_0^{x_j} \sigma(x) dx$ , what does  $\sigma(x) dx$  means?  $\sigma$  is the inverse of  $\rho$  so  $q\mu$  of  $x$

(Refer Slide Time: 31:16)

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$$\therefore R = R_s \left( \frac{L}{w} \right) \quad N(x,t) = n(x)$$

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

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

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

Logos: NPTEL, CDEEP IIT Bombay, EE 669 L / Slide

$dx$ , from zero to  $x_j$ . I multiply it by  $x_j$  both sides so  $x_j$  upon this, just note down.

So this is the  $R_s x_j$  is some kind of this function which I write down again. Why I wrote  $N(x) - N_B$ ? Because up to  $x_j$  that profile has some concentration, minus  $N_B$  is the resistance available for you, Ok.  $\sigma(x)$

(Refer Slide Time: 31:44)

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

$$R_s = \frac{\rho}{t} \quad \& \quad R_s \rho = \frac{1}{q\mu_n n} \quad (n\text{-type})$$
$$\therefore R = R_s \left(\frac{L}{w}\right) \quad N(x,t) = n(x)$$

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

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

The image shows handwritten notes on a whiteboard. It includes the definition of sheet resistance  $R_s$  for a uniformly doped semiconductor bar, the relationship between  $R_s$  and resistivity  $\rho$ , and the formula for  $R_s$  in a graded semiconductor. A hand is pointing at the bottom right of the whiteboard. Logos for CDEEP IIT Bombay and NPTEL are visible.

again is  $q \mu N x$  minus  $N B$  substitute here. Ok.

(Refer Slide Time: 31:50)



I am not sure whether Raman has done the such a detailed this,

(Refer Slide Time: 31:55)

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

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

$$\frac{1}{R_s} \frac{N(x) - N_B}{x_j}$$

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

Then  $(R_s x_j)^{-1} = \frac{1}{x_j} q \mu [N(x=0) - N_B] dx$

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

The graph shows carrier concentration  $N(x)$  on the y-axis (log scale from  $10^{16}$  to  $10^{18}$  /cc) versus distance  $R_s x_j$  (in  $\mu\text{m}$ ) on the x-axis. Two curves are shown:  $N_s$  (higher concentration) and  $N_B$  (background concentration).

Logos: NPTEL, CDEEP IIT Bombay, EE 669 L / Slide

but final answers are here. So if I say 1 upon

(Refer Slide Time: 31:58)

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

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

$$\frac{1}{R_s} \frac{N(x) - N_B}{x_j}$$

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

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at  $x=0 \rightarrow N_s$  surface conc. Hence we can have graph

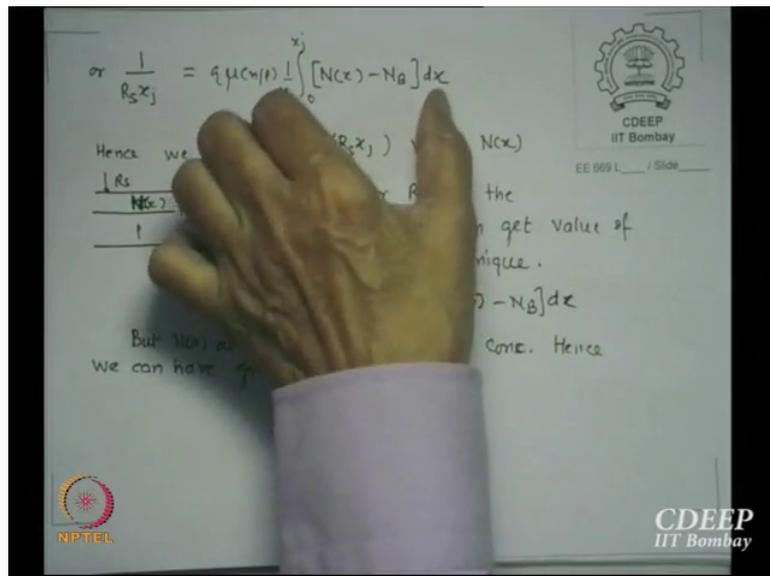
The graph shows carrier concentration  $N(x)$  on the y-axis (log scale from  $10^{16}$  to  $10^{18}$  /cc) versus distance  $R_s x_j$  (in  $\mu\text{m}$ ) on the x-axis. Two curves are shown:  $N_s$  (higher concentration) and  $N_B$  (background concentration).

Logos: NPTEL, CDEEP IIT Bombay, EE 669 L / Slide

$R_s x_j$  is  $q \mu, n$  or  $p$  I wrote because it can be p typed dopant or n type so either of them can  $N(x) - N_B$  can be p type or n type depending on what doping you start and what this.  $N(x) - N_B$  and this is 1 upon  $x_j$ .

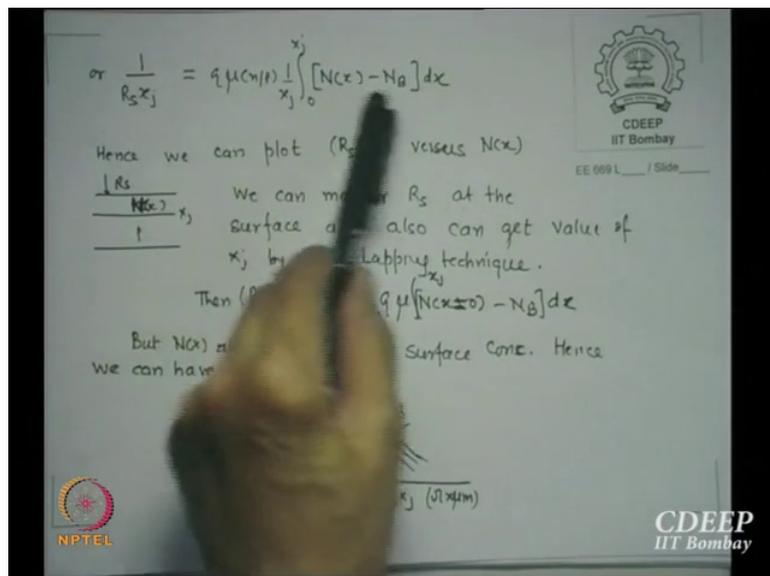
Can you think quickly this is integral of

(Refer Slide Time: 32:17)



something is averaging,  $\frac{1}{x_j} \int_0^{x_j} f(x) dx$  is the average of values. So this is average value. So  $q \mu N$  average is essentially what we are getting is  $\frac{1}{R_s}$ . Is that point clear?  $\frac{1}{x_j} \int_0^{x_j} f(x) dx$  is average value of  $f(x)$ , Ok, very standard method. So this is the average conductivity  $q \mu N$ .  $\frac{1}{R_s}$  is given by  $\frac{1}{R_s x_j}$ . So what we do is essentially,

(Refer Slide Time: 32:47)



there is a  $N_B$  variation in real life. There will be different base concentrations. Substrate may have a different concentration. You may have  $N(x)$  any profile for that matter. Right now we assume  $\mu$  is constant but in real life even that needs to be modified. So what we plot

(Refer Slide Time: 33:06)

$$or \frac{1}{R_s x_j} = q \mu (C_1/D) \int_{x_j}^{x_j} [N(x) - N_B] dx$$

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

$\frac{1/R_s}{N(x) x_j}$  We can monitor  $R_s$  at the surface and also can get value of  $x_j$  by Angle Lapping technique.

Then  $(R_s x_j)^{-1} = \frac{1}{q \mu} \int_{x_j}^{x_j} [N(x) - N_B] dx$

But  $N(x)$  at  $x=0 \rightarrow N_s$  Surface Conc. Hence we can have graph

The graph shows  $N_s$  (Surface Conc) on the y-axis and  $R_s x_j$  (1/m) on the x-axis. Two curves, labeled  $N_B$  and  $N_s$ , are shown. The  $N_s$  curve is a straight line starting from the y-axis at  $N_s$ . The  $N_B$  curve is a curve that starts at the same point on the y-axis but curves downwards.

Logos: NPTEL, CDEEP IIT Bombay, EE 669 / Slide

is surface concentration versus  $R S x_j$  at different  $N B$  values. Is that point clear?

I plot surface concentration

(Refer Slide Time: 33:21)

$$or \frac{1}{R_s x_j} = q \mu (C_1/D) \int_{x_j}^{x_j} [N(x) - N_B] dx$$

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

$\frac{1/R_s}{N(x) x_j}$  We can monitor  $R_s$  at the surface and also can get value of  $x_j$  by Angle Lapping technique.

Then  $(R_s x_j)^{-1} = \frac{1}{q \mu} \int_{x_j}^{x_j} [N(x) - N_B] dx$

But  $N(x)$  at  $x=0 \rightarrow N_s$  Surface Conc. Hence we can have graph

The graph shows  $N_s$  (Surface Conc) on the y-axis and  $R_s x_j$  (1/m) on the x-axis. Two curves, labeled  $N_B$  and  $N_s$ , are shown. The  $N_s$  curve is a straight line starting from the y-axis at  $N_s$ . The  $N_B$  curve is a curve that starts at the same point on the y-axis but curves downwards.

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for two step diffusion we know, so surface concentration versus  $R S x_j$  at different value of this. If I can get, actually I am resubstituting from here, this, Ok. So what we are essentially

saying that if I monitor R S and if I monitor x j, what will I monitor? I will monitor R S for the surface concentration and I will monitor x j by some other technique. So I know this.

(Refer Slide Time: 33:57)

or  $\frac{1}{R_s x_j} = q \mu (C/N) \int_{x_j}^{x_j} [N(x) - N_b] dx$

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

$\frac{1}{R_s} \frac{N(x)}{x_j}$  We can monitor  $R_s$  at the surface and also can get value of  $x_j$  by Angle Lapping technique.

Then  $(R_s x_j)^{-1} = \frac{1}{x_j} q \mu [N(x=0) - N_b] dx$

But  $N(x)$  at  $x=0 \rightarrow N_s$  Surface conc. Hence we can have graph

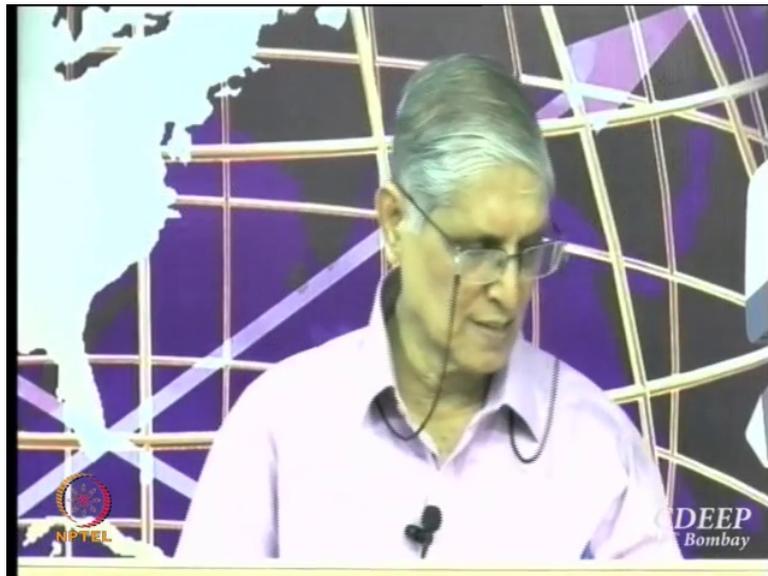
The graph shows  $N(x)$  vs  $x_j$  (in  $\mu m$ ). The y-axis is labeled  $N(x)$  and has a tick mark for  $N_s$ . The x-axis is labeled  $x_j$  (in  $\mu m$ ) and has a tick mark for  $10^4$ . Two curves are shown: one starting at  $N_s$  and another starting at  $N_b$ . The curves are labeled  $N_s$  and  $N_b$  respectively.

Logos: NPTEL, CDEEP IIT Bombay

Is that clear?

I have already started with base concentration or background concentration I decided. So for a given background concentration, for given R S x j, depending on what kind of diffusion you perform, you could have done p type error function, n type error function, complementary and p type Gaussian and or n type, four possibilities, so for all of four, I can do these graphs. These integrals to be put into this graph itself, I will show

(Refer Slide Time: 34:26)



you the graph.

And once I know  $R_s x_j$  value, I know  $N_B$  value; I can calculate the surface concentration of the profile. Is that point clear to you?

I monitor  $R_s$ , I monitor  $x_j$  so I, and normally this is explained Ohm into microns,

(Refer Slide Time: 34:47)

$$R_s x_j = \frac{1}{q \mu_n n_0} \int_0^{x_j} [N(x) - N_0] dx$$

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

$$\frac{1}{R_s x_j} = \frac{q \mu_n n_0}{N(x) - N_0}$$

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

Then  $(R_s x_j)^{-1} = \frac{1}{q \mu_n [N(x=0) - N_0]} dx$

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

$R_s \times j$  product is defined as Ohm into microns, so do not make it centimeters there. This is plots of Ohms into microns against per cent of the surface. So I will monitor  $R_s$  which is Ohm per square, and monitor  $x_j$ , I get a product of  $R_s \times j$ , with these four possible profiles I will show, I can get my surface concentration.

What surface concentration in Gaussian two step diffusion?  $2 N_0 \sqrt{D_1 t_1}$  by pi under root

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$D_1 t_1$  by  $D_2 t_2$  is your  $N_s$ , is that clear? So if I monitor this, and I know  $D_1 t_1$ ,  $D_2 t_2$ ,  $N_0$ , so I can get  $R_s$ ,  $N_s$  from there. Essentially now I am saying if I bring now one of the times, and if I now monitor this, I know that time. Is that point clear? D.

If suppose I do not know  $D_2 t_2$ . Ok. Since I do not know  $t_2$ , but I now found  $N_s$  by this measurement, so  $N_s$  is  $2 N_0 \sqrt{D_1 t_1 D_2 t_2}$  under root of this, so  $D_2$  is known,  $D_1$  is known,  $t_1$  is known but  $t_2$  is not known. But since  $N_s$  was known, I calculate the time for drive-in. Is that correct? So this is, inverse calculations can be performed for a known required value of  $N_s$  I can actually decide in design how much drive-in I should perform. Is that clear to you?

This is the inverse process I am talking. This is straight forward. But in real life I will be asked to find what time I should drive-in so that I get this much  $N_s$  value, Ok for a given  $x_j$ .

I want for a given  $x_j$  that  $N_s$  value. So I must know how much drive-in time I should have, Ok.

So I say Ok, I know  $D_1$ ,  $D_2$ . I know the temperature of drive-in. But I do not know the time for which I should do. So I monitor  $R_s$  on a device. This can be calculated also and plot on  $N_s$ , this and get value of  $N_s$  which will give me  $t_2$  time.

So this is how the design of process starts. Given something, we go back and figure out how much temperature times I should adjust so that I get the value of my choice. Technology is here. Technology is not analyzing data. Technology is something has to be unknown, and said this is what I want. If I want, what do I do?

Ok you could say, if there is a possibility in some case problem may appear in your book, time for predeposition is also not known. Somewhere data must be provided so that I should be able to get  $t_1$  value. Or even in known  $D_1$ , temperature is 0:37:32.0.

So all possible combinations are done by some measurements and then we can figure out what should have been done then, or what should be done so that these values are attainable. I will solve a problem and solve this, Ok.

For example in the case of

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Example  
For a case of Const. Source Diffusion  
$$N(x) = N_s \operatorname{erfc}\left(\frac{x}{2\sqrt{Dt}}\right) \text{ where } N_s = N_0$$
  
While for a case of Limited Source Diffusion  
$$N(x) = 2N_0 \sqrt{\frac{D_1 t_1}{D_2 t_2}} \exp\left(-\frac{x^2}{4D_2 t_2}\right)$$
  
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.

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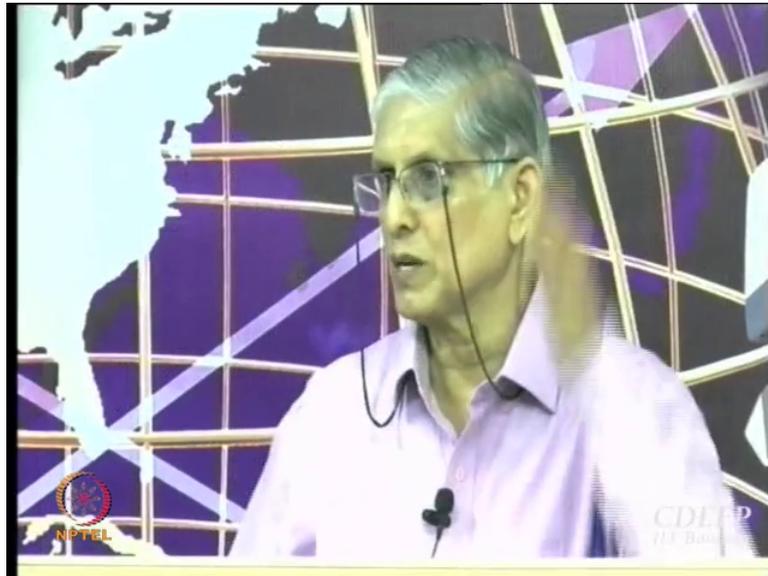
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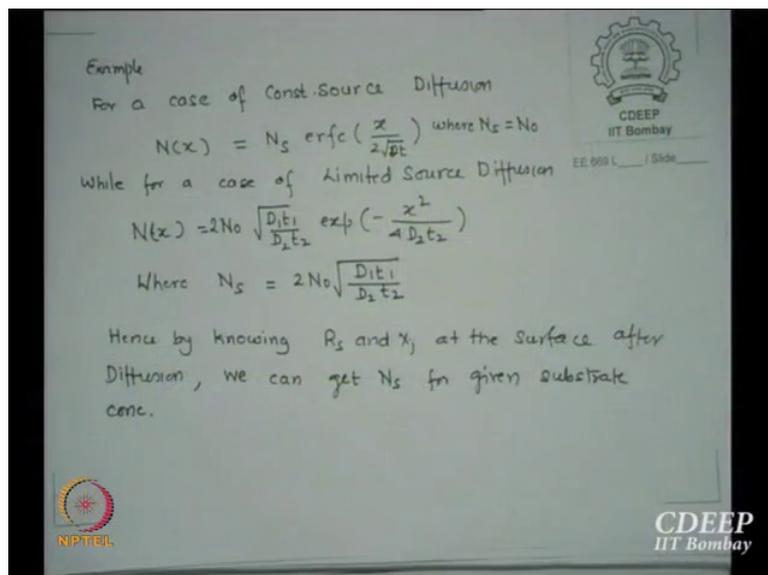
constant source diffusion,  $N_x$  is  $N_s \operatorname{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)$ , please remember in the case of error, complementary error function what is surface concentration? The solid solubility element  $N_s$ ,  $N_0$  which

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you get from the graph which I will show you.

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Ok, I will come back to problem then I will show you. So since I know  $N_0$  from a graph itself or from the tables, I know this value.

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Example  
For a case of Const. Source Diffusion  
 $N(x) = N_s \operatorname{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)$  where  $N_s = N_0$   
While for a case of Limited Source Diffusion  
 $N(x) = 2N_0 \sqrt{\frac{D_1 t_1}{D_2 t_2}} \exp\left(-\frac{x^2}{4D_2 t_2}\right)$   
Where  $N_s = 2N_0 \sqrt{\frac{D_1 t_1}{D_2 t_2}}$   
... by knowing  $R_s$  and  $x_j$  at the surface after  
diffusion ... we can get  $N_s$  for given substrate  
...  
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For a Gaussian it is this, there the surface concentration is this. So either of the data missing could be calculated if I measure  $R_s$   $x_j$  and see it on  $N_s$  versus this graph so one of the missing data could be obtained. Is that clear?

Or to say you actually did a

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diffusion, you monitored  $D_1 t_1$ , the whole thing and monitor  $R_s$   $x_j$ , from that you found  $N_s$ . If that value of  $N_s$  and this value does not match that means there is additional mischief

you have done somewhere, time temperature cycle exceeded, or reduced depends on which is lower, higher values. So there is some calculations which you earlier did has a mistake which resulted in something different from what you actually monitored, Ok.

So there is an, you can also verify your results from, so what this computer simulation C A D tool does for this process simulation? Given a data I will process data. I can find the process cycles. Or for a given process cycle, they can give me what values I will monitor, Ok. And they define monitor in real device and if I get them, that means my steps are correct. Is that clear?

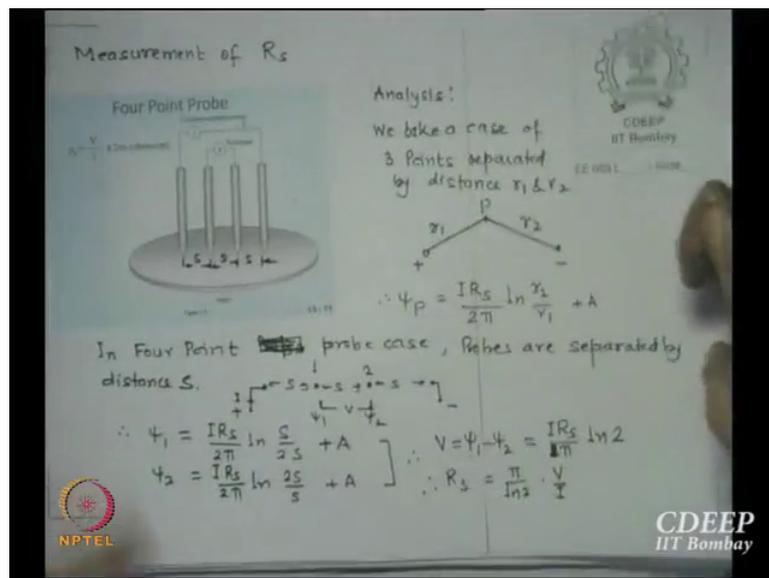
Both ways. I did a process on computer, Ok. This is called, and there are varieties, one is Sentaurus; there is old program called SUPREM, then there is DIOS. So there are many process simulators. What process simulators need? All the maths available to you which you are doing by hand, that should be told to computer.

Here we take some assumptions. There you need not because any numerical solution for them, for a system is not very difficult. You need to know which process. Someone has already written those programs, Ok. So you just have to tell, Ok, I have this, what is R S and x j I should get? You got it. You went through that process in real life. And verify it, whether it occurred or it did not.

And to your great surprise, it may not occur, Ok? That is the best part of all of it. So this is called first turnaround. You do something and you do not match. Then you start guessing which step is overstepping it, so you re-tailor it on the program. Take 2 loops, 1 loop, 3 loops; you actually get the same values. Then you know what is the new value you get for which we should do the process.

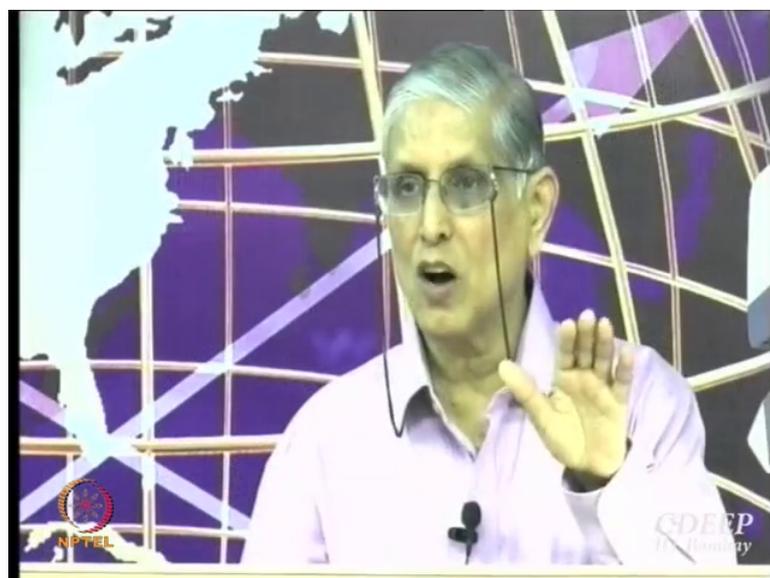
The reason is why this does not match, because the models which I assume, is I assumed. Silicon does not know it. So it did behave otherwise. I have to figure out how did it behave? So I keep changing my model to suit the result, Ok. That is what all modeling people do, Ok, with due regards.

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Ok so how will I monitor  $R_s$ ? There is a standard technique which is called four point probe. Ok. On the doped silicon wafer, please remember, there is, the  $R_s$  is only monitored on silicon doped area and not on oxide. So first thing you have to do is

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etch out the oxide wherever it is, wherever you want to measure the resistivity.

Let us say these are four probes, Ok. They are normally phosphor, this material,

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Measurement of  $R_s$

Four Point Probe

Analysis:

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

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

Point ~~probe~~ probe case, Probes are separated by distance  $S$ .

$\therefore V = \phi_1 - \phi_2 = \frac{IR_s}{2\pi} \ln 2$

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

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which I forgot, so these are very sharp-edged, these are of course steel, but phosphate bronze, sorry. These are phosphate bronzed tips below. The advantage of phosphor bronze is they do not have large tensile strength. So they do not actually penetrate. But they do give very good contacts.

So way it is, if we take case of distance of three points separated by

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Measurement of  $R_s$

Four Point Probe

Analysis:

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

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

In Four Point ~~probe~~ probe case, Probes are separated by distance  $S$ .

$\therefore \phi_1 = \frac{IR_s}{2\pi} \ln \frac{S}{2S} + A$

$\phi_2 = \frac{IR_s}{2\pi} \ln \frac{2S}{S} + A$

$\therefore V = \phi_1 - \phi_2 = \frac{IR_s}{2\pi} \ln 2$

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

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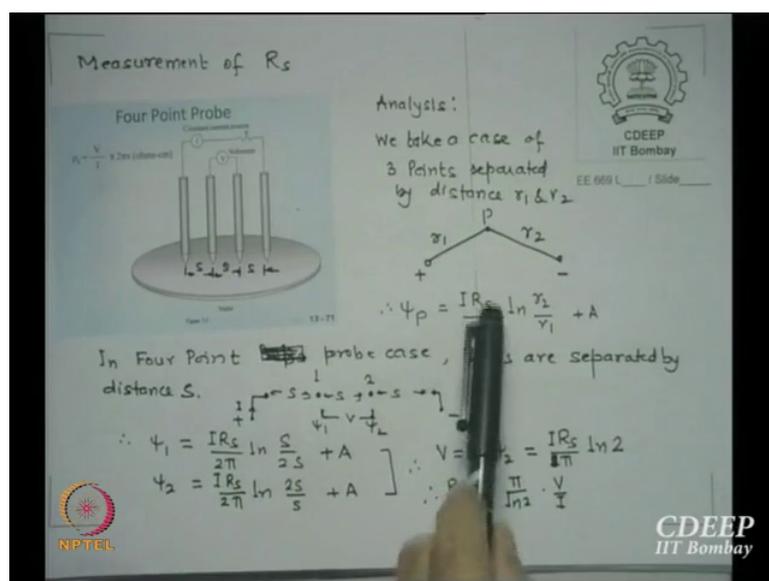
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distance  $r_1$  and  $r_2$ , and let us say I passed the current  $I$  in this, this is the nodal point and let us say, this plus minus from which current is flowing and I want to know potential at point P. P is separated from V plus and V minus by distance of  $r_1$  and  $r_2$

This is the case of solution of Poisson's equation, which some if you are, I think you are doing Mister Basu's course, n times Poisson's equation will appear, n times continuity equation will appear. So you will know more about it in case there is an issue there compared to what I hope, do call me. Normally I also teach devices many years. So hopefully I am right, Ok.

So  $\psi_P$  is  $I R_s \dots$  of course as I said derived it and I did not want to derive it for you, just take values.

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$R_s$  is the sheet resistance. So I can say that potential at  $\psi$  is essentially given potential name, so  $\psi$  at P is  $I R_s$  upon  $2\pi \ln r_2$  by  $r_1$  plus integral constant. Because  $d\psi$  by  $dx$  is  $\rho$  by  $x$  or  $\rho$  by  $\epsilon$ , is that clear?

This is the Poisson statement. So we solved this in this. Now for this I know, from two point source V plus V minus I can find potential at any point P. Why I did not take straight line? Because even at any angle it does not matter for me. So I just made it any angle, Ok. This distance and this distance should be known. This theory has been utilized in four probe. Is that clear why did I show this?

This Poisson equation solving is actually utilized in solving this problem. In a four point case, four point probe case, probes are separated by distance S, Ok each probe is separated by distance S.

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**Measurement of  $R_s$**

**Four Point Probe**

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.

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

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

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

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

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This is my plus and let us say the way it is, last two probes, I pass a constant current source.

This small r

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**Measurement of  $R_s$**

**Four Point Probe**

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.

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

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

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

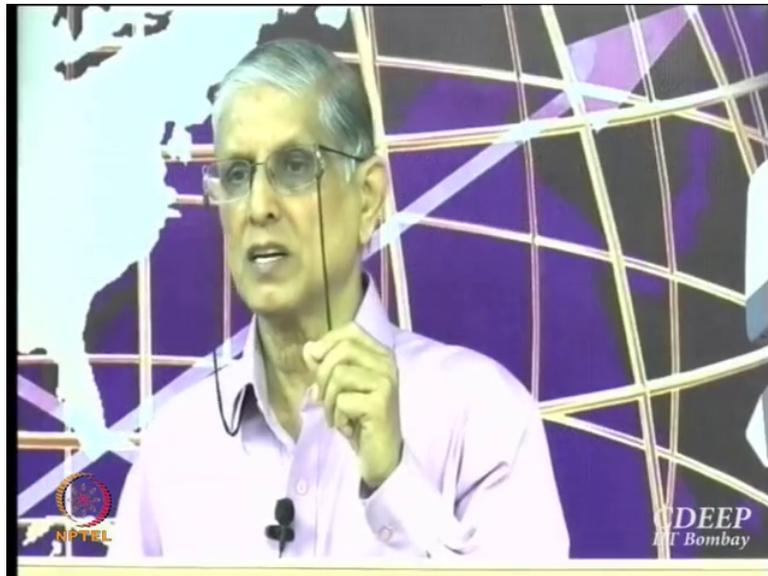
$\therefore R_s = \frac{\pi}{\ln 2} \cdot \frac{V}{I}$

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**NPTEL**

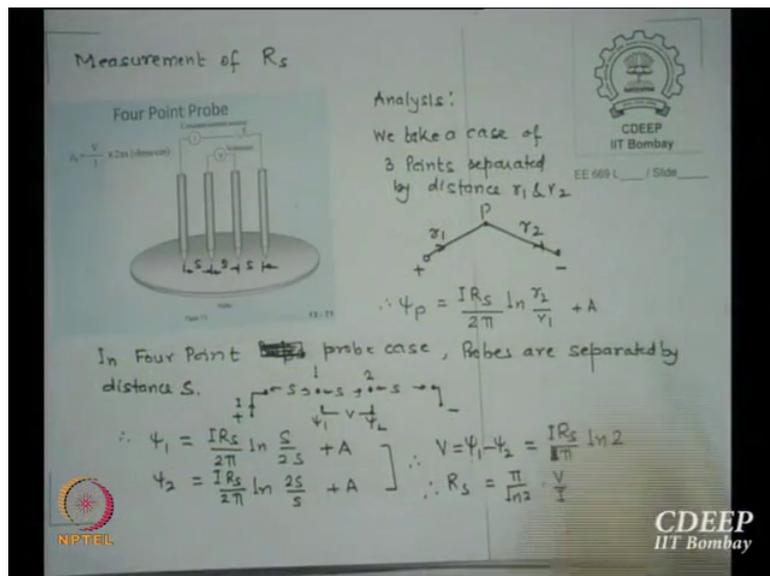
that is introduced there is essentially to limit the current. Please remember you need to limit the current.

(Refer Slide Time: 44:32)



Infinite current should not flow. So it is a constant current source. And  $r$  is limiter here, Ok. So I pass the current in the outside probes, Ok. So to say current is

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entering like this, Ok. Then please remember I want to calculate

(Refer Slide Time: 44:57)

Measurement of  $R_s$

Four Point Probe

Analysis:

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

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

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

$\therefore \phi_1 = \frac{IR_s}{2\pi} \ln \frac{S}{2s} + A$

$\phi_2 = \frac{IR_s}{2\pi} \ln \frac{S}{2s} + A$

$\therefore V = \phi_1 - \phi_2 = \frac{IR_s}{\pi} \ln 2$

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

potential at 1 and potential at 2.

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Measurement of  $R_s$

Four Point Probe

Analysis:

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

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

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

$\therefore \phi_1 = \frac{IR_s}{2\pi} \ln \frac{S}{2s} + A$

$\phi_2 = \frac{IR_s}{2\pi} \ln \frac{S}{2s} + A$

$\therefore V = \phi_1 - \phi_2 = \frac{IR_s}{\pi} \ln 2$

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

In between two probes I applied a voltmeter. Between the center probes I applied a voltmeter. So I want to know voltage difference between these two, Ok. Is that clear?

The outermost I put it at constant current source  $I$ , and in center two of them, please remember from here, this probe is how much distance?  $2S$ . From this, it is only  $S$ . Inverse it

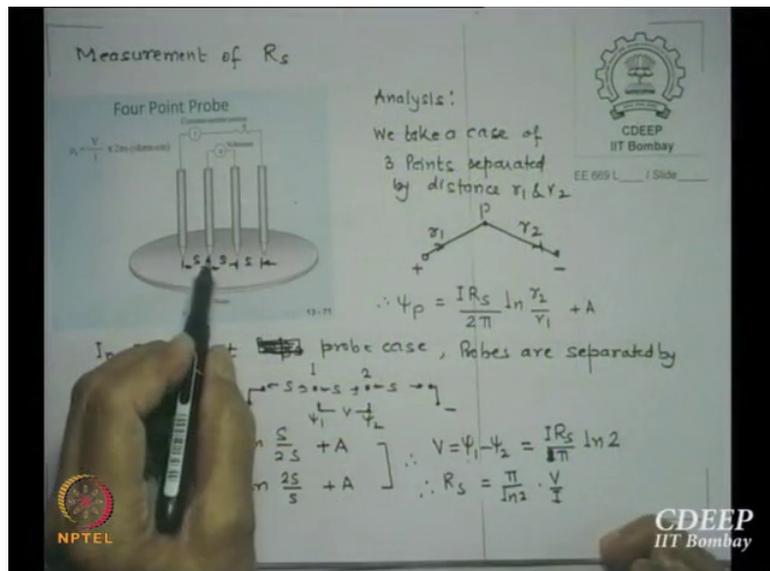
is equally true. From here it is 2 S, here it is S. Same way here it is 2 S and here it is S. This is symmetry what is I am looking for. That is why I used uniform spaced probes. Ok.

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So I calculate psi 1

(Refer Slide Time: 45:47)



potential at this, this I call 1, first point which is from I plus it is S distance.

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Measurement of  $R_s$

Four Point Probe

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  $S$ .

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

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

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

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

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So  $\psi_1$  is  $\frac{IR_s}{2\pi} \ln \frac{S}{2S}$ , is that clear?  $S$  upon

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Measurement of  $R_s$

Four Point Probe

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  $S$ .

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

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

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

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

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2 S. Ok,

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Measurement of  $R_s$

Four Point Probe

Analysis:

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

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

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

$\therefore \phi_1 = \frac{IR_s}{2\pi} \ln \frac{S}{2S} + A$

$\phi_2 = \frac{IR_s}{2\pi} \ln \frac{2S}{S} + A$

$\therefore V = \phi_1 - \phi_2 = \frac{IR_s}{\pi} \ln 2$

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

plus some integral constant A.

If I calculate potential

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Measurement of  $R_s$

Four Point Probe

Analysis:

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

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

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

$\therefore \phi_1 = \frac{IR_s}{2\pi} \ln \frac{S}{2S} + A$

$\phi_2 = \frac{IR_s}{2\pi} \ln \frac{2S}{S} + A$

$\therefore V = \phi_1 - \phi_2 = \frac{IR_s}{\pi} \ln 2$

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

here with reference to this  $\ln \frac{r_2}{r_1}$  I am taking the ratio, difference I am calculating. So  $\psi_2$  is  $\frac{IR_s}{2\pi} \ln \frac{2S}{S}$ ,  $\psi_1$  is  $\frac{IR_s}{2\pi} \ln \frac{S}{2S}$

(Refer Slide Time: 46:24)

Measurement of  $R_s$

Four Point Probe

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  $S$ .

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

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

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

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

by  $S$  plus  $A$ , the difference of potential between 1 and 2 is  $\psi_1$  minus  $\psi_2$ , which is the voltage the voltmeter is going to monitor, Ok. If I subtract this,

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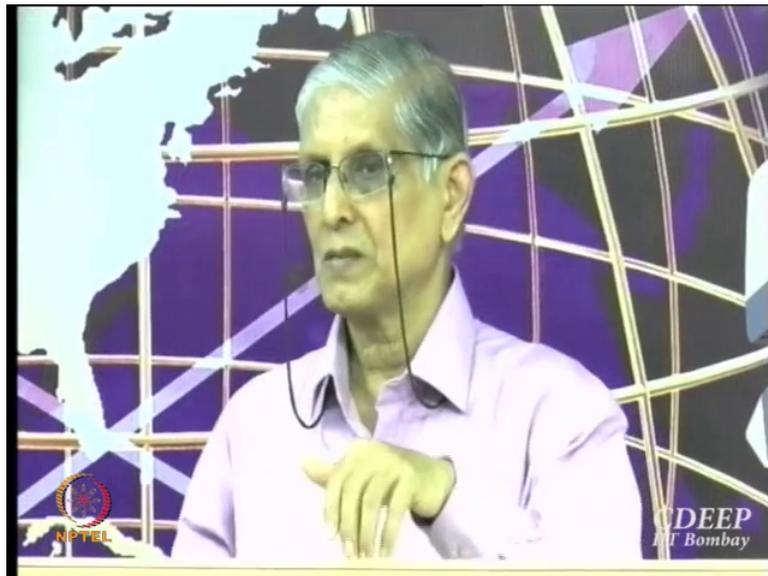
I get  $IR_s$  by  $\pi \ln 2$ ,  $A$  removes because that will get subtracted. From here  $R_s$  is  $\pi$  upon  $\ln 2$  into  $V$  by  $I$ . Is that clear?

So what did I do? I took a four probe which I fixed on a base, 0:47:02.3 just push it down, put a current source connect between the last two probes and monitor voltage between the center

probes. Ok. I measure  $V$ .  $I$  is known from a constant current source which is what I am fixing. So I know  $I$ . I know measured voltage  $V$ .  $\ln 2$  is a numerical number,  $\pi$  is a numerical number. So I can monitor my  $R_s$ . Is that correct?

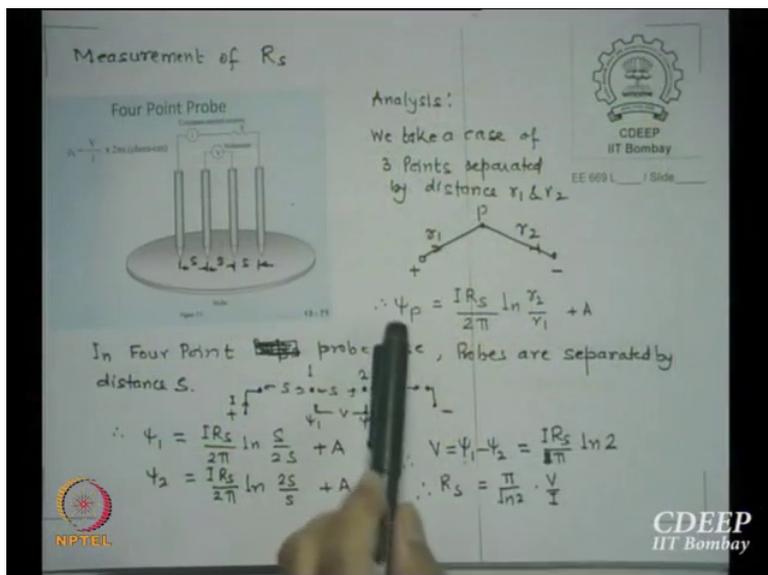
Four point probe is the easiest technique of monitoring sheet resistivity or sheet resistance  $R_s$ . Ok. Now this, is that clear? I diffused,

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I can calculate by Poisson's equation

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potential at any point separated by  $r_1$  &  $r_2$  from two points  $r$ . The current  $I$  is flowing through them. Ok. For this probe, potential at this point is  $\frac{IRs}{2\pi S}$  upon the other where from you are measuring  $r_1$  &  $r_2$ . This is  $r_2$ , this is  $r_1$ . So  $\frac{IRs}{2\pi S} + A$ .

For the other side I want to find potential here. So

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Measurement of  $R_s$

Four Point Probe

Analysis:

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

$\therefore \phi_p = \frac{IRs}{2\pi} \ln \frac{r_2}{r_1} + A$

Four Point probe case, Probes are separated by distance  $S$ .

$\therefore \phi_1 = \frac{IRs}{2\pi} \ln \frac{S}{2S} + A$

$\phi_2 = \frac{IRs}{2\pi} \ln \frac{2S}{S} + A$

$\therefore V = \phi_1 - \phi_2 = \frac{IRs}{\pi} \ln 2$

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

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I should,  $\frac{IRs}{2\pi S}$  upon  $S$ , Ok using the same method. So I get

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Measurement of  $R_s$

Four Point Probe

Analysis:

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

$\therefore \phi_p = \frac{IRs}{2\pi} \ln \frac{r_2}{r_1} + A$

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

$\therefore \phi_1 = \frac{IRs}{2\pi} \ln \frac{S}{2S} + A$

$\phi_2 = \frac{IRs}{2\pi} \ln \frac{2S}{S} + A$

$\therefore V = \phi_1 - \phi_2 = \frac{IRs}{\pi} \ln 2$

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

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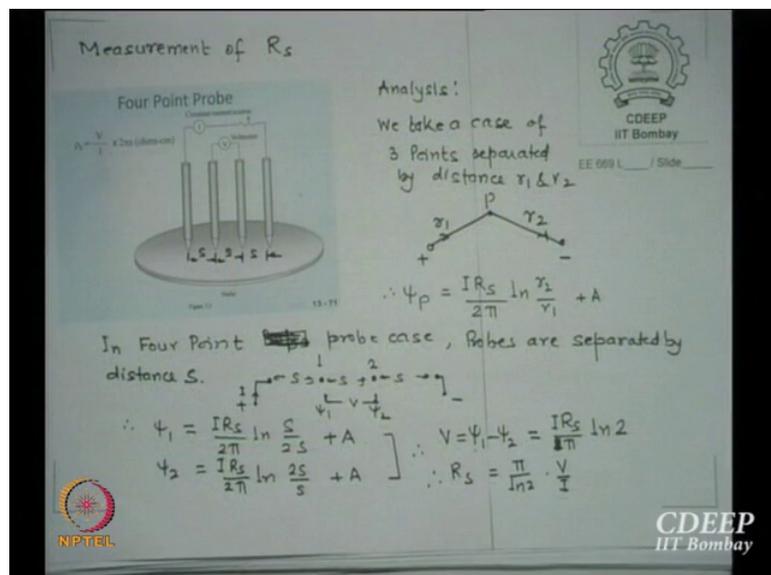
$\ln 2$  as  $R S$  upon  $2 \pi$

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$\ln 2$  by  $S$ ,  $S$  cancels,

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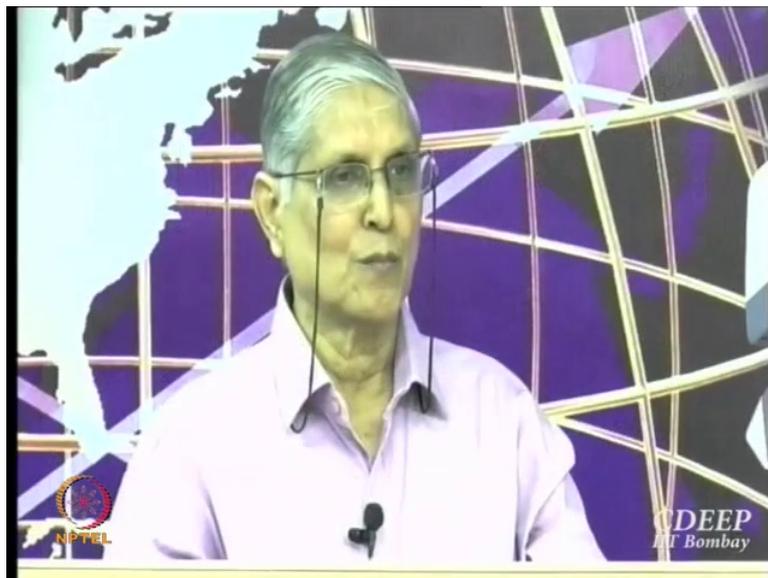


so it is  $\ln 2$ , and  $\ln$ , minus  $\ln$  by  $2$ . But minus minus will become plus so that  $2 \pi$  will become  $\pi$ , so  $I R S$  by  $\pi \ln 2$  is the voltage, Ok.

Or R S from here is pi upon 1 n 2 into V by I. Since pi is known, 1 n 2 is known, Ok, how much is 1 n 2? Log 2 is point 3 0 1 0, 2 point by 3 0 3 multiply, whatever it comes. So, and 3 point 1 4 1 5 7 9 8 is the pi value if you want or 555 by 111, many numbers, there is a good mathematical research going on even on pi value, think of it. Ok. How will I define pi? Ok.

So is that clear how to monitor R S? So one of the parameter of R S, x j was

(Refer Slide Time: 49:14)



monitoring R S, so which I did, Ok. Is that Ok? Everyone understood? Ok. Of course there are

(Refer Slide Time: 49:28)

Measurement of  $R_s$

Four Point Probe

Analysis:  
We take a case of 3 points separated by distance  $r_1$  &  $r_2$

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

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

$\therefore \phi_1 = \frac{IR_s}{2\pi} \ln \frac{S}{2S} + A$   
 $\phi_2 = \frac{IR_s}{2\pi} \ln \frac{2S}{S} + A$

$\therefore V = \phi_1 - \phi_2 = \frac{IR_s}{\pi} \ln 2$   
 $\therefore R_s = \frac{\pi}{\ln 2} \cdot \frac{V}{I}$

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methods which I did not say, three point probe, 2 point probe, 6 point probes but some other time.

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Junction Depth Evaluation

$R^2 = a^2 + c_1^2$   
 or  $c_1 = \sqrt{R^2 - a^2}$

Further  $R^2 = b^2 + c_2^2$   
 or  $c_2 = \sqrt{R^2 - b^2}$

$\therefore c_2 - c_1 = X_j = \sqrt{R^2 - b^2} - \sqrt{R^2 - a^2}$

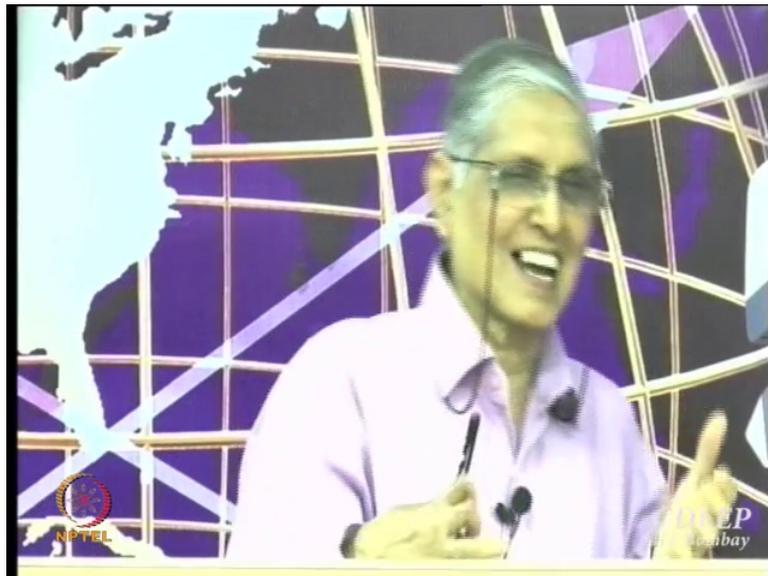
If we choose screws such that  $R \gg a$  &  $R \gg b$

$X_j = c_2 - c_1 = R \left[ \left(1 - \frac{b^2}{2R^2}\right) - \left(1 - \frac{a^2}{2R^2}\right) \right] = \frac{a^2 - b^2}{2R}$

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When you are in lab, you actually do many mischief, Ok. In the class I do not want to show you many other mischief you could do and still

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get correct answers, Ok. Ok.

Now the next value

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Junction Depth Evaluation

$$R^2 = a^2 + c_1^2$$
$$\text{or } c_1 = \sqrt{R^2 - a^2}$$

Further  $R^2 = b^2 + c_2^2$

$$\text{or } c_2 = \sqrt{R^2 - b^2}$$
$$\therefore c_2 - c_1 = x_j = \sqrt{R^2 - b^2} - \sqrt{R^2 - a^2}$$

If we choose screws such that  $R \gg a$  &  $R \gg b$

$$x_j = c_2 - c_1 = R \left[ \left(1 - \frac{b^2}{2R^2}\right) - \left(1 - \frac{a^2}{2R^2}\right) \right] = \frac{a^2 - b^2}{2R}$$

which I want to evaluate is the junction depth, Ok. This is called screwing techniques, screw.

This has a radius



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**Junction Depth Evaluation**

Diagram: A cross-section of a junction with radius  $R$ , depth  $a$ , and width  $2a$ . A second junction with radius  $R$  and depth  $b$  is shown below it. The distance between the centers of the two junctions is  $c_2$ . The junction depth is  $x_j$ .

Equations:

$$R^2 = a^2 + c_1^2$$

$$\text{or } c_1 = \sqrt{R^2 - a^2}$$

Further  $R^2 = b^2 + c_2^2$

$$\text{or } c_2 = \sqrt{R^2 - b^2}$$

$$\therefore c_2 - c_1 = x_j = \sqrt{R^2 - b^2} - \sqrt{R^2 - a^2}$$

If we choose Screw such that  $R \gg a$  &  $R \gg b$

$$= R \left[ \left(1 - \frac{b^2}{2R^2}\right) - \left(1 - \frac{a^2}{2R^2}\right) \right] = \frac{a^2 - b^2}{2R}$$

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like, this is the gray area. So this area will actually go. Which area? This whole area

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**Junction Depth Evaluation**

Diagram: A cross-section of a junction with radius  $R$ , depth  $a$ , and width  $2a$ . A second junction with radius  $R$  and depth  $b$  is shown below it. The distance between the centers of the two junctions is  $c_2$ . The junction depth is  $x_j$ .

Equations:

$$R^2 = a^2 + c_1^2$$

$$\text{or } c_1 = \sqrt{R^2 - a^2}$$

Further  $R^2 = b^2 + c_2^2$

$$\text{or } c_2 = \sqrt{R^2 - b^2}$$

$$\therefore c_2 - c_1 = x_j = \sqrt{R^2 - b^2} - \sqrt{R^2 - a^2}$$

If we choose Screw such that  $R \gg a$  &  $R \gg b$

$$= R \left[ \left(1 - \frac{b^2}{2R^2}\right) - \left(1 - \frac{a^2}{2R^2}\right) \right] = \frac{a^2 - b^2}{2R}$$

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will actually go. Because as I screw I will remove the silicon from there, Ok. However what is open to

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Junction Depth Evaluation

Substrate

$$R^2 = a^2 + c_1^2$$

$$\text{or } c_1 = \sqrt{R^2 - a^2}$$

$$\text{Further } R^2 = b^2 + c_2^2$$

$$\text{or } c_2 = \sqrt{R^2 - b^2}$$

$$\therefore c_2 - c_1 = x_j = \sqrt{R^2 - b^2} - \sqrt{R^2 - a^2}$$

If we choose screws such  $R \gg a$  &  $R \gg b$

$$x_j = c_2 - c_1 = R \left[ \left(1 - \frac{b^2}{2R^2}\right) - \left(1 - \frac{a^2}{2R^2}\right) \right] = \frac{a}{2R}$$

me there, I will see this distance, I will see this distance and I will also see this distance. This is what I see from the top, is that clear?

If I groove it like this, this portion, this portion and flat portion, this is what I am going to see. Ok. So let us calculate some ratio in terms of the available. Since R is the radius of the curvature of the screw down, Ok, so R is constant everywhere, Ok.

Let us say point where,

(Refer Slide Time: 51:15)

Junction Depth Evaluation

$R^2 = a^2 + c_1^2$   
 $\text{or } c_1 = \sqrt{R^2 - a^2}$   
 Further  $R^2 = b^2 + c_2^2$   
 $\text{or } c_2 = \sqrt{R^2 - b^2}$   
 $\therefore c_2 - c_1 = x_j =$   
 $= (R^2 - b^2)^{1/2} - (R^2 - a^2)^{1/2}$   
 If we choose screws such that  
 $R \gg a$  &  $R \gg b$   
 $x_j = R \left[ \left(1 - \frac{b^2}{2R^2}\right) - \left(1 - \frac{a^2}{2R^2}\right) \right] = \frac{a}{2R}$

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at the surface with the center point

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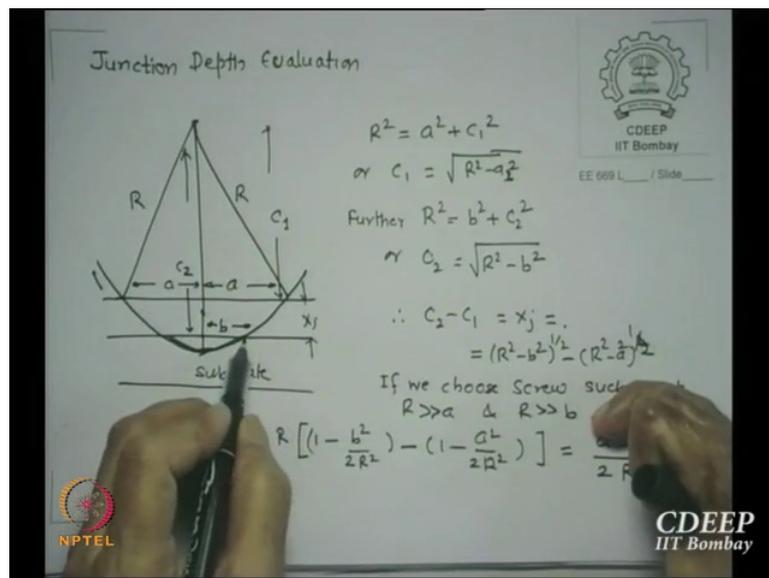
Junction Depth Evaluation

$R^2 = a^2 + c_1^2$   
 $\text{or } c_1 = \sqrt{R^2 - a^2}$   
 Further  $R^2 = b^2 + c_2^2$   
 $\text{or } c_2 = \sqrt{R^2 - b^2}$   
 $\therefore c_2 - c_1 = x_j =$   
 $= (R^2 - b^2)^{1/2} - (R^2 - a^2)^{1/2}$   
 If we choose screws such that  
 $R \gg a$  &  $R \gg b$   
 $x_j = R \left[ \left(1 - \frac{b^2}{2R^2}\right) - \left(1 - \frac{a^2}{2R^2}\right) \right] = \frac{a}{2R}$

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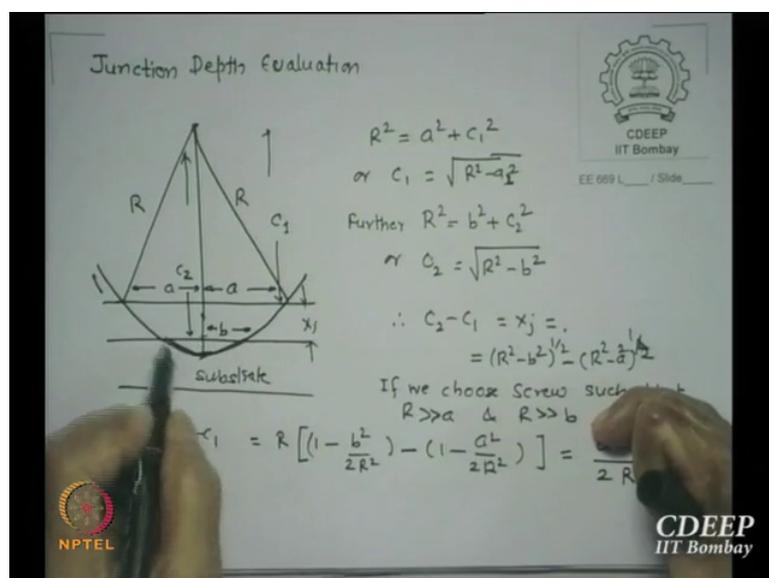
is a distance a is identical both sides, Ok. It is a universal, uniform screw. Let us say from the junction

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from this point, this point will be visible to you, because the etching will do, but this portion will 0:51:35.8. This point to this point is  $b$ , same as this is  $b$ .

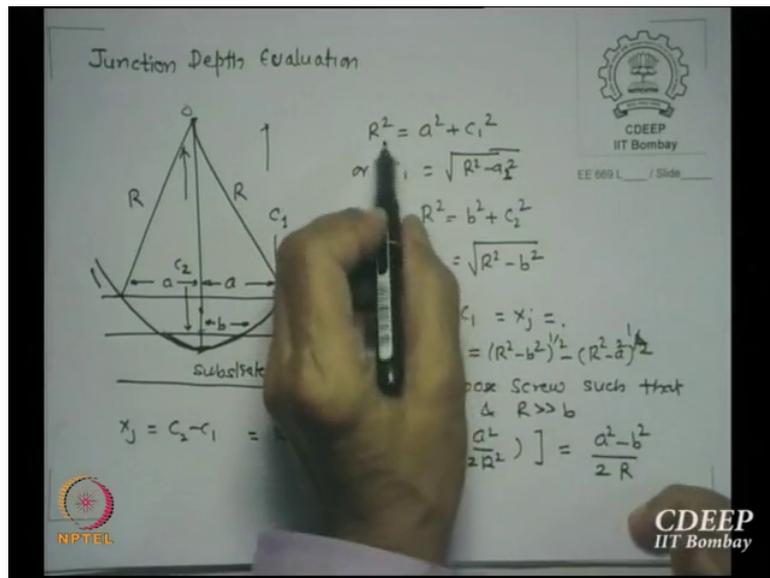
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We call this is  $R$  but we call this flat portion where we actually the distance is called  $c_2$  and from the top surface, this region I call this as  $c_1$ , Ok. This is my maths, nothing great.

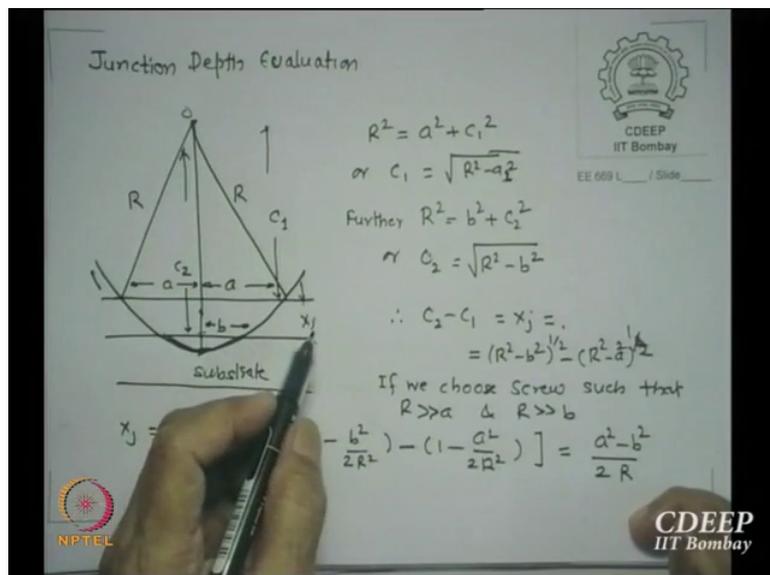
Assuming curve as large enough comparatively so that can be treated linear in most cases,

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I could say R square is a square plus c 1 square.

(Refer Slide Time: 52:11)



Hypotenuse square is this distance square plus distance square. So c 1 is under root R Square minus a 1 square.

By same logic if you look at this, b square, of course I should have done this. I should have drawn another line here. So R Square is equal to b square

(Refer Slide Time: 52:37)

Junction Depth Evaluation

$R^2 = a^2 + c_1^2$   
 or  $c_1 = \sqrt{R^2 - a^2}$   
 Further  $R^2 = b^2 + c_2^2$   
 or  $c_2 = \sqrt{R^2 - b^2}$   
 $\therefore c_2 - c_1 = x_j =$   
 $= (R^2 - b^2)^{1/2} - (R^2 - a^2)^{1/2}$   
 If we choose screws such that  
 $R \gg a$  &  $R \gg b$   
 $\left[ \left(1 - \frac{b^2}{2R^2}\right) - \left(1 - \frac{a^2}{2R^2}\right) \right] = \frac{a^2 - b^2}{2R}$

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plus  $c_2$  square. What I am doing is this which I did not draw. So this is again  $R$ , this is  $b$  and this is  $c_2$ . So  $c_2$  square plus  $b$  square is again  $R$  Square, Ok. So  $c_2$  is under root  $R$  Square minus  $b$  square. So  $c_2$  minus,

(Refer Slide Time: 53:04)

Junction Depth Evaluation

$R^2 = a^2 + c_1^2$   
 or  $c_1 = \sqrt{R^2 - a^2}$   
 Further  $R^2 = b^2 + c_2^2$   
 or  $c_2 = \sqrt{R^2 - b^2}$   
 $\therefore c_2 - c_1 = x_j =$   
 $= (R^2 - b^2)^{1/2} - (R^2 - a^2)^{1/2}$   
 If we choose screws such that  
 $R \gg a$  &  $R \gg b$   
 $x_j = R \left[ \left(1 - \frac{b^2}{2R^2}\right) - \left(1 - \frac{a^2}{2R^2}\right) \right] = \frac{a^2 - b^2}{2R}$

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what is junction depth?

$c_2$  minus  $c_1$  is the junction depth. So  $c_2$  minus  $c_1$  is  $x_j$   $R$  square

(Refer Slide Time: 53:14)

Junction Depth Evaluation

$$R^2 = a^2 + c_1^2$$

$$\text{or } c_1 = \sqrt{R^2 - a^2}$$

$$\text{Further } R^2 = b^2 + c_2^2$$

$$\text{or } c_2 = \sqrt{R^2 - b^2}$$

$$\therefore c_2 - c_1 = x_j =$$

$$= (R^2 - b^2)^{1/2} - (R^2 - a^2)^{1/2}$$

If we choose  $R \gg a$  &  $R \gg b$  such that

$$x_j = c_2 - c_1 = R \left[ \left(1 - \frac{b^2}{R^2}\right)^{1/2} - \left(1 - \frac{a^2}{R^2}\right)^{1/2} \right] = \frac{a^2 - b^2}{2R}$$

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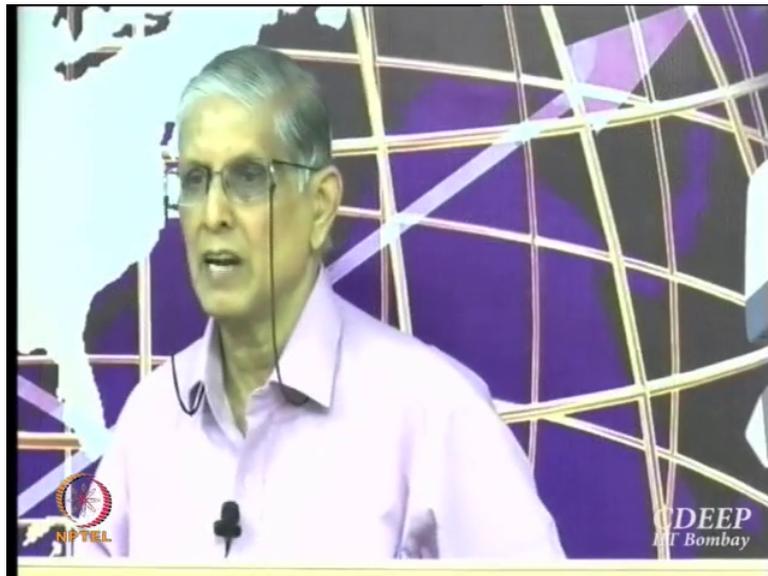
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minus b square to the power half minus R square minus b square to the power half.

Now the way we have made the choice of the screw is this distance is a, a and b are much smaller than radius of curvature of the screw which we have used, Ok which is large enough. So here you can use binomial expansions if a and b are smaller than R, you rewrite this term by expansion so  $R \left(1 - \frac{b^2}{2R^2}\right) - R \left(1 - \frac{a^2}{2R^2}\right)$ . So by subtracting correctly, I get  $x_j$  as  $\frac{a^2 - b^2}{2R}$ .

R is given to me from the screw I used. R is known to me. So what I have to monitor to get  $x_j$ ? a and b, is that clear? So if I monitor

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a and b, I have the value of junction depth. Ok. Now how do I monitor a and b? This portion is known to me, is that correct? This portion I will see. Assuming this is linear roughly, Ok, because this curvature is large enough so it will, this can be treated as a straight line, Ok.

So what I do is I take this etch, a screw where silicon has gone out, I dip it into some copper sulphate plus H C l solution, Ok. If I dip this into H C l plus copper sulphate, H C l removes much of the oxygen around and copper sulphate actually plates

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Junction Depth Evaluation

$$R^2 = a^2 + c_1^2$$
$$\text{or } c_1 = \sqrt{R^2 - a^2}$$
$$\text{Further } R^2 = b^2 + c_2^2$$
$$\text{or } c_2 = \sqrt{R^2 - b^2}$$
$$\therefore c_2 - c_1 = x_j = \sqrt{R^2 - b^2} - \sqrt{R^2 - a^2}$$

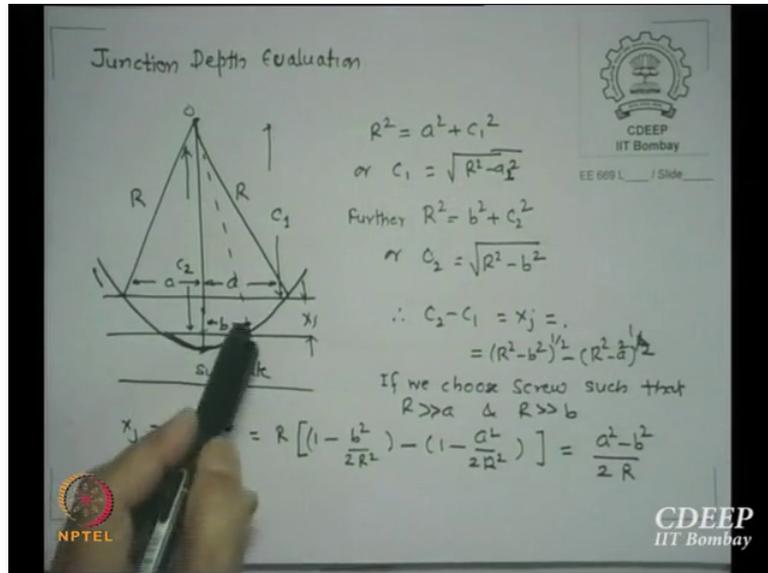
If we choose screws such that  $R \gg a$  &  $R \gg b$

$$x_j = c_2 - c_1 = R \left[ \left(1 - \frac{b^2}{2R^2}\right) - \left(1 - \frac{a^2}{2R^2}\right) \right] = \frac{a^2 - b^2}{2R}$$

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the surface. This is called electroless plating. Ok. This is called electroless plating.  
So this portion where silicon is available to you, and also this dome,

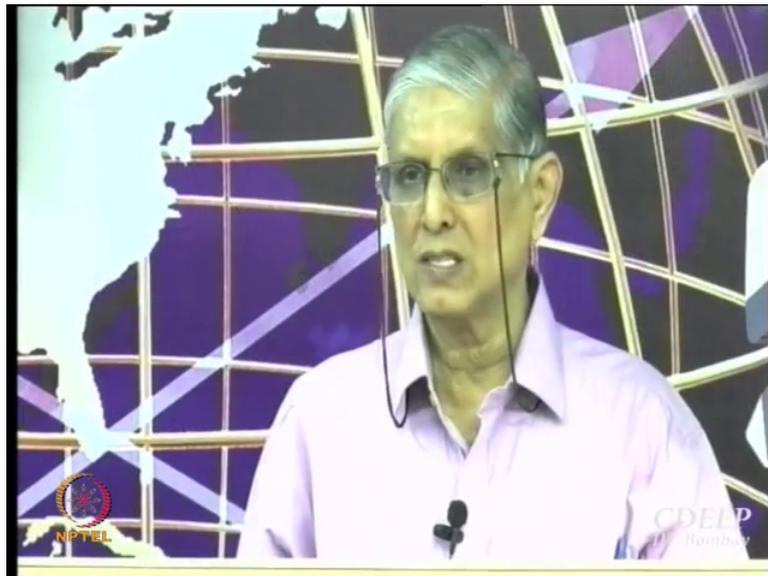
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you will get coating. Now from the microscope I can actually see two annular rings on the top. One is  $2b$  dia, other is  $2a$  dia. So I can actually monitor  $2a$  minus  $2b$  or  $2a$  and  $2b$  therefore I know  $a$  and  $b$  and since I know  $a$  and  $b$ , I will be able to find out  $x_j$ . This is called junction depth, these are called screw techniques.

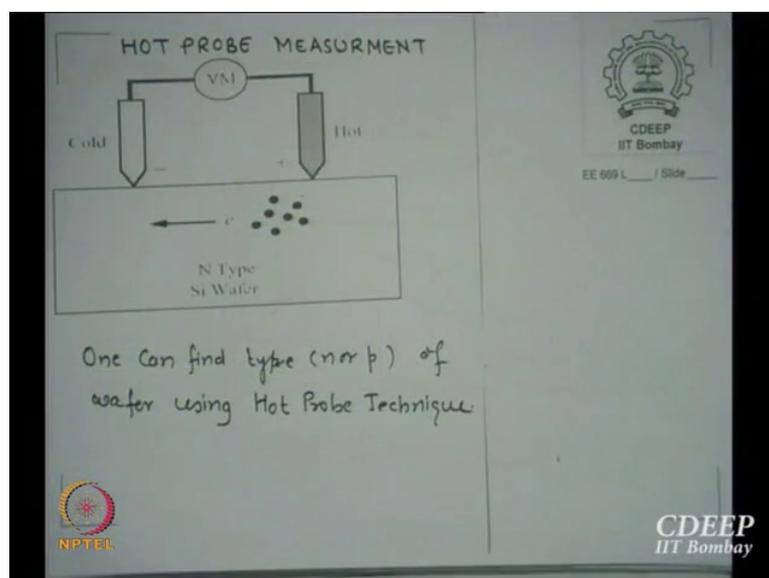
There are other methods

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which are more advanced methods like SIMS method, optical, this book, Raman's book has given many other techniques, much more advanced techniques but I just thought you that this is how I did in 1973 or 1972. It worked even now.

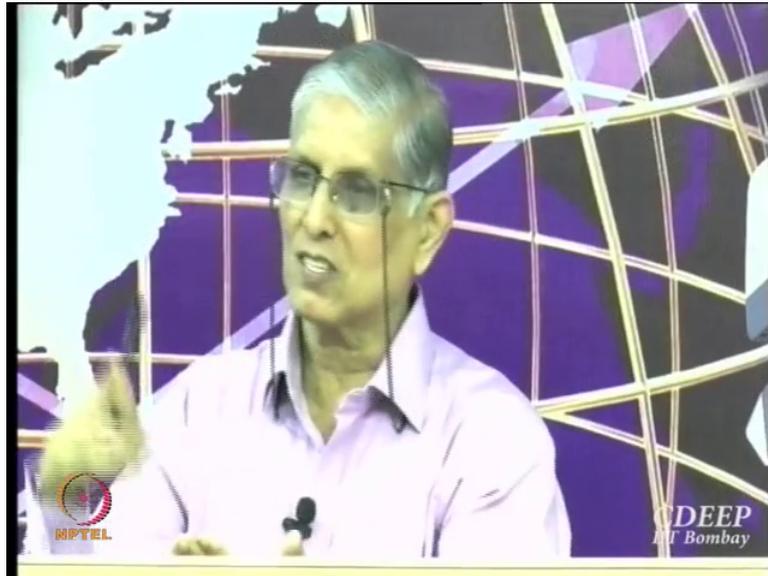
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Ok.

Another few things we will have to monitor. When you start a wafer, this was a question I told you last, how do I know N B is p type or n type? Let us say generally wafers are given with all kinds of data. So when you take out

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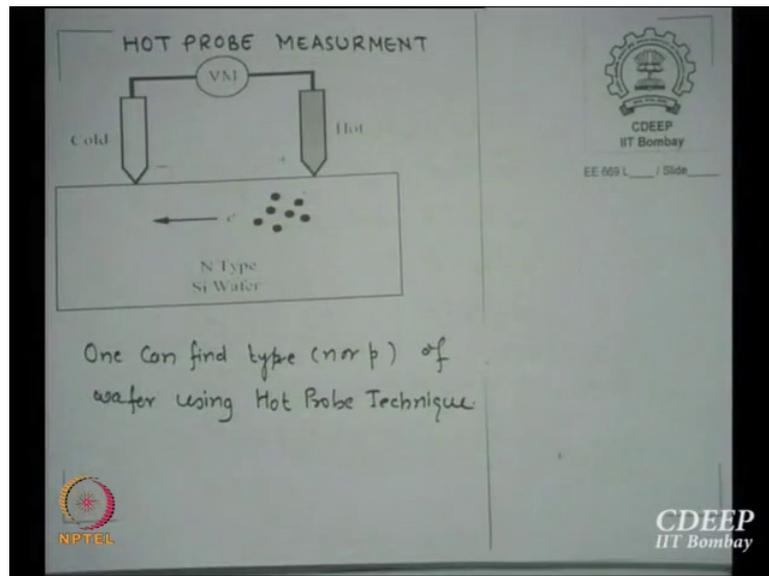


of the box, you know which wafer, what orientation, what doping is given.

But let us say x man has taken yesterday some wafers and put it on a rack. And this man was asked to do the process in the night. Now he never told him which wafers he took. So how does he know that which p type or n type you started? So he has to figure out what is the kind of wafer?

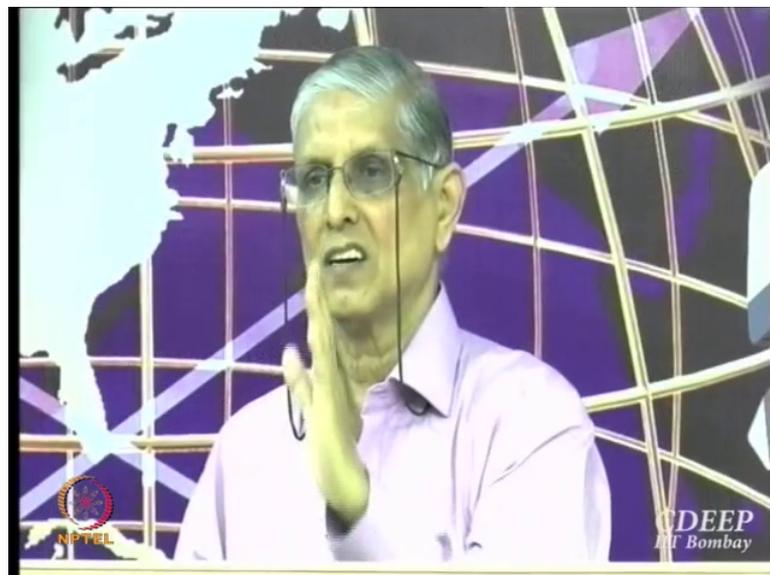
So this is a hot probe method

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in which I can find out whether the wafer is n type or p type. Example given is an n type. The way it is done is we have a silicon wafer. And we have two probes which is connected by a voltmeter, center zero voltmeter that means

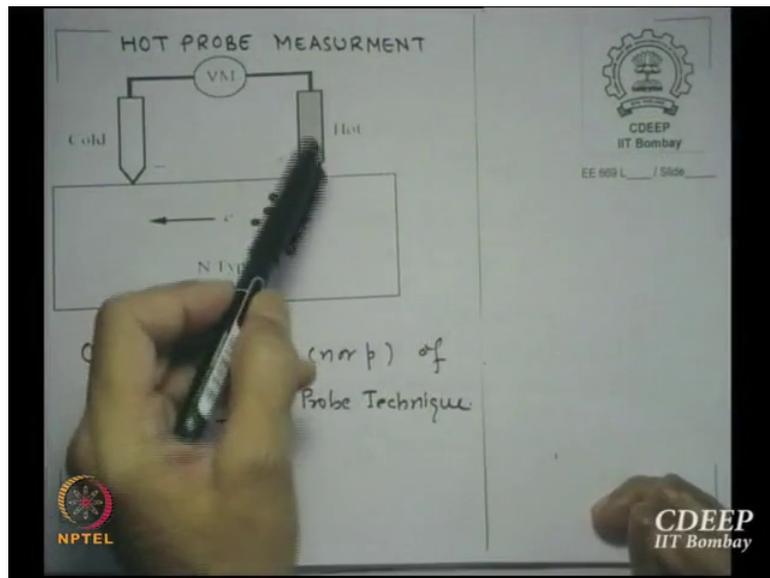
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the arm is in the center. It can go on the right and go on the left, Ok.

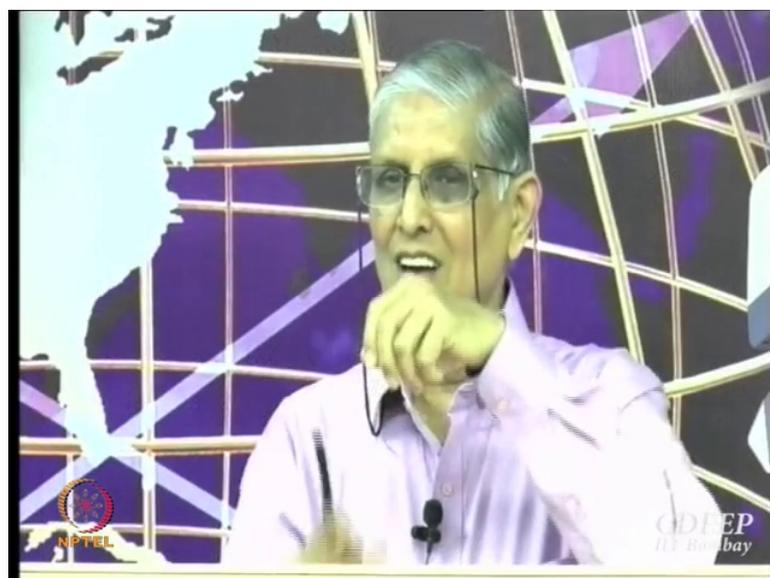
One of the

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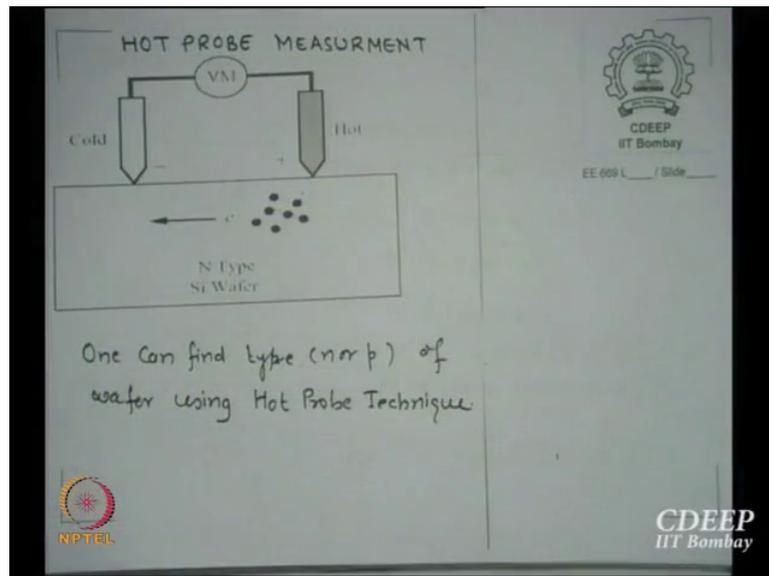
probe shown here, I can, actually has a, many a time this probe was used by the, what is the probe I can use? Of course, tip I will have to change. What could be heater here? The soldering iron itself is sufficient. It itself heats,

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Ok. Tip it a little below, correctly. So you can fix a tip there. So this can become a hot

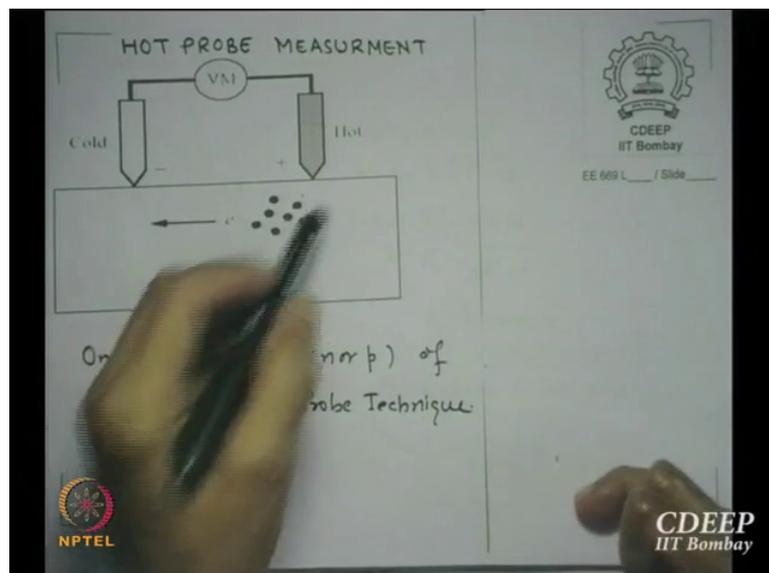
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probe. The other terminal of that is connected to a cold area. 0:57:39.2.

Now since it is a n type, yes, since it is a n type; hopefully it has larger number of electrons than holes that is why it is called n type, Ok.

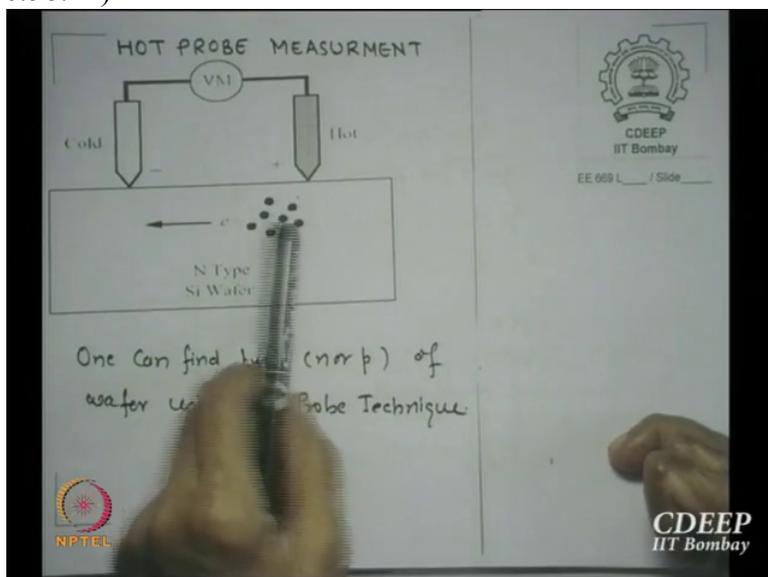
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So if I heat the electrons below this hot area or hot volume there actually will energize the electrons, Ok, because you are heating the, this area. Of course this is a small tip so it does not expand to the whole area, only a small area gets heated.

And the electrons below that area gets excited. Since they get excited actually so they start moving. As they start

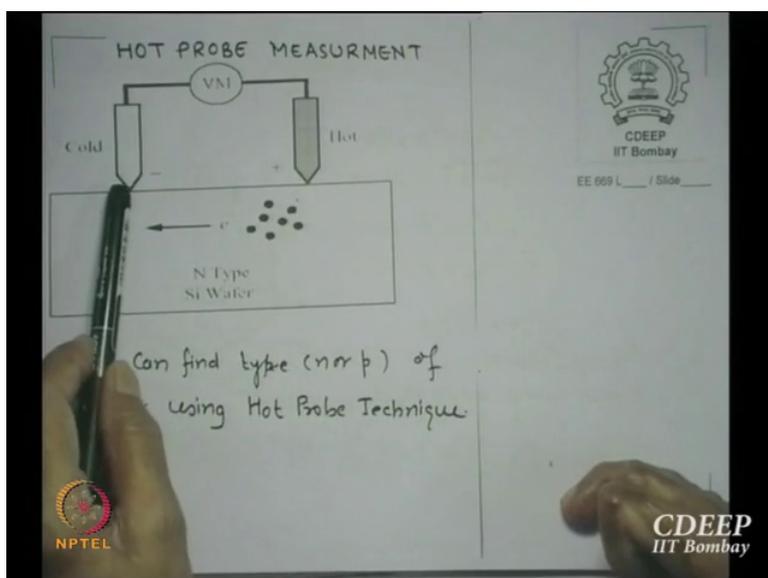
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moving, equivalently positive charge is starting 0:58:28.5, after all, whenever electron leaves the lattice, the ionized donors come there. So electrons start moving, donor starts moving, ionized donor positive charge Ok.

As this becomes positive and this

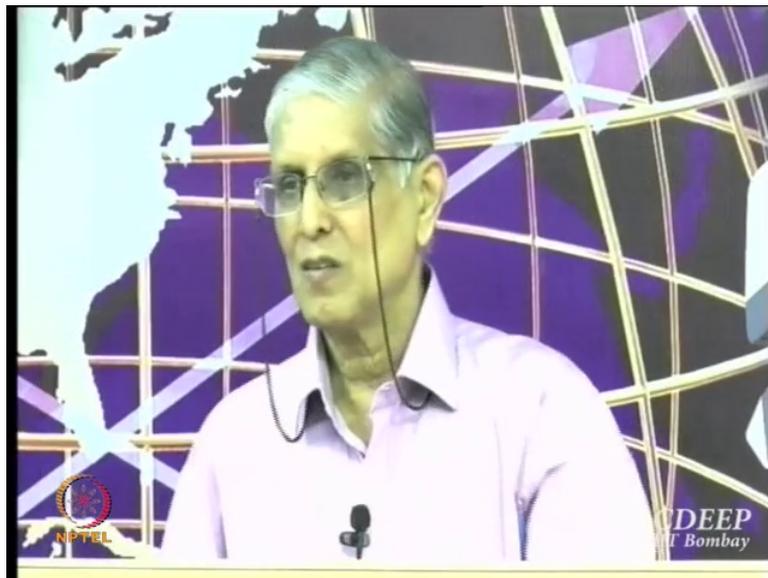
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essentially is cold so most of this, they actually dissipate their energy and they are collected here. Since electrons are negative, so this probe becomes negative, this probe becomes positive. So this is positive, so the displacement will be on the left so you know, if the base is n type the deflection would have been there.

Now the question is very interesting. If it is a p type, we still argue that holes move away. Acceptors are released and the

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meter will show opposite polarity. So I know it is p type. Electrons are known particles, Ok. So I am 100 percent sure, if I heat, they will move. Holes are not particles.

Holes are absence of electrons, Ok. They are on the valence band. These are quantum electronics. They only move in valence band. So when I heat why should holes move? These are bound electrons in the valence band. So how do they move? And if they do not move, why should probe show the other direction? That means they moved.

This is, how I could know? At most what they will do? They will jump in the valence band from one side to other side. But there is no hole motion in the valence band, quantum bands. So how a hot probe still show you a p type material which by theory is not valid. Ok

The another experiment which I had to do before I did this, I many times want to know, what the standard book refers uniform doping. I want to know the mobility of the carriers and I also want to know carrier concentrations, Ok. One of course is the sheet resistance measurement and you can always get R equal to R S L by W.

But that is understanding it is an uniform, square, rectangular this. In real life there is nothing rectangular. Though we do solve problems for 1:00:37.0 Cartesian coordinates, Ok. Ok so 1:00:40.7 by resistance? So here is the Hall sample, Ok.

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Codec-5 Selfview

### Hall Effect Measurement

We have

$$\frac{\rho L}{A} = R$$

With No Magnetic Field

$$R = \frac{V_x}{I_x} \quad \& \quad A_{\text{area}} = W \cdot t$$

$$\therefore \rho = \frac{W \cdot t}{L} \frac{V_x}{I_x}$$

If Semiconductor is n-type, then

$$\rho = \frac{1}{q \mu_n n_0 + q \mu_p \frac{n_i^2}{n_0}} \approx \frac{1}{q \mu_n n_0}$$

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It is not exactly like this but almost like this.

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Hall Effect Measurement

We have  $\frac{\rho L}{A} = R$

With No Magnetic Field  $R = \frac{V_x}{I_x}$  & Area =  $W \cdot t$

$\therefore \rho = \frac{W \cdot t}{L} \frac{V_x}{I_x}$

If Semiconductor is n-type, then  $\rho = \frac{1}{q \mu_n n_0 + q \mu_p p_0} \approx \frac{1}{q \mu_n n_0}$

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I have, I apply a potential across this which pushes a current  $I_x$  and we say  $V_x$  by  $I_x$  is,

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Hall Effect Measurement

We have  $\frac{\rho L}{A} = R$

With No Magnetic Field  $R = \frac{V_x}{I_x}$  & Area =  $W \cdot t$

$\therefore \rho = \frac{W \cdot t}{L} \frac{V_x}{I_x}$

If Semiconductor is n-type +

$\rho = \frac{1}{q \mu_n n_0 + q \mu_p p_0}$

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and area this is my  $W$ , this is my thickness, this is my length, so  $R$  is equal to  $\rho L$  by  $A$  which is  $V_x$  by  $I_x$ , if I find the potential here, then it is this. If I substitute in this, I get  $\rho w t$  by  $L V_x$  by  $I_x$ .

If semiconductor is n type, rho is q mu n zero. Plus q mu p p zero. But p zero into n zero is n i square, so it is n i square by n zero. But if it is n type, then n zeroes are larger than p zero. So we neglect that. So you get q mu n n zero, Ok.

The directions I have already said. This is x. This is y and this, the top

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Hall Effect Measurement

We have  $\frac{\rho L}{A} = R$

With No Magnetic Field  $R = \frac{V_x}{I_x}$  & Area =  $W \cdot t$

$\therefore \rho = \frac{W \cdot t}{L} \frac{V_x}{I_x}$

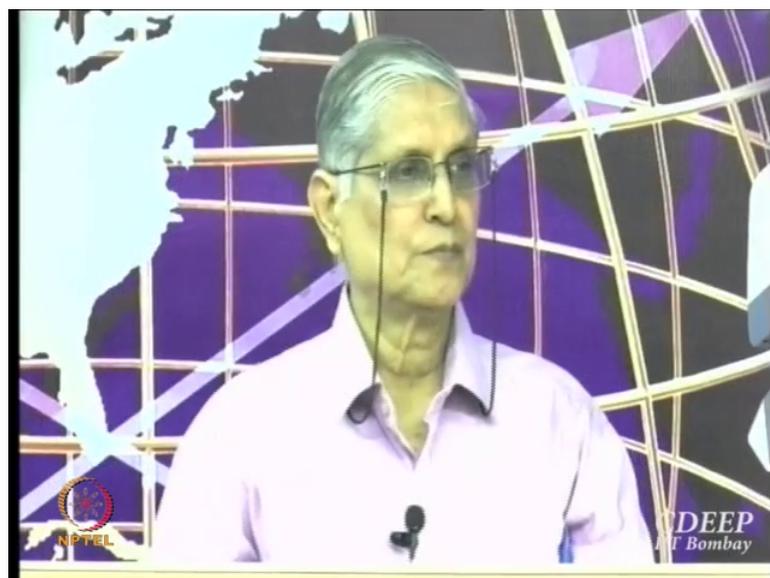
If Semiconductor is n-type, then

$$\rho = \frac{1}{q Y_n n_0 + q Y_p \frac{n_i^2}{n_0}}$$

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portion is z, Ok. Vertically z, this is x, this is y, Ok. Is that Ok?

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This is Hall sample. Of course Hall sample is slightly different from this. It has to be made actually.

(Professor – student conversation starts)

student: Side should be downward or ...

Professor: Which one? It can be either side. The carriers will go left side or right side.

(Professor – student conversation ends)

Ok, so if I do this, now this is which I will right now do wrongly.

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We now apply Magnetic field  $B_2$  along z-direction.

The current direction shown ( $I_x$ ), means electrons move from  $V_x^-$  to  $V_x^+$ .

They are accelerated due to electric field  $E_x (= \frac{V_x}{L})$  and experience a force  $q \frac{V_x}{L}$

Due to Orthogonal Magnetic field  $B_2$ , electrons experience Lorentz Force =  $q v_y B_2$  ( $v_y$  is velocity along y direction)

In equilibrium

$$q v_y B_2 + q E_x = 0$$
$$\text{or } E_x = - v_y B_2 = + B_2 \frac{I_x}{q n w t n_0}$$

$I = q n v$   
 $n = \text{electron conc.}$

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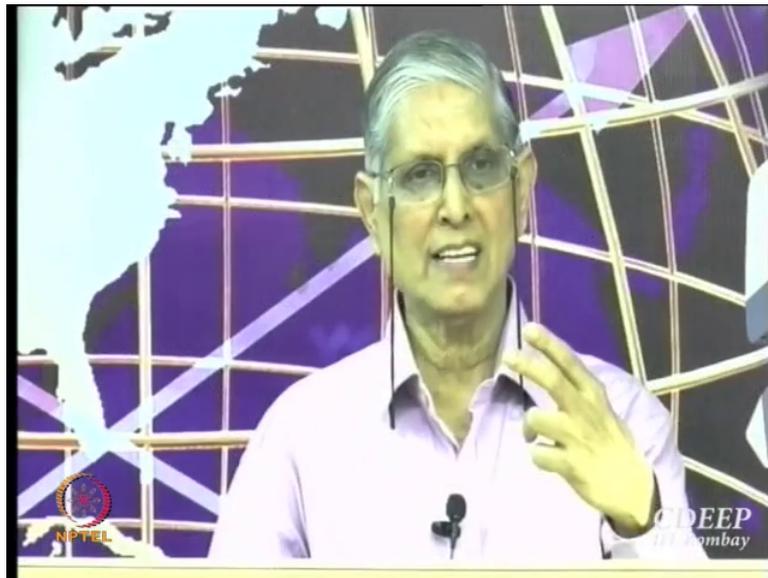
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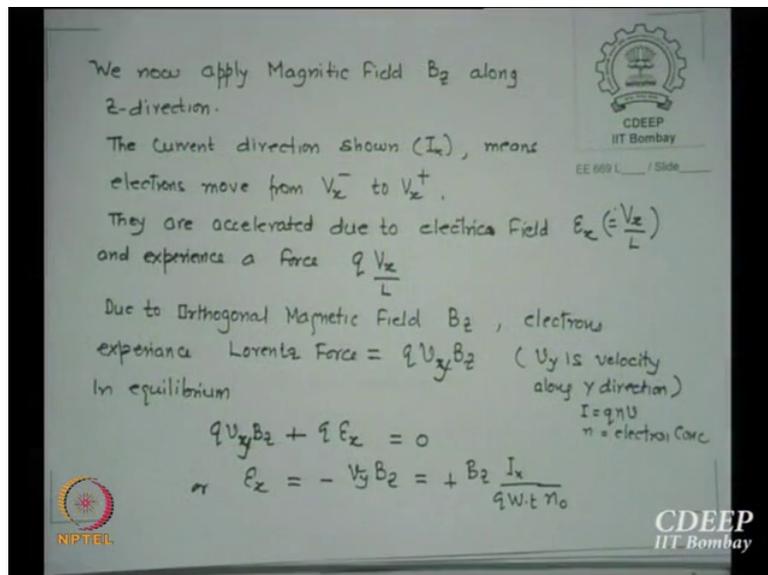
You know if I apply a magnetic field orthogonal to the motion of electrons going from V plus to V minus then flowing a current  $I_x$ , and therefore there is a electric field of  $V_x$

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by length which is the  $E \times$  field, electric field which gives the force of  $E q$ ,  $E e$  is the force of  $q V \times$  by  $L$ , the electric force

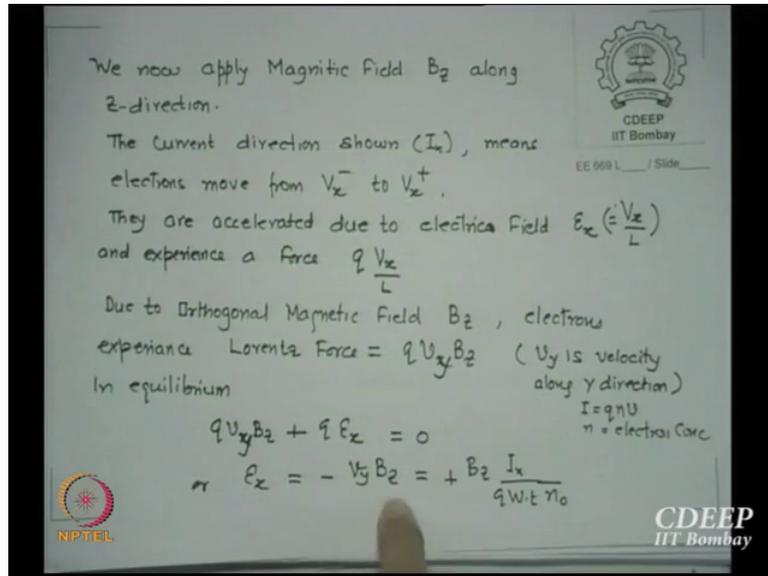
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but when I apply a magnetic field, it also experiences a Lorentz force which is actually  $q V$  cross  $B$  in 3 dimensions, Ok, it is a curl of  $V$  and  $B$ .

But in case, our case  $V_y B_z$ . And the net force, the electrons do not move, because the current is zero, it is steady state.  $q V_y B_z$  must be equal to zero, Ok. So  $E_x$ , from here is minus  $V_y B_z$ .

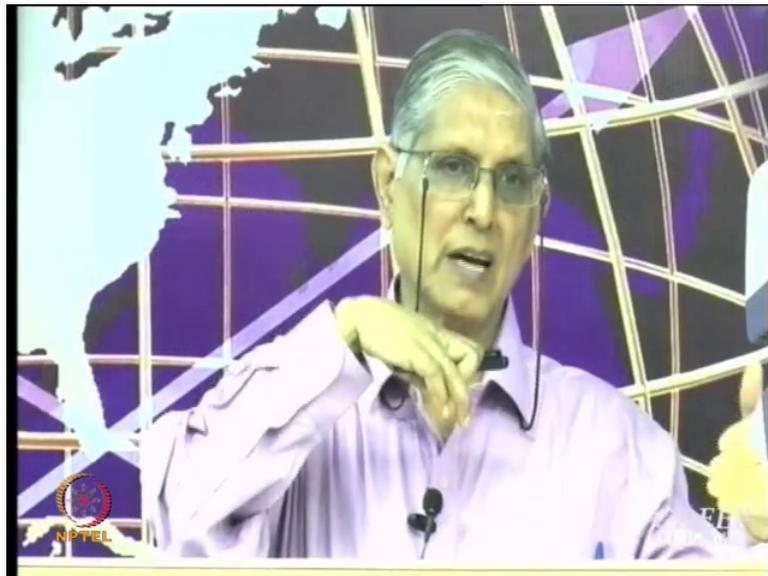
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But  $V_y I_x$  just can calculate,  $I_x$  upon, the last term I calculated is this. So now I know electric field is proportional to magnetic field through term of this.

So what will happen? It will create, essentially what, if you have written down what is 1:03:48.1, the electrons were moving in x direction, but as soon as you apply they, Lorentz forces is orthogonal so it will

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try to push the electrons in one side whichever is the electron, that contact will become minus, the opposite contact will become plus, Ok. If it is opposite, the electrons will move outside and this minus plus will change. So that is not the problem. Is that Ok?

So what Hall is trying to do is to relate this  $B_z$  term with  $E_x$  and I know how much magnetic intensity of the magnetic field I am giving, so many gauss, Ok. There is a standard, this Hall probe available. So you do not really do anything. Fix  $B$ , fix  $R$  also. You just put your sample. But how do we get is the numbers, is that Ok?

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Hall Voltage  $V_y = -\int_0^w E_x dy$   
 $= B_z \frac{I_x}{q t n}$

We define Hall Coeff  $R_H = \frac{t V_y}{B_z I_x}$

$\pm q R_H = \frac{1}{n} \quad \therefore n, p = \pm \frac{1}{q R_H}$

We know  $\rho_n = \frac{1}{q \mu_n n_0} = \sigma^{-1}$

$\therefore \mu_n = \frac{R_H}{\rho_n} = |R_H| \cdot \sigma_n$   
 $\mu_p = |R_H| \cdot \sigma_p$

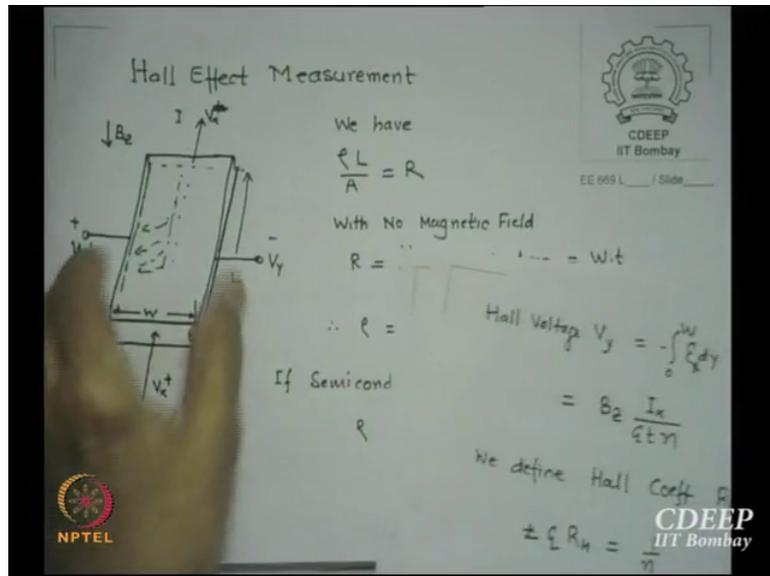
$R_H = +$  for Holes  
 $R_H = -$  for Electrons

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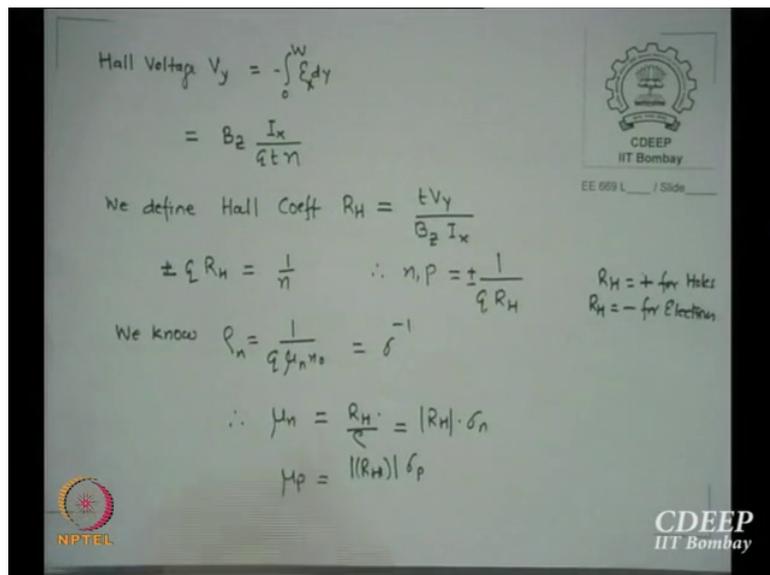
So the Hall voltage that is across, if you see the, I am sorry,

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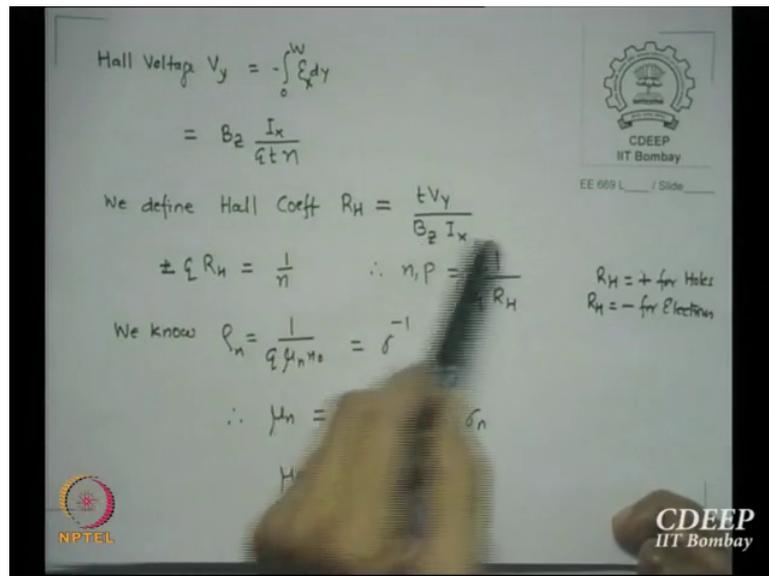
since the electrons can be either this, wherever electrons go, sorry this should be minus plus , so we have a potential difference between, this is 1:05:06.1. This is again Poisson equation. You can find the  $V_y$ .  $V_y$  is the integral  $V_x \cdot dy$ . And you

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calculate all of it, so you get this term  $t V_y$  upon  $B_z I_x$

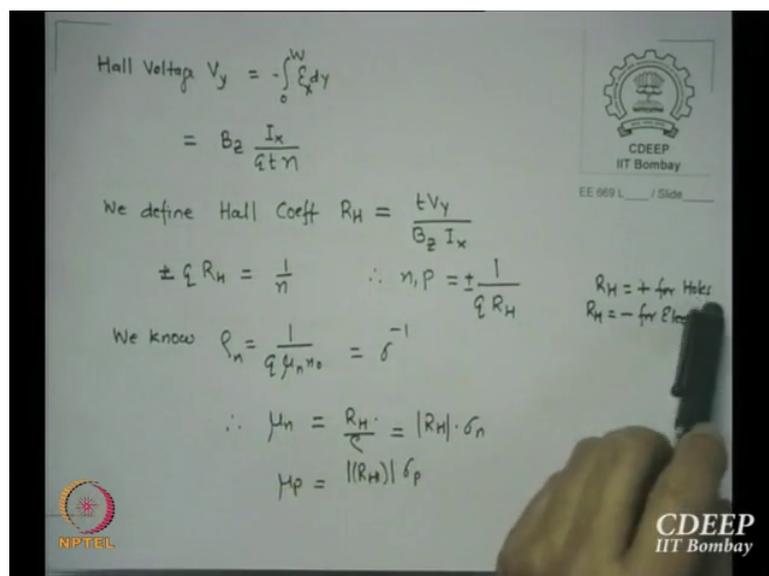
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is called Hall coefficient.

It is known,  $V_y$  is monitored,  $V_z$  and  $I_x$  you have forced, this is a constant current source, so this  $R_H$  is called Hall coefficient, Ok. So if I substitute that here, I get concentration  $n$  or  $p$  is  $1$  upon  $q R_H$  depending on  $V_y$  is plus or  $V_y$  is minus, Ok.  $R_H$  is positive

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for holes, negative for electrons.

Since I know my  $n$  p, 1:05:56.4 this, I use this

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Hall Voltage  $V_y = -\int_0^w E_x dy$   
 $= B_z \frac{I_x}{q t n}$

We define Hall Coeff  $R_H = \frac{t V_y}{B_z I_x}$   
 $\pm q R_H = \frac{1}{n} \quad \therefore n, p = \pm \frac{1}{q R_H}$

We know  $\rho_n = \frac{1}{q \mu_n n_0} = \sigma^{-1}$   
 $\therefore \mu_n = \frac{R_H}{\rho} = |R_H| \cdot \sigma_n$   
 $\mu_p = |R_H| \cdot \sigma_p$

$R_H = +$  for Holes  
 $R_H = -$  for Electrons

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resistivity term  $q \mu_n n_0$  for n type where  $\mu_n$  therefore is corresponding to this  $R_H$  upon  $\rho$ , or  $R_H$  upon  $\sigma$  since  $\sigma$  can be monitored by four probe. Uniform is very easiest to monitor there,  $R_{SL}$  by  $w$ , so I know  $\sigma$ . I have just monitored  $R_H$ . So I know the mobility of electrons or holes.

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So I can get concentrations and I can also get the mobility of carrier. So Hall Effect is very powerful tool. There is a version of Hall; this is called the van der Pauw samples. Those who are in technology company, I will show you what is van der Pauw. Ok.

So these are some measurements. I have left many measurements. There are n number of measurements we can do right now. Let us say there is 1 0 1 1 plane. There is a method called X R D, X ray diffractions, one can find distance between planes, Ok. So I know X R D so I know the planes which I am getting, because  $2 d \sin \theta$  is known to me.

If I want to know the concentration, I have mini ESCA method, SIMS method. I can do many optical spectroscopy techniques. I can do optical techniques, Ok, it measures epsilon; it measures the direct strengths, Ok. So I have many measurements possible, both optical, electrical, non-electrical which F T I R, for example if I want to know whether S i O bond is correct, so I do a F T I R. F T I R is Fourier Transform Infra Red Spectroscopy.

So if I do that I know p H bond has some energy associated. So absorption is maximum there. So if I pass through and see a peak down, I know S i O bond has come. So oxide is there. So there are many techniques and various technology you need to actually ascertain. Then you want to see the material, how it looks, texture as it is called, t ns , you want to monitor areas, you can do S E M, scanning electron microscope.

So if you really go to good V L S I lab, technology lab, there has to be so much analytical instrumentation apart from the standard C V, I V, which all of us have 0:08:23.1, I V and C V that is what we think is end of it. But you are needed to do many, many measurements before you arrive at something tangible, Ok.

So please remember, we all, whenever we make a process we have van der Pauw samples, Hall probe, Hall areas, we have measurement for sheet resistance areas we have many test areas. One chip is dedicated to, 5. 4 corners, 1 center just to monitor the process, Ok. This is the test chip.

Ok so one of the most important thing in designing a process is to design a test area. How do I know what I really do individually? And this is most important in the case of test. So some

of the tests which we do is shown here. These are least complete but I have given how many possibilities.

And if you are

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Example for Two Step Diffusion:

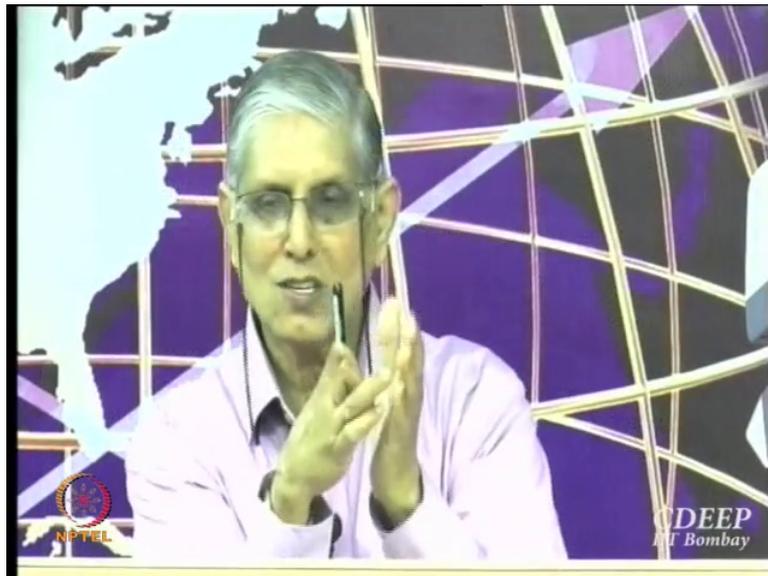
1. P type doping into n-type Silicon
2.  $N_d = 4 \times 10^{16} / \text{cc}$
3. Predeposition:  $T_1 = 950^\circ\text{C}$  for time  $t_1 = 10 \text{ min}$   
From Diffusion Const. - Temp. Graph:  $D_1(950^\circ) \approx 10^{-14} \text{ cm}^2/\text{sec}$   
 $1000/1223^\circ\text{K} = 0.8176$   
 $t_1 = 600 \text{ sec.}$   $\therefore D_1 t_1 = 6 \times 10^{-12} \text{ cm}^2$   
or  $\sqrt{D_1 t_1} = 2.45 \times 10^{-6} \text{ cm.}$

a) Drive-In after Predeposition in  $\text{O}_2$  ambient ( $+\text{N}_2$ )  
for for 60 minutes at  $T_2 = 1100^\circ\text{C} = 1373^\circ\text{K}$   
Hence  $t_2 = 3600 \text{ sec}$  and  $D(T_2) = D_2 = 4 \times 10^{-13} \text{ cm}^2/\text{sec}$   
 $\therefore D_2 t_2 = 1.44 \times 10^{-9} \text{ cm}^2$  or  $\sqrt{D_2 t_2} = 3.79 \times 10^{-5} \text{ cm}$

NPTEL logo is visible in the bottom left corner of the slide. CDEEP IIT Bombay logo is visible in the top right and bottom right corners of the slide.

really going to, someday in TSMC or something, you will never know other technique. You will be in a group. You do only

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simulation. And you will say I am in technology. In TSMC you are in any foundry, you are not allowed to move out of some 10 by 20 feet area. You are cocooned. No one knows what is next door. Ok.

Global Foundry is coming. I think some of you may, of course you are in first year. Second year students may appear.

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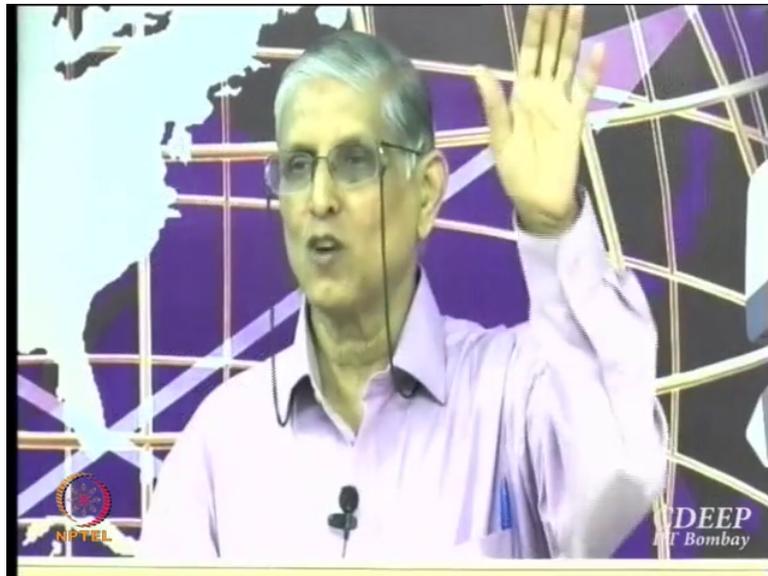
Example for Two Step Diffusion:

1. P type doping into n-type Silicon
2.  $N_d = 4 \times 10^{16} / \text{cc}$
3. Predeposition:  $T_1 = 950^\circ\text{C}$  for time  $t_1 = 10 \text{ min}$   
From Diffusion Const. -Temp. Graph:  $D_1(950) \approx 10^{-14} \text{ cm}^2/\text{sec}$   
 $1000/1223^\circ\text{K} = 0.8176$   
 $t_1 = 600 \text{ sec.}$   $\therefore D_1 t_1 = 6 \times 10^{-12} \text{ cm}^2$   
or  $\sqrt{D_1 t_1} = 2.45 \times 10^{-6} \text{ cm.}$

A Drive-In after Predeposition in  $\text{O}_2$  ambient (+ $\text{N}_2$ ) for for 60 minutes at  $T_2 = 1100^\circ\text{C} = 1373^\circ\text{K}$   
Hence  $t_2 = 3600 \text{ sec}$  and  $D(T_2) = D_2 = 4 \times 10^{-13} \text{ cm}^2/\text{sec}$   
 $\therefore D_2 t_2 = 1.44 \times 10^{-9} \text{ cm}^2$ ,  $\sqrt{D_2 t_2} = 3.79 \times 10^{-5} \text{ cm}$

So most foundries do not allow too much leeway. Only large like us, here also you have many formalities, you cannot interfere, you cannot enter. So you probably do not know what is

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going on in the next room, Ok, unless your friend tells, Ok which he may not nowadays. He will hide it. Why should he come to know?

Ok. Example to solve quickly before we quit for the day. I

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Example for Two Step Diffusion:

1. P type doping into n-type Silicon
2.  $N_d = 4 \times 10^{16} / \text{cc}$
3. Predeposition:  $T_1 = 950^\circ\text{C}$  for time  $t_1 = 10 \text{ min}$   
From Diffusion Const. - Temp. Graph:  $D_1(950) \approx 10^{-14} \text{ cm}^2/\text{sec}$   
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or  $\sqrt{D_1 t_1} = 2.45 \times 10^{-6} \text{ cm.}$

A Drive-In after Predeposition in  $\text{O}_2$  ambient ( $+\text{N}_2$ )  
for for 60 minutes at  $T_2 = 1100^\circ\text{C} = 1373^\circ\text{K}$   
Hence  $t_2 = 3600 \text{ sec}$  and  $D(T_2) = D_2 = 4 \times 10^{-13} \text{ cm}^2/\text{sec}$   
 $\therefore D_2 t_2 = 1.44 \times 10^{-9} \text{ cm}^2$  or  $\sqrt{D_2 t_2} = 3.79 \times 10^{-5} \text{ cm}$

Logos: NPTEL, CDEEP IIT Bombay

actually did a solution for this use of glass, Ok. So I have a p type doping to be done in n type. And I started

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Example for Two Step Diffusion:

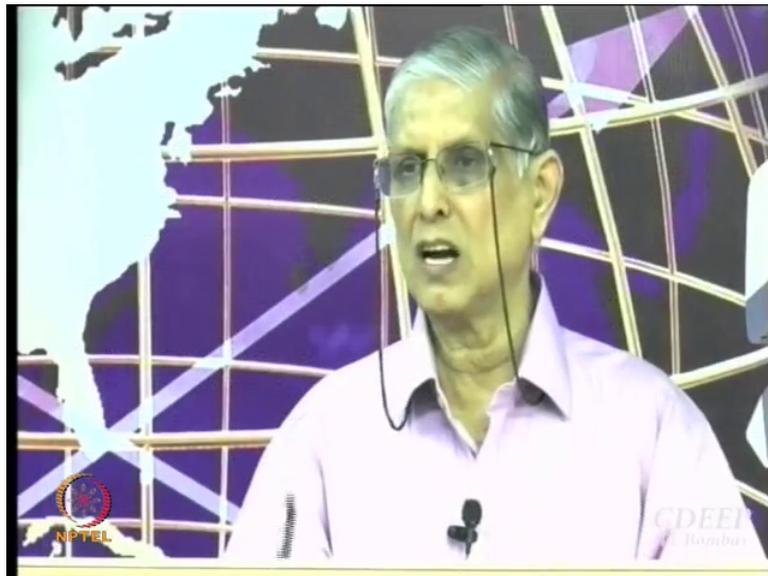
1. P type doping into n-type Silicon
2.  $N_d = 4 \times 10^{16} / \text{cc}$
3. Predeposition:  $T_1 = 950^\circ\text{C}$  for time  $t_1 = 10 \text{ min}$   
From Diffusion Const. - Temp. Graph:  $D_1(950) \approx 10^{-14} \text{ cm}^2/\text{sec}$   
 $1000/1223^\circ\text{K} = 0.8176$   
 $t_1 = 600 \text{ sec.}$   $\therefore D_1 t_1 = 6 \times 10^{-12} \text{ cm}^2$   
or  $\sqrt{D_1 t_1} = 2.45 \times 10^{-6} \text{ cm.}$

A Drive-In after Predeposition in  $\text{O}_2$  ambient ( $+\text{N}_2$ )  
for for 60 minutes at  $T_2 = 1100^\circ\text{C} = 1373^\circ\text{K}$   
Hence  $t_2 = 3600 \text{ sec}$  and  $D(T_2) = D_2 = 4 \times 10^{-13} \text{ cm}^2/\text{sec}$   
 $\therefore D_2 t_2 = 1.44 \times 10^{-9} \text{ cm}^2$  or  $\sqrt{D_2 t_2} = 3.79 \times 10^{-5} \text{ cm}$

Logos: NPTEL, CDEEP IIT Bombay

with n type dopant, n type doper which has 4 into 10 to power 16 as background concentration. I did a predeposition at temperature  $T_1$  of 950 degrees Centigrade. These values are typically for a 5 micron process. They will be

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to scaled down in many ways when I go to a nanometer scales.

Why I use this 5 microns, because this gives number big enough to see something happening.

Ok. And I did predeposition

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Example for Two Step Diffusion:

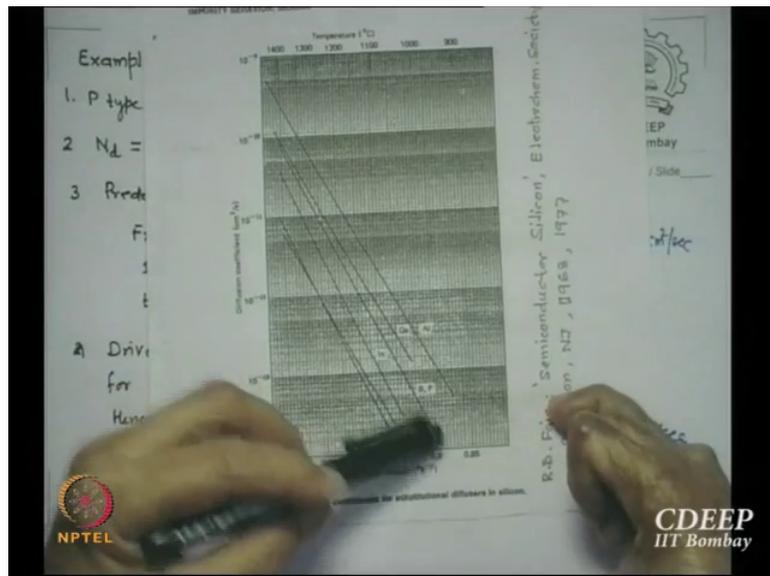
1. P type doping into n-type Silicon
2.  $N_d = 8 \times 10^{16} / \text{cc}$
3. Predeposition:  $T_1 = 950^\circ\text{C}$  for time  $t_1 = 10 \text{ min}$   
From Diffusion Const. -Temp. Graph:  $D_1(950^\circ) \approx 10^{-14} \text{ cm}^2/\text{sec}$   
 $1000/1223^\circ\text{K} = 0.8176$   
 $t_1 = 600 \text{ sec.}$   $\therefore D_1 t_1 = 6 \times 10^{-12} \text{ cm}^2$   
 $\sqrt{D_1 t_1} = 2.45 \times 10^{-6} \text{ cm.}$

A Drive-In after Predeposition in  $\text{O}_2$  ambient ( $+\text{N}_2$ )  
for for 60 minutes at  $T_2 = 1100^\circ\text{C} = 1373^\circ\text{K}$   
Hence  $t_2 = 3600 \text{ sec}$  and  $D(T_2) = D_2 = 4 \times 10^{-13} \text{ cm}^2/\text{sec}$   
 $\therefore D_2 t_2 = 1.44 \times 10^{-9} \text{ cm}^2$   $\sqrt{D_2 t_2} = 3.79 \times 10^{-5} \text{ cm}$

for 10 minutes, Ok. Here you do not write down right now. First I will find out. So I figured out I want to find out D 1 at 950 degrees Centigrade. So



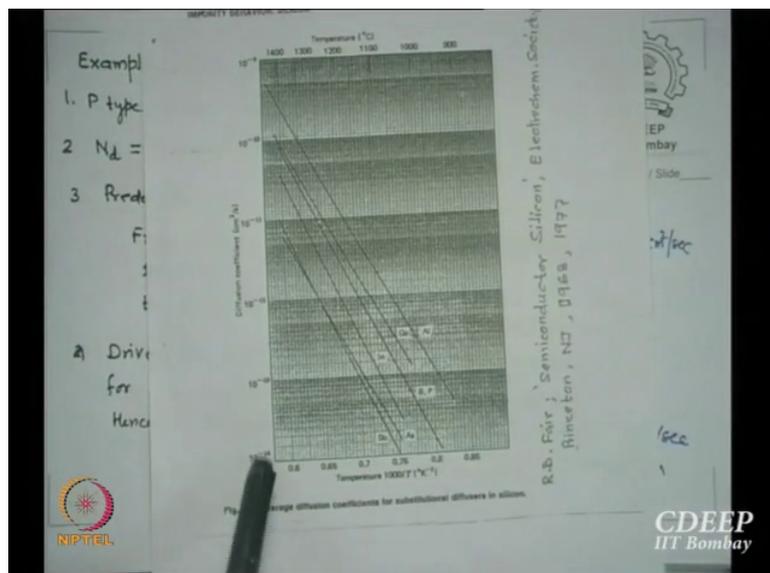
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this line is the line for phosphorus and boron. Any other impurity will have to go for other this...what is they are implanting, what is they are diffusing? Boron in n type wafer.

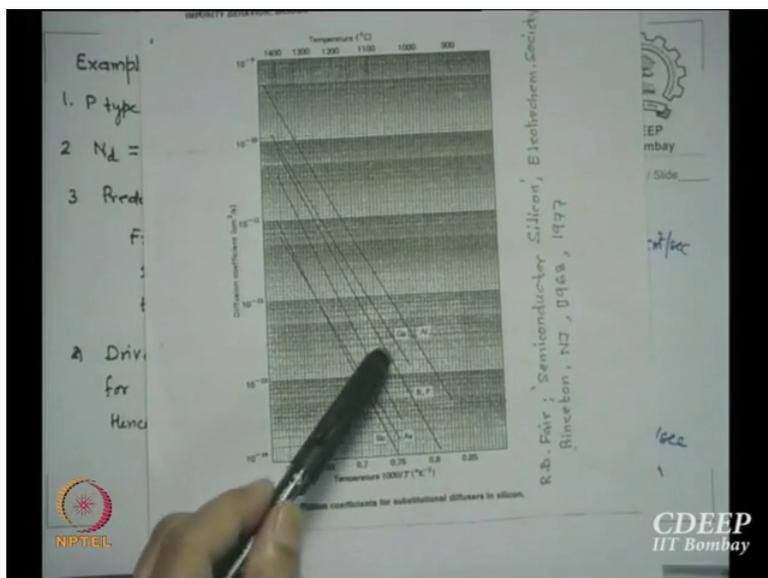
So for this curve, roughly point 2 8 1 5 or whatever it is,

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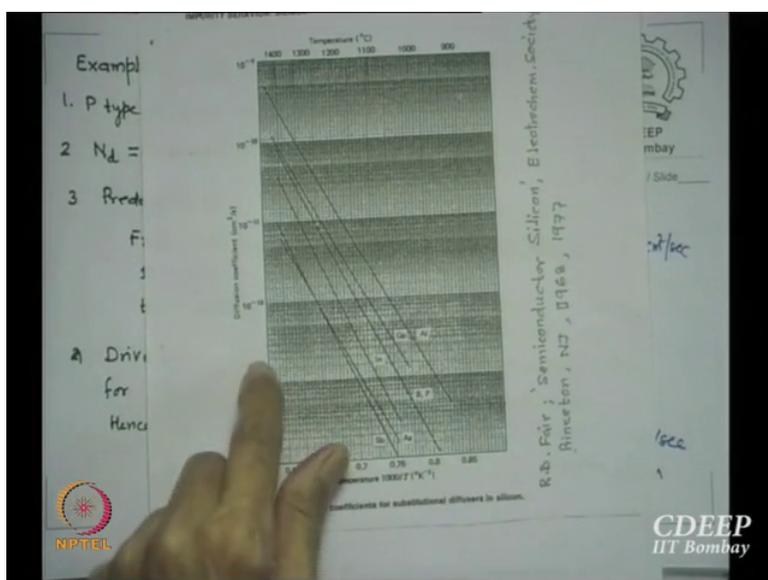
these 10 to power minus 14 centimeter square per second. Is that Ok? Any other value, you will have to go out and monitor, Ok. Is that clear? Any other point 7 5 or point 7 5,

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so this is the value, this will be around 1 point 5 into 10 to the power minus 13. Depends on the ratio. Yeah it will be, this will be 2,

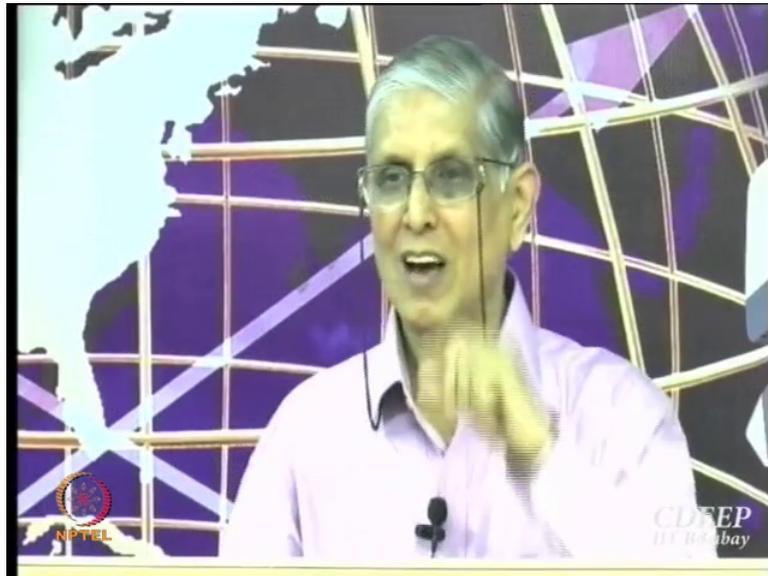
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so it will be slightly less, Ok.

This log in log A; remember each is also a log, log of log. So you will have to also think how far you are

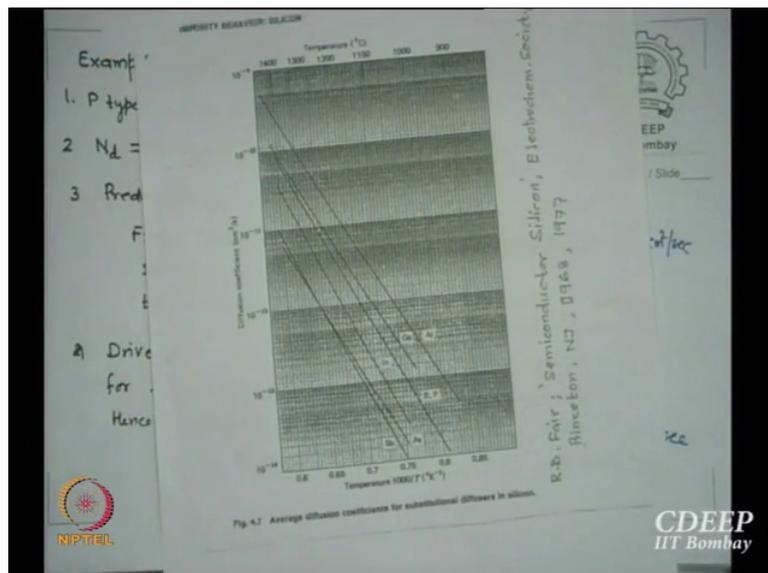
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away. 50 percent point is around point 3, Ok of that. 60 percent is point 4 or point 5. So some guesswork for us, Ok.

So this is the first graph you will use to find out

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what is D 1,

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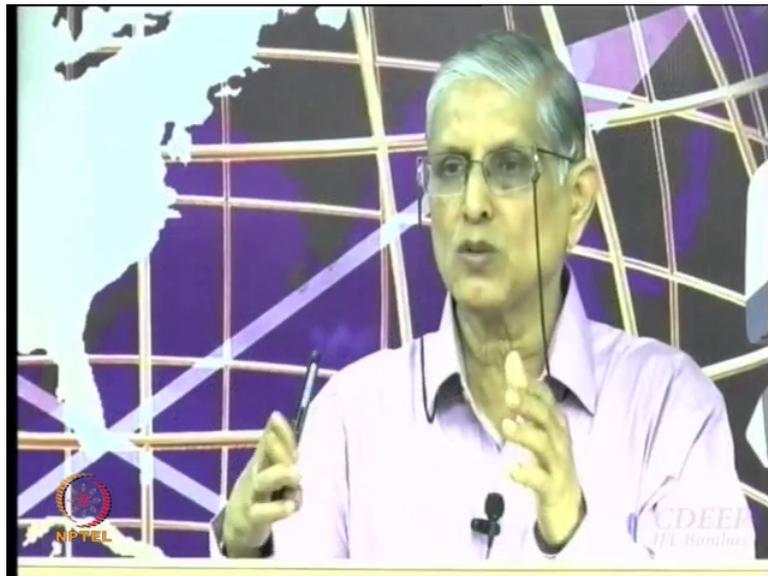
Example for Two Step Diffusion:

1. P type doping into n-type Silicon
2.  $N_d = 4 \times 10^{16} / \text{cc}$
3. Predeposition:  $T_1 = 950^\circ\text{C}$  for time  $t_1 = 10 \text{ min}$   
 From Diffusion Const. - Temp. Graph:  $D_1(950) = 10^{-14} \text{ cm}^2/\text{sec}$   
 $3000/1223\text{K} = 0.8176$   
 $t_1 = 600 \text{ sec.}$   $\therefore D_1 t_1 = 6 \times 10^{-12} \text{ cm}^2$   
 or  $\sqrt{D_1 t_1} = 2.45 \times 10^{-6} \text{ cm.}$
4. Drive-In after Predeposition in  $\text{O}_2$  ambient (+ $\text{N}_2$ )  
 for 60 minutes at  $T_2 = 1100^\circ\text{C} = 1373\text{K}$   
 Hence  $t_2 = 3600 \text{ sec}$  and  $D(T_2) = D_2 = 4 \times 10^{-13} \text{ cm}^2/\text{sec}$   
 $\therefore D_2 t_2 = 1.44 \times 10^{-9} \text{ cm}^2$ ,  $\sqrt{D_2 t_2} = 3.79 \times 10^{-5} \text{ cm}$

so although  $D_1$  is equal to  $10$  to the power minus  $14$ , temperature I fixed but time I said  $10$  minutes which is  $600$  seconds, make it seconds. So  $D_1 t_1$  is  $6$  into  $10$  to power minus  $12$ , or under root  $D_1 t_1$  is  $2.45 \times 10^{-6}$  centimeters. So this is predeposition data.

One more data I missed but I think maybe I will come back to that. Then I did drive-in at, of course as I said, I removed glass and then started drive-in in oxygen. Some nitrogen is also added, Ok and that I did at  $1100$  degrees Centigrade for  $60$  minutes. Drive-in is too big, actually. I am doing too deep junction right now. This number was just

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chosen so that junction depth is big enough, Ok.

So again,

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Example for Two Step Diffusion:

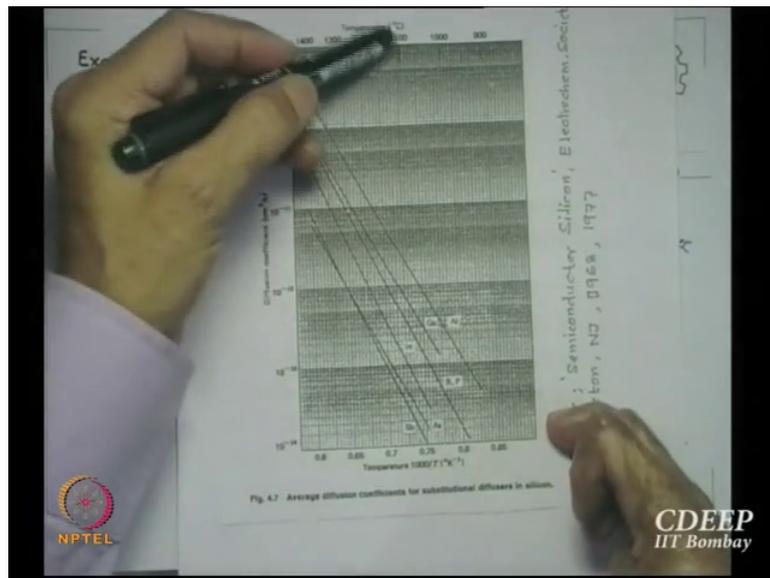
1. P type doping into n-type Silicon
2.  $N_d = 4 \times 10^{16} / \text{cc}$
3. Predeposition:  $T_1 = 950^\circ\text{C}$  for time  $t_1 = 10 \text{ min}$   
From Diffusion const. - Temp. Graph:  $D_1(950^\circ) \approx 10^{-14} \text{ cm}^2/\text{sec}$   
 $1000/1223^\circ\text{K} = 0.8176$   
 $t_1 = 600 \text{ sec.}$   $\therefore D_1 t_1 = 6 \times 10^{-12} \text{ cm}^2$   
or  $\sqrt{D_1 t_1} = 2.45 \times 10^{-6} \text{ cm.}$

a) Drive-In after Predeposition in  $\text{O}_2$  ambient (+ $\text{N}_2$ )  
for for 60 minutes at  $T_2 = 1100^\circ\text{C} = 1373^\circ\text{K}$   
Hence  $t_2 = 3600 \text{ sec}$  and  $D(T_2) = D_2 = 4 \times 10^{-13} \text{ cm}^2/\text{sec}$   
 $\therefore D_2 t_2 = 1.44 \times 10^{-9} \text{ cm}^2$  or  $\sqrt{D_2 t_2} = 3.79 \times 10^{-5} \text{ cm}$

what is the temperature? 1373 degree Kelvin. Ratio of 1000 to 1376 is point 7 or something.

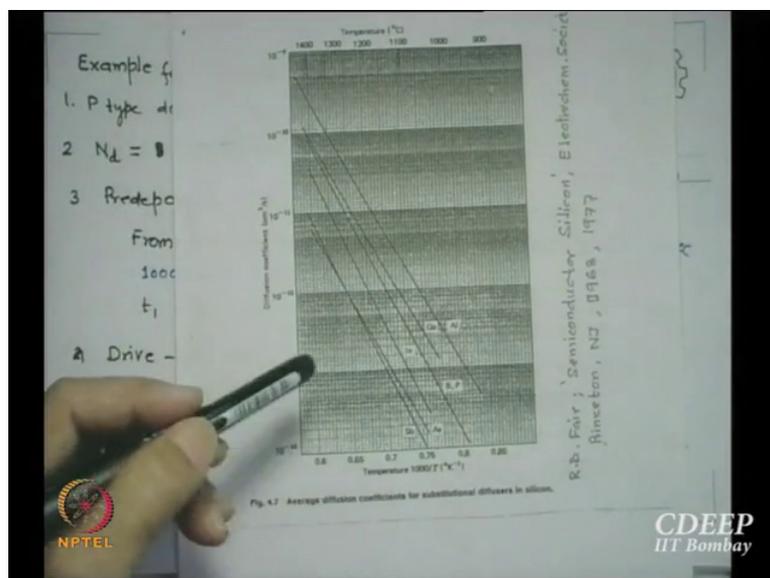
So we go back on the graph again and what we have here is

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1100 degree Centigrade also. So correspondingly you find the D. This is Centigrade. So you can use Centigrade, come to this graph,

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read correctly from the, correctly in the sense nearest to that. You cannot correctly monitor it but roughly close to the value. 1 point 4 and 1 point 5 is Ok. But 2 I am not agreeing because 2 is a larger number there, Ok. Is that Ok?

So given a temperature, I can find diffusion coefficient for any species and particularly from graph, boron or phosphorus. So if I do this,

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Example for Two Step Diffusion:

1. P type doping into n-type Silicon
2.  $N_d = 4 \times 10^{16} / \text{cc}$
3. Predeposition:  $T_1 = 950^\circ\text{C}$  for time  $t_1 = 1 \text{ min}$   
 From Diffusion Const. - Temp. Graph:  $D_1(950^\circ) \approx 10^{-14} \text{ cm}^2/\text{sec}$   
 $1000/1223^\circ\text{K} = 0.8176$   
 $t_1 = 600 \text{ sec.}$   
 $\therefore D_1 t_1 = 6 \times 10^{-12} \text{ cm}^2$   
 $\text{or } \sqrt{D_1 t_1} = 2.45 \times 10^{-6} \text{ cm.}$

A Drive-In after Predeposition in  $\text{O}_2$  ambient ( $+\text{N}_2$ )  
 for for 60 minutes at  $T_2 = 1100^\circ\text{C} = 1373^\circ\text{K}$   
 Hence  $t_2 = 3600 \text{ sec}$  and  $D(T_2) = D_2 = 4 \times 10^{-13} \text{ cm}^2/\text{sec}$   
 $\therefore D_2 t_2 = 1.44 \times 10^{-9} \text{ cm}^2$ ,  $\sqrt{D_2 t_2} = 3.79 \times 10^{-5} \text{ cm}$

Logos: NPTEL, CDEEP IIT Bombay

I get  $D_2 t_2$  is  $4 \times 10^{-13}$  centimeter square per second.  $t_2$  is 3600 seconds.

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Example for Two Step Diffusion:

1. P type doping into n-type Silicon
2.  $N_d = 4 \times 10^{16} / \text{cc}$
3. Predeposition:  $T_1 = 950^\circ\text{C}$  for time  $t_1 = 1 \text{ min}$   
 From Diffusion Const. - Temp. Graph:  $D_1(950^\circ) \approx 10^{-14} \text{ cm}^2/\text{sec}$   
 $1000/1223^\circ\text{K} = 0.8176$   
 $t_1 = 600 \text{ sec.}$   
 $\therefore D_1 t_1 = 6 \times 10^{-12} \text{ cm}^2$   
 $\text{or } \sqrt{D_1 t_1} = 2.45 \times 10^{-6} \text{ cm.}$

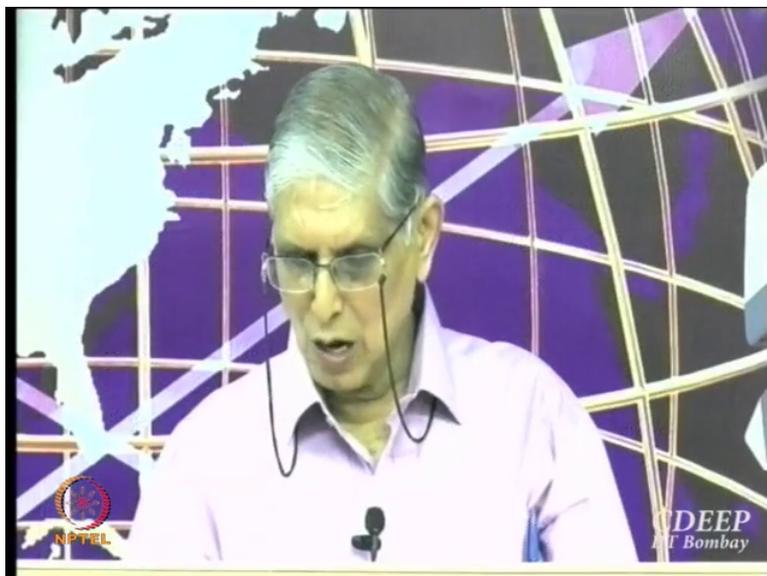
A Drive-In after Predeposition in  $\text{O}_2$  ambient ( $+\text{N}_2$ )  
 for for 60 minutes at  $T_2 = 1100^\circ\text{C} = 1373^\circ\text{K}$   
 Hence  $t_2 = 3600 \text{ sec}$  and  $D(T_2) = D_2 = 4 \times 10^{-13} \text{ cm}^2/\text{sec}$   
 $\therefore D_2 t_2 = 1.44 \times 10^{-9} \text{ cm}^2$ ,  $\sqrt{D_2 t_2} = 3.79 \times 10^{-5} \text{ cm}$

Logos: NPTEL, CDEEP IIT Bombay

Then it is how much? 60 minutes, so 3600 seconds. So  $D_2 t_2$  is product of these two which is  $1.44 \times 10^{-9}$  centimeter square. Or  $\sqrt{D_2 t_2}$  is  $3.79 \times 10^{-5}$  centimeters.

So I know under root  $D_1 t_1$ , I know under root  $D_2 t_2$ .

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I also want to know No 1,

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Example for Two Step Diffusion:

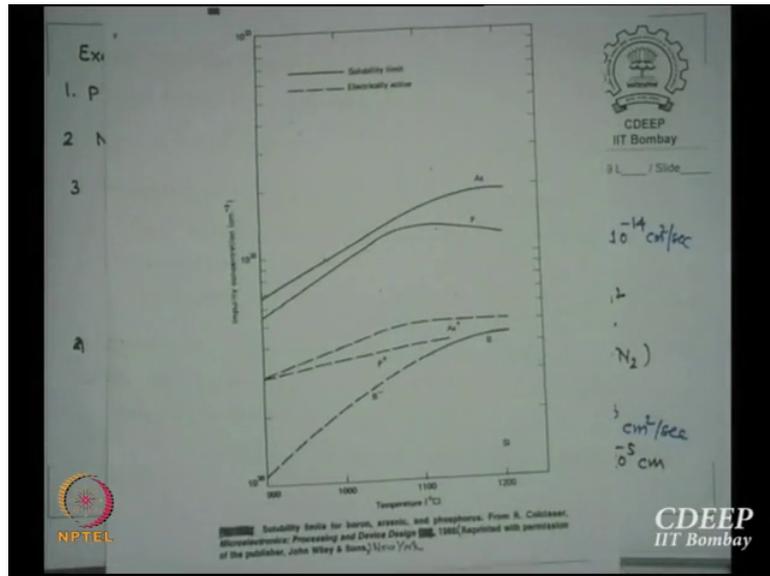
1. P type doping into n-type Silicon
2.  $N_d = 4 \times 10^{16} / \text{cc}$
3. Predeposition:  $T_1 = 950^\circ\text{C}$  for time  $t_1 = 60 \text{ min}$   
From Diffusion Const. - Temp. Graph:  $D_1(950^\circ) \cong 10^{-14} \text{ cm}^2/\text{sec}$   
 $1000/1223^\circ\text{K} = 0.8176$   
 $t_1 = 3600 \text{ sec.}$   
 $\therefore D_1 t_1 = 6 \times 10^{-12} \text{ cm}^2$   
 $\text{or } \sqrt{D_1 t_1} = 2.45 \times 10^{-6} \text{ cm.}$

A Drive-In after Predeposition in  $\text{O}_2$  ambient ( $+\text{N}_2$ )  
for for 60 minutes at  $T_2 = 1100^\circ\text{C} = 1373^\circ\text{K}$   
Hence  $t_2 = 3600 \text{ sec}$  and  $D(T_2) = D_2 = 4 \times 10^{-13} \text{ cm}^2/\text{sec}$   
 $\therefore D_2 t_2 = 1.44 \times 10^{-9} \text{ cm}^2$ ,  $\sqrt{D_2 t_2} = 3.79 \times 10^{-5} \text{ cm}$

Logos for NPTEL and CDEEP IIT Bombay are present in the bottom corners of the slide.

I also want to know No 1, that is for predeposition temperature 900,

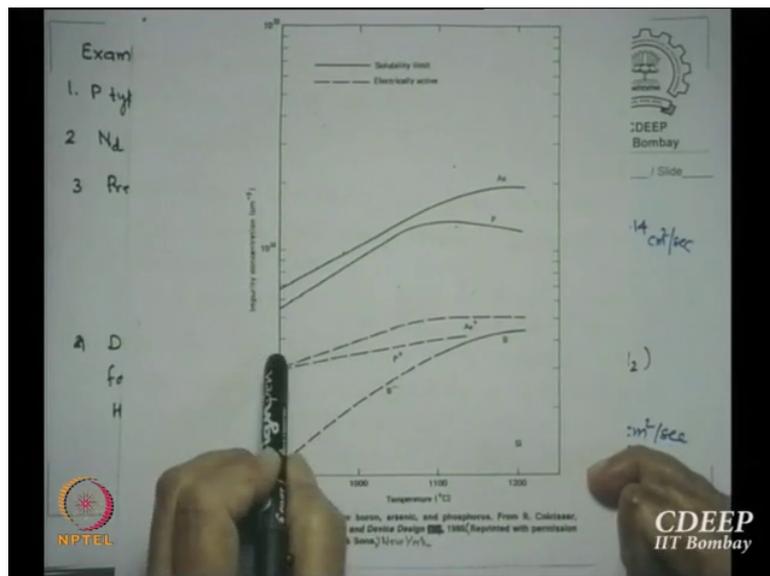
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Ok, 950. This is linear scale. Please remember lower scale is linear. And this is log scale. So 950 is somewhere here. Which species, which graph I should use, this one or this one? Lower one, active concentrations.

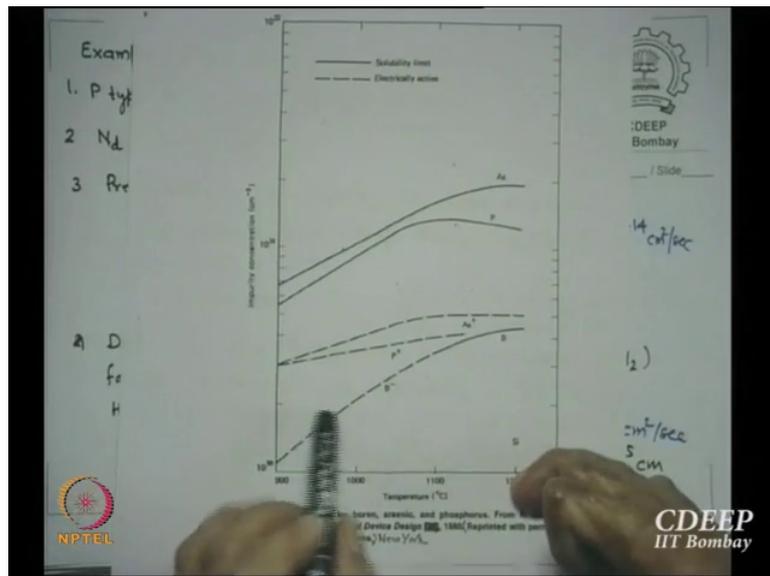
So for phosphorus at 950, roughly we read from here, 950

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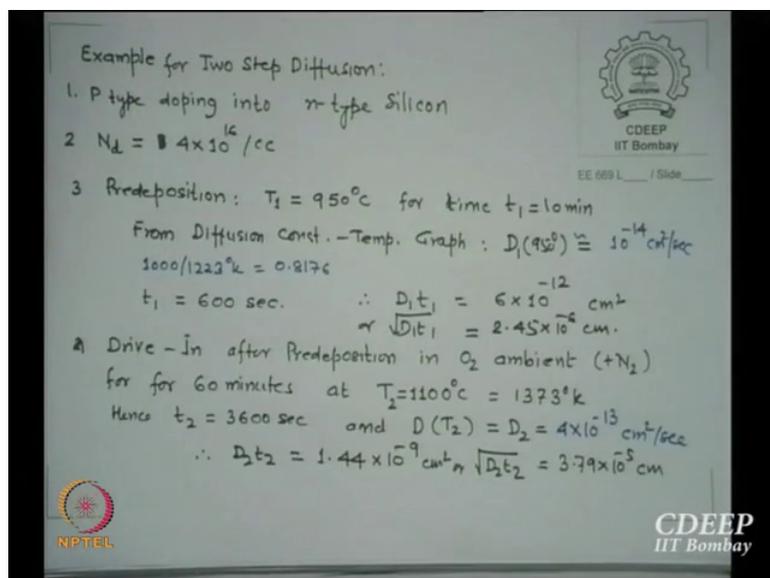
this value, Ok. Now for the...sorry, sorry, thank you. So for boron may be I might have taken then wrong number. So just check it correctly.

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So you think it is p n junction, instead of n p Ok. Ok. So might be I did mischief, may be, but Ok. You read this.

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So here I think I did correctly.

So

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5. During Predeposition, Temperature was  $950^{\circ}\text{C}$ .  
The active Solid Solubility  $N_{o1} = 3 \times 10^{20}/\text{cc}$   
for Phosphorus.

6. Evaluate  $R_s$  value.

7. From  $R_s x_j - N_{\text{surf}}$  graph for  $N_B = 4 \times 10^{16}/\text{cc}$ ,  
and for Gaussian Profile, we can get  $R_s x_j$  if  
 $N_{\text{surf}}$  is known. If we also know  $x_j$ , then we  
know  $R_s$ .

8. For 2-step Diffusion

$$N(x, t_1, t_2) = \frac{2N_{o1}}{\pi} \sqrt{\frac{D_1 t_1}{D_2 t_2}} \exp\left[-\frac{x^2}{4D_2 t_2}\right]$$
$$= N_{\text{surf}} \exp\left[-\frac{x^2}{4D_2 t_2}\right]$$

I get at 950 degree boron has, sorry, for boron, roughly it is Ok, not very wrong.

(Refer Slide Time:01:16:27)

5. During Predeposition, Temperature was  $950^{\circ}\text{C}$ .  
The active Solid Solubility  $N_{o1} = 3 \times 10^{20}/\text{cc}$   
for Phosphorus. Boron

6. Evaluate  $R_s$  value.

7. From  $R_s x_j - N_{\text{surf}}$  graph for  $N_B = 4 \times 10^{16}/\text{cc}$ ,  
and for Gaussian Profile, we can get  $R_s x_j$  if  
 $N_{\text{surf}}$  is known. If we also know  $x_j$ , then we  
know  $R_s$ .

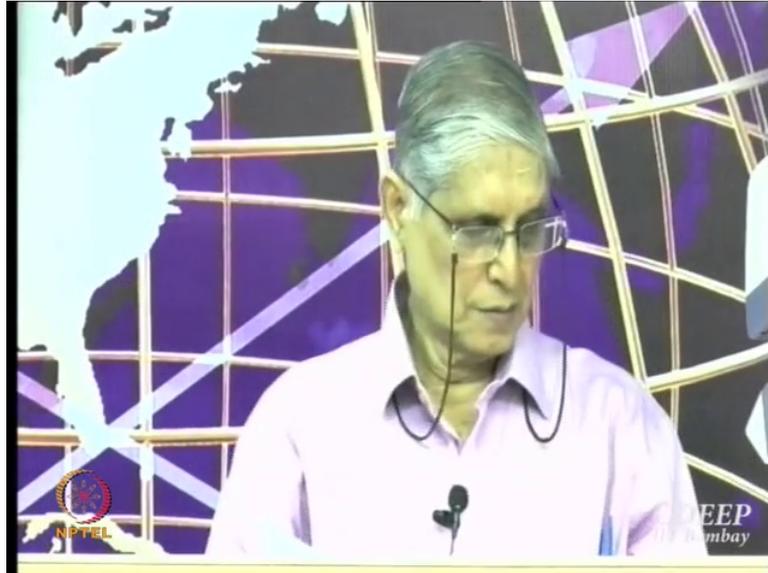
8. For 2-step Diffusion

$$N(x, t_1, t_2) = \frac{2N_{o1}}{\pi} \sqrt{\frac{D_1 t_1}{D_2 t_2}} \exp\left[-\frac{x^2}{4D_2 t_2}\right]$$
$$= N_{\text{surf}} \exp\left[-\frac{x^2}{4D_2 t_2}\right]$$

Actually I took boron data but wrote phosphorus. So we have started with  $N_{o1}$ , so this 3 into 10 to power 20 per c c is your surface concentration of this, yeah surface concentration in solid it is same. Now I want to evaluate  $R_s$ .

From  $R_s \times j$  graph, Ok, I have done Gaussian profile two step diffusion. Ok, I have 4 graphs. Ok but all these graphs are now all loaded on the site. You can choose this. Please download and get its prints.

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This is a two step diffusion

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5. During Predeposition, Temperature was  $950^\circ\text{C}$   
 The active Solid Solubility  $N_0 = 3 \times 10^{20}/\text{cc}$   
 for Amorphous Boron

6. Evaluate  $R_s$  value.

7. From  $R_s \times j$  - Surface graph for  $N_B = 4 \times 10^{16}/\text{cc}$ ,  
 and for Gaussian Profile, we can get  $R_s \times j$  if  
 Surf. is known. If we also know  $x_j$ , then we  
 know  $R_s$ .

8. For 2-step Diffusion

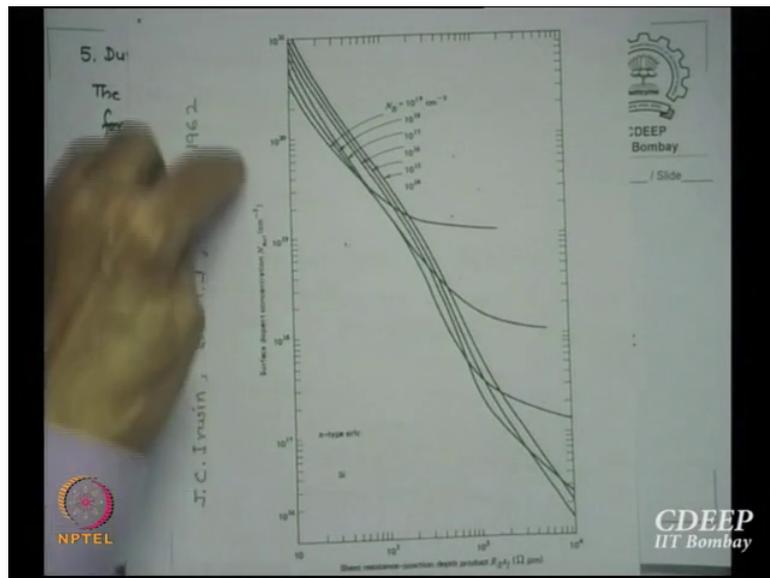
$$N(x, t_1, t_2) = \frac{2N_0}{\pi} \sqrt{\frac{D_1 t_1}{D_2 t_2}} \exp\left[-\frac{x^2}{4D_2 t_2}\right]$$

$$= N_{\text{surf}} \exp\left[-\frac{x^2}{4D_2 t_2}\right]$$

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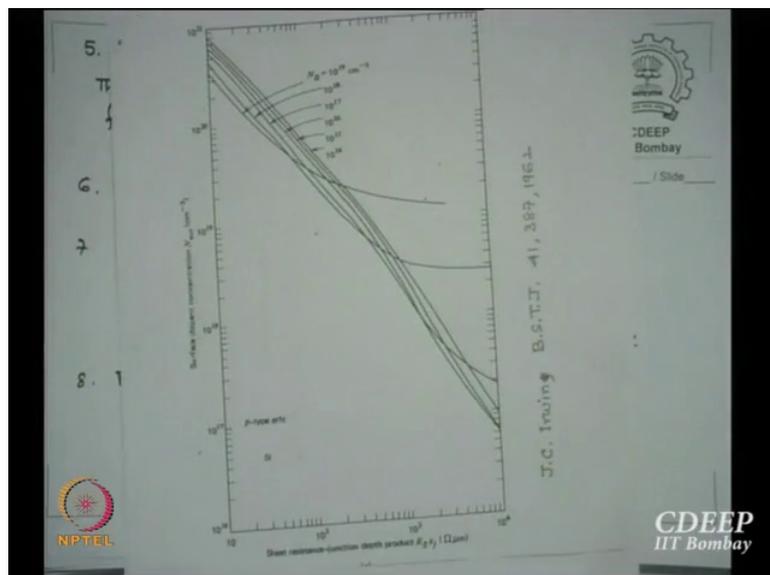
profile. These are 4 graphs I may show you. This is for entire complementary error function. I am plotting surface

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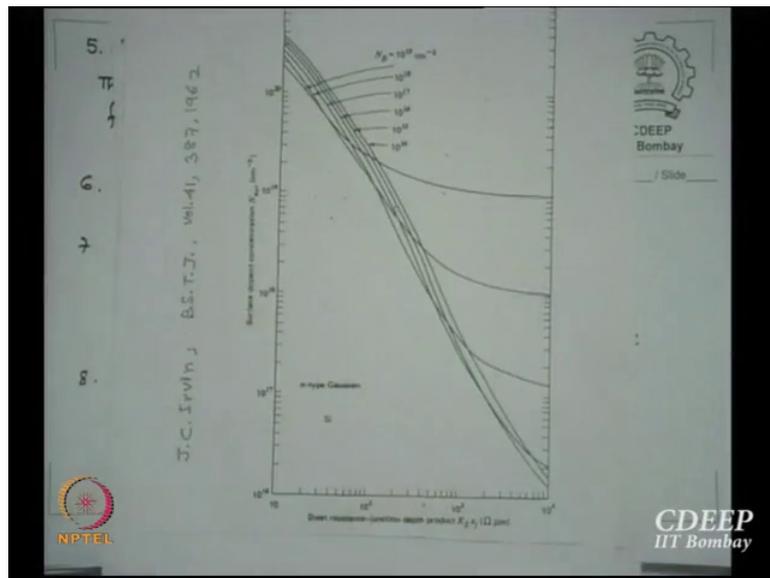
concentration versus  $R_s \times j$  at different  $N_B$ . This is for p type error function;

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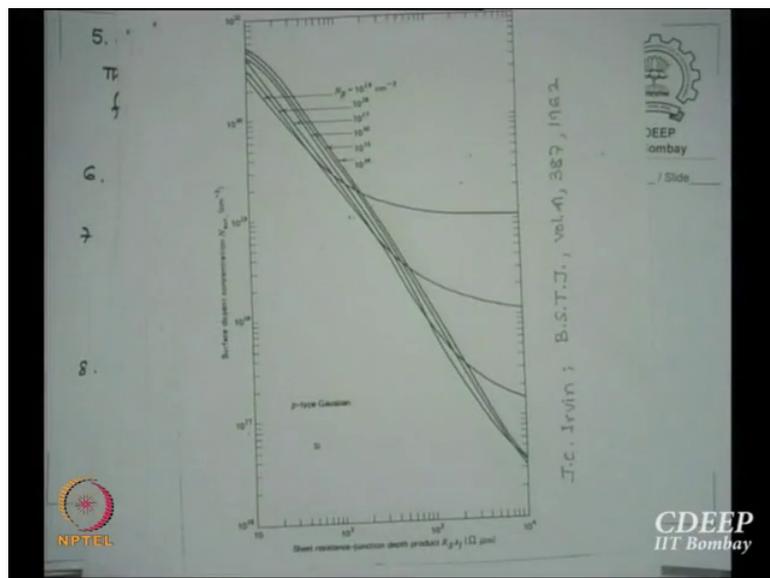
this is n type Gaussian,

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and this p type Gaussian.

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So whichever is the this, you should correspondingly choose the graph.

So in our case it is p type Gaussian which we have to use. So what we do is,

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5. During Predeposition, Temperature was  $950^{\circ}\text{C}$   
 The active Solid Solubility  $N_{01} = 3 \times 10^{20}/\text{cc}$   
 for Phosphorus. Boron

6. Evaluate  $R_s$  value.

7. From  $R_s x_j$  - Neufouca graph for  $N_B = 4 \times 10^{16}/\text{cc}$ ,  
 and for Gaussian Profile, we can get  $R_s x_j$  if  
 Neuf. is known. If we also know  $x_j$ , then we  
 know  $R_s$ .

8. For 2-step Diffusion

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

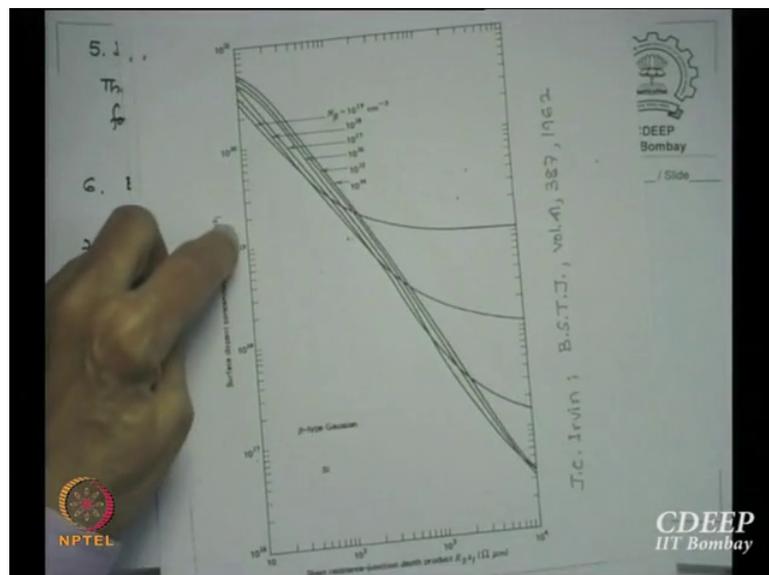
$$= N_{01} \exp\left[-\frac{x^2}{4D_2 t_2}\right]$$


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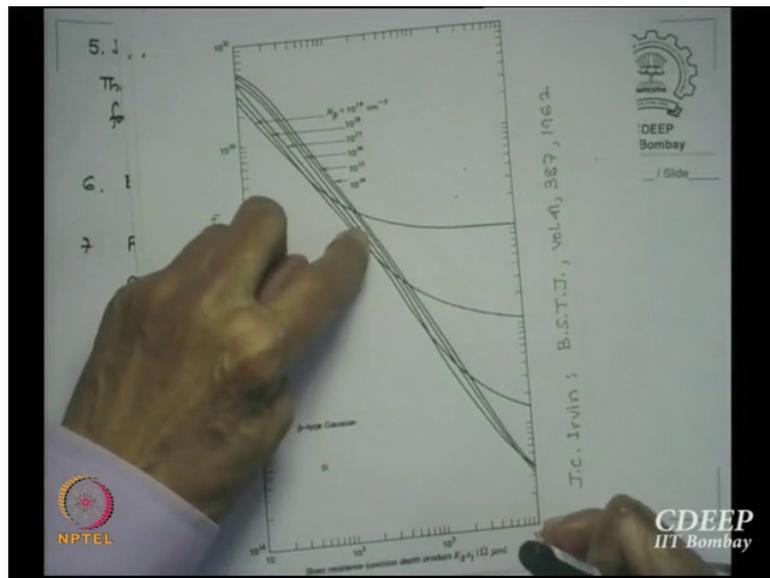

just I will come back, to get  $R_s$  first I should know  $N_s$ . From this graph if I know  $N_s$ ,

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for given  $N_B$ ,

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what can I calculate?  $R_s \times x_j$ , is that correct? For given  $N_s$ , how come, how will I get  $N_s$ ?  $2 N_0$  by  $\pi$  root

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5. During Predeposition, Temperature was  $950^\circ\text{C}$ .  
The active Solid Solubility  $N_0 = 3 \times 10^{20} / \text{cc}$   
for Phosphorus. Boron

6. Evaluate  $R_s$  value.

7. From  $R_s x_j - N_{\text{surf}}$  graph for  $N_B = 4 \times 10^{16} / \text{cc}$ ,  
and for Gaussian Profile, we can get  $R_s x_j$  if  
 $N_{\text{surf}}$  is known. If we also know  $x_j$ , then we  
know  $R_s$ .

8. For 2-step Diffusion

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

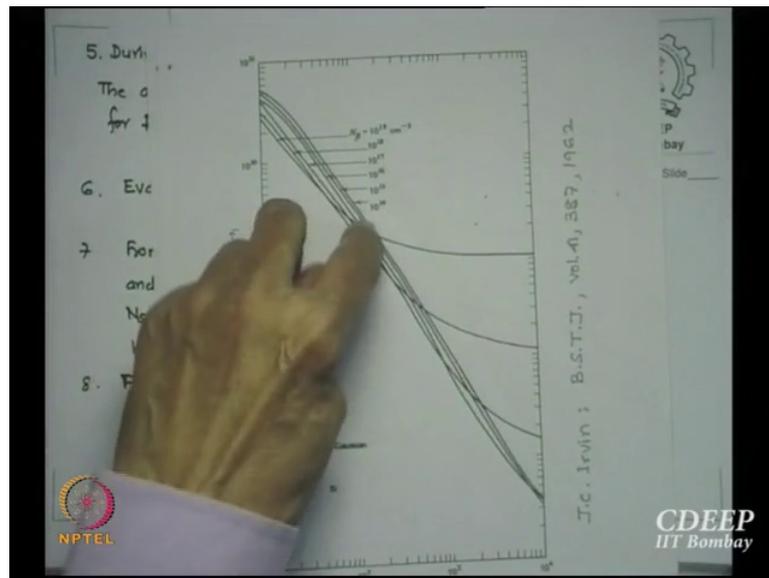
$$= N_{\text{surf}} \exp\left[-\frac{x^2}{4D_2 t_2}\right]$$

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$D_1 t_1$  upon  $D_2 t_2$  is surface concentration for Gaussian. So I know that value.

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For this I calculate  $R_s x_j$ . Is that clear?

So once I get  $R_s x_j$  value from this graph,

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then I can calculate

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$$\therefore N_{surf} = \frac{2N_0l}{\pi} \sqrt{\frac{D_1 t_1}{D_2 t_2}}$$

$$= \frac{2 \times 3 \times 10^{20}}{3.14} \sqrt{\frac{4 \times 10^{-12}}{1.44 \times 10^9}}$$

$$= \frac{6 \times 10^{20}}{3.14} \cdot \frac{2.45 \times 10^{-6}}{3.79 \times 10^5} = 1.24 \times 10^{19} / cc$$

9. Further  $x_j = 2 \sqrt{D_2 t_2} \left[ \ln \frac{N_{surf}}{N_B} \right]^{1/2}$   

$$= 2 \times 3.79 \times 10^{-5} \left[ \ln \frac{1.24 \times 10^{19}}{4 \times 10^{16}} \right]$$
  

$$\approx 2 \times 3.79 \times 10^{-5} \times 5.74$$
  

$$= 4.35 \mu m.$$

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x j. How I calculate x j?  $2 \sqrt{D_2 t_2} \ln \frac{N_{surf}}{N_B}$  upon n p to the power half. This is the Gaussian profile at x is equal to x j. N is N b. So I solve this and I get x j of 4 point 3 5 microns. Is that clear?

Previous slide, Ok. Sorry. No, no, no. So R S

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5. During Predeposition, Temperature was  $950^\circ C$   
 The active Solid Solubility  $N_0 = 3 \times 10^{20} / cc$   
 for Phosphorus. Boron

6. Evaluate  $R_s$  value.

From  $R_s x_j - N_{surf}$  graph for  $N_B = 4 \times 10^{16} / cc$ ,  
 and for Gaussian Profile, we can get  $R_s x_j$  if  
 $N_{surf}$  is known. If we also know  $x_j$ , then we  
 know  $R_s$ .

8. For 2-step Diffusion

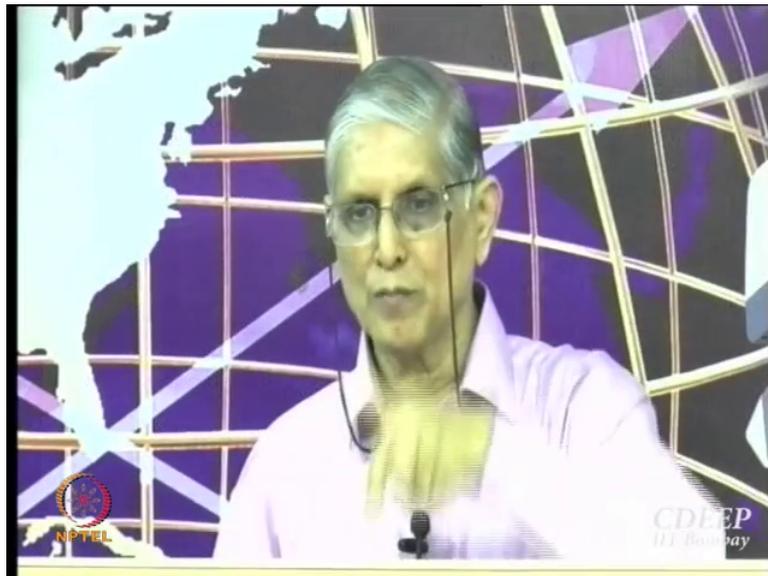
$$N(x, t_1, t_2) = \frac{2N_0l}{\pi} \sqrt{\frac{D_1 t_1}{D_2 t_2}} \exp\left[-\frac{x^2}{4D_2 t_2}\right]$$

$$= N_{surf} \exp\left[-\frac{x^2}{4D_2 t_2}\right]$$

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x j I will monitor from that graph because N Surface I know, N B I know

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so from Gaussian profile for p type I know how much is  $R S \times j$ . And what is the unit? Ohm microns. Please remember. Is that Ok?

From the graph what will monitor surface concentration known, for given  $N B$  you can figure out  $R S \times j$ . That value we have noted down from the graph, Ok. Now question was asked earlier by many, that Sir if so much simulation is possible, Sentaraus does so well? No. Whether Sentaraus does correct or not, who will know? Because program is only a program, Ok.

So this is called analytical starting point. We know where we are. So verify we are right. These days you do not have to do everything is not correct. You cannot do 100 percent on system, Ok. You have to know what system is doing. Even that you do not know, you just run programs. So there also you do not know what models they have used, Ok. Is that Ok?

So let me write, two slides I will show. Is that Ok? So I know this profile. So

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5. During Annealposition, Temperature was  $950^{\circ}\text{C}$   
 The active Solid Solubility  $N_0 = 3 \times 10^{20} / \text{cc}$   
 for theophenous. Boron

6. Evaluate  $R_s$  value.

7. From  $R_s x_j - N_{\text{surf}}$  graph for  $N_B = 4 \times 10^{16} / \text{cc}$ ,  
 and for Gaussian Profile, we can get  $R_s x_j$  if  
 $N_{\text{surf}}$  is known. If we also know  $x_j$ , then we  
 know  $R_s$ .

8. For 2-step Diffusion

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

$$= N_{\text{surf}} \exp\left[-\frac{x^2}{4D_2 t_2}\right]$$

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this is my surface concentration. So I can get  $R_s x_j$ . Is that Ok, all of you? So I calculate

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$$\therefore N_{\text{surf}} = \frac{2N_0}{\pi} \sqrt{\frac{D_1 t_1}{D_2 t_2}}$$

$$= \frac{2 \times 3 \times 10^{20}}{3.14} \sqrt{\frac{6 \times 10^{-12}}{1.44 \times 10^{-9}}}$$

$$= \frac{6 \times 10^{20}}{3.14} \cdot \frac{2.45 \times 10^{-6}}{3.79 \times 10^5} = 1.24 \times 10^{19} / \text{cc}$$

9. Further  $x_j = 2 \sqrt{D_2 t_2} \left[ \ln \frac{N_{\text{surf}}}{N_B} \right]^{1/2}$

$$= 2 \times 3.79 \times 10^{-5} \left[ \ln \frac{1.24 \times 10^{19}}{4 \times 10^{16}} \right]$$

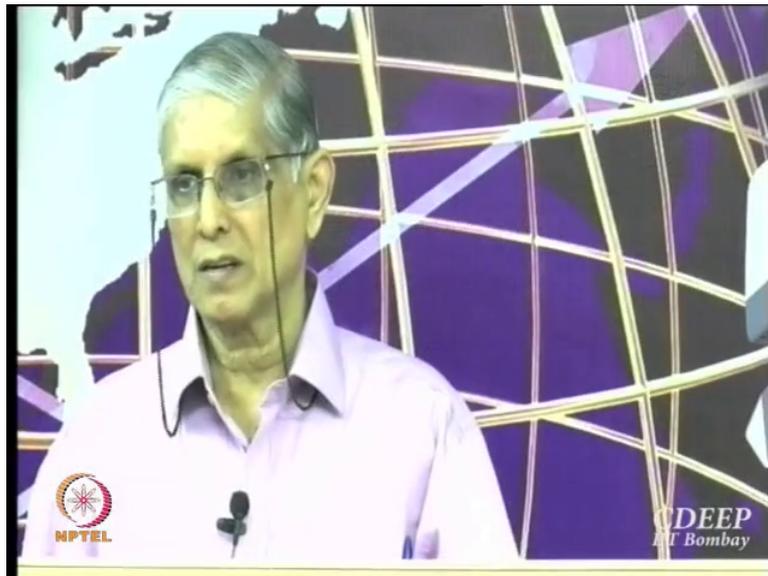
$$\approx 2 \times 3.79 \times 10^{-5} \times 5.74$$

$$= 35 \mu\text{m}$$

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$x_j$  from  $2 \sqrt{D_2 t_2} \ln \frac{N_{\text{surf}}}{N_B}$  all this. I know all the values. So I get 4 point 3 5 as my junction depth, and I also have evaluated  $R_s x_j$  from the graph for given  $N_{\text{Surface}}$  and  $N_B$ .

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Is that clear?

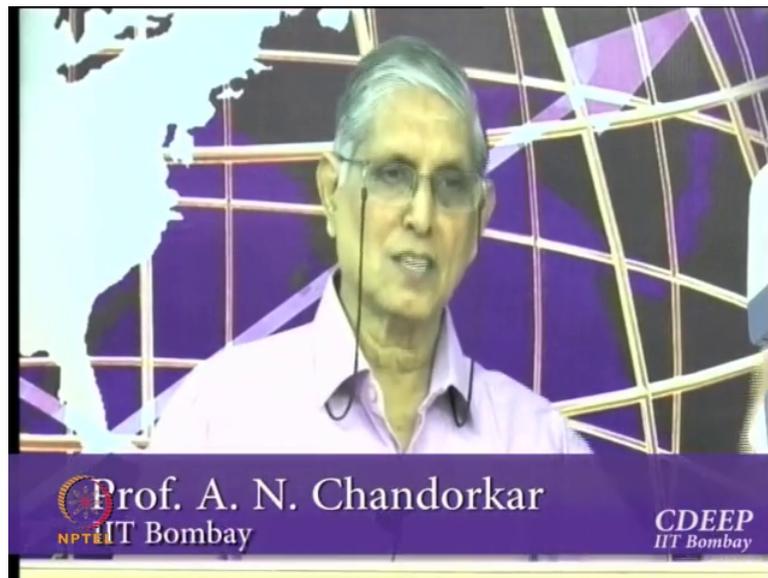
So what is to be found out now?  $R_s$ .  $R_s x_j$  is known,  $x_j$  is known, so  $R_s$  is known. Just note down. I will show you the final answer.

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$$\begin{aligned} \therefore N_{surf} &= \frac{2N_0l}{\pi} \sqrt{\frac{D_1t_1}{D_2t_2}} \\ &= \frac{2 \times 3 \times 10^{20}}{3.14} \sqrt{\frac{6 \times 10^{-12}}{1.44 \times 10^9}} \\ &= \frac{6 \times 10^{20}}{3.14} \cdot \frac{2.45 \times 10^{-6}}{3.79 \times 10^5} = 1.24 \times 10^{19} / \text{cc} \end{aligned}$$
$$\begin{aligned} \text{f. Further } x_j &= 2 \sqrt{D_2 t_2} \left[ \ln \frac{N_{surf}}{N_0} \right]^{1/2} \\ &= 2 \times 3.79 \times 10^{-5} \left[ \ln \frac{1.24 \times 10^{19}}{4 \times 10^{16}} \right] \\ &\approx 2 \times 3.79 \times 10^{-5} \times 5.74 \\ &= 4.35 \mu\text{m} \end{aligned}$$

So all of you will bring these sheets during exam, whatever, so till mid sem if I finish oxidation so bring oxidation

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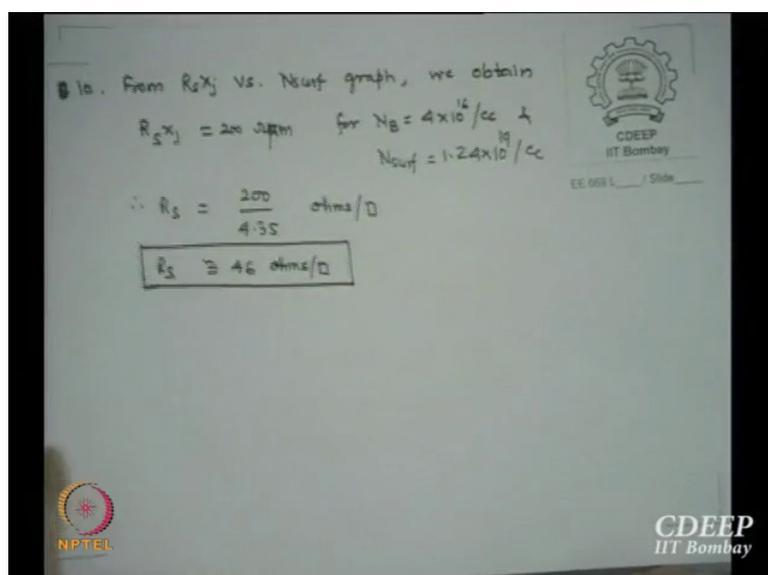


also. If I do not, then bring only diffusion. If I finish implant then you also bring implant profiles.

So all this data is already created. From various papers I have copied. These are available on our course website. Please download and print. I am not going to supply you any of these sheets. I have forgotten so be forgotten. That is it, Ok. Is that Ok?

So since  $R_s \times j$  was found as 200 ohm microns

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from the graph, for this 4 into 10 to power 16 and surface concentration of 1 point 2 into 19 per c c. R S is 2 upon 4, just now you said yes, after that only...

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$$\therefore N_{surf} = \frac{2N_0}{\pi} \sqrt{\frac{D_1 t_1}{D_2 t_2}}$$

$$= \frac{2 \times 3 \times 10^{20}}{3.14} \sqrt{\frac{6 \times 10^{-12}}{1.44 \times 10^{-9}}}$$

$$= \frac{6 \times 10^{20}}{3.14} \cdot \frac{2.45 \times 10^{-6}}{3.79 \times 10^5} = 1.24 \times 10^{19} / cc$$

9. Further  $x_j = 2 \sqrt{D_2 t_2} \left[ \ln \frac{N_{surf}}{N_0} \right]^{1/2}$   

$$= 2 \times 3.79 \times 10^{-5} \left[ \ln \frac{1.24 \times 10^{19}}{4 \times 10^{16}} \right]$$
  

$$\approx 2 \times 3.79 \times 10^{-5} \times 5.74$$
  

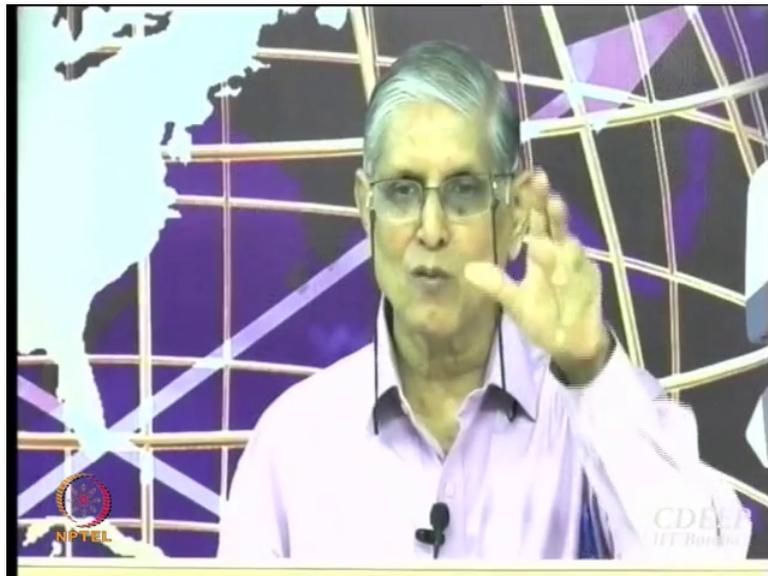
$$= 4.35 \mu m.$$

Logos: NPTEL (bottom left), CDEEP IIT Bombay (top right and bottom right). Slide number: EE 569 L / Slide.

After this you write this directly. You do the substitution. So I am doing it because I am first time doing it. So I will have to go through steps. You can directly write the solution.

I also write steps because from there roughly I know I am right in calculations or not, that is all. I can directly one time substitute, I never do that. If you have seen I put steps. The reason is obvious. That at least mistake in one

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I can figure out, the rest is correct. Otherwise we do not know which place it went wrong, Ok. Some system you should create, Ok. Is that Ok?

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$$\begin{aligned} \therefore N_{surf} &= \frac{2N_0 l}{\pi} \sqrt{\frac{D_1 t_1}{D_2 t_2}} \\ &= \frac{2 \times 3 \times 10^{20}}{3.14} \sqrt{\frac{6 \times 10^{-12}}{1.44 \times 10^9}} \\ &= \frac{6 \times 10^{20}}{3.14} \cdot \frac{2.45 \times 10^{-6}}{3.79 \times 10^5} = 1.24 \times 10^{19} / \text{cc} \end{aligned}$$

∴ Further  $x_j = 2 \sqrt{D_2 t_2} \left[ \ln \frac{N_{surf}}{N_0} \right]^{1/2}$

$$\begin{aligned} &= 2 \times 3.79 \times 10^{-5} \left[ \ln \frac{1.24 \times 10^{19}}{9 \times 10^{14}} \right] \\ &\approx 2 \times 3.79 \times 10^{-5} \times 5.74 \\ &= 4.35 \mu\text{m}. \end{aligned}$$

4 point 3 5.

So R S x j

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Q 10. From  $R_s \times j$  vs.  $N_{surf}$  graph, we obtain  
 $R_s \times j = 200 \mu\Omega\text{m}$  for  $N_B = 4 \times 10^{16}/\text{cc}$  &  
 $N_{surf} = 1.24 \times 10^{19}/\text{cc}$   
 $\therefore R_s = \frac{200}{4.35} \text{ ohms}/\square$   
 $R_s \cong 46 \text{ ohms}/\square$

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from the graph is 200 micron. Divide 4 point 3 5 to 200, sheet resistance is declared as ohms per square, Ok 200 by 4 point, which is 46, roughly 46 Ohm per square is the sheet resistance, Ok. Inverse could have been what?

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I monitored R S. I monitored  $x_j$ . Then calculated N S. And then saw something is missing in predeposition drive-in cycle. Figure it out what was that, Ok. Is that the method clear to you?

So these graphs help you to actually get, these are integrals. So it is difficult every time integrals, so these are put into graphs directly. Plotted, Ok. This finishes the diffusion techniques. Tomorrow we start with techniques, this is only diffusion maths, physics we did. May be little physics is left, we will do it. And we will look into how actual diffusion is performed. Ok.