Lecture 18: Diffusion II

- **Announcements:**
- Lab 1 Report will be due Friday, April 23
  - Instructions for the report will be online on the EE143 Lab link
  - You can (and should) start on it now!
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- **Lecture Topics:**
  - Diffusion
    - Basic Process for Selective Doping
    - Diffusion Modeling
    - Predeposition Modeling
    - Drive-in Modeling
    - Successive Diffusions
    - Diffusion Coefficient
    - Junction Depth
    - Sheet Resistance
    - Irvin's Curves
- ------------------------------------
- **Last Time:**

Two-Step Diffusion

Predeposition or I/I → erfc profile / Gaussian

↓

Drive-In → Gaussian

Which profile do we end up with?

↳ Governed by the relative (Dt) product.

$(Dt)_{predep} \gg (Dt)_{drive\text{-}in} \Rightarrow$ impurity profile is complementary error function

$(Dt)_{drive} \gg (Dt)_{predep} \Rightarrow$ " " is Gaussian ← usually the case

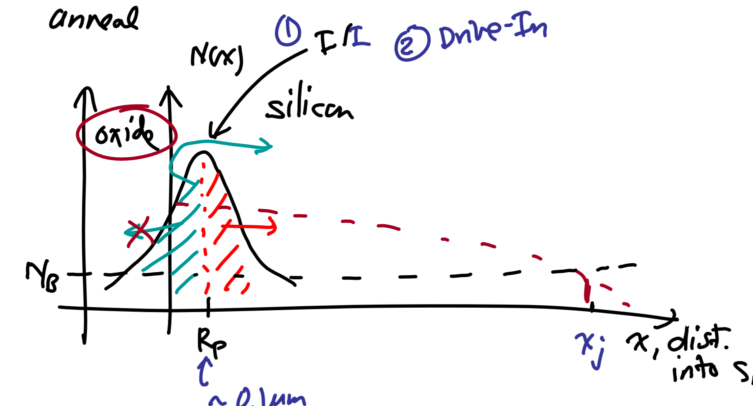
Successive Diffusions

For actual processes → junction formation is only one of many high temp. steps.

(1) Selective Doping
(a) implant → effective $(Dt)_1 = \frac{\Delta R_p^2}{2}$ (it's Gaussian)
(b) drive-in/activation
↳ $D_2 t_2$

(2) Other high temp. steps: $D_3 t_3, D_4 t_4, D_5 t_5,$
↓
oxidation, LPCVD, anneal

$$\boxed{(Dt)_{tot} = \sum_i D_i t_i}$$



Revisit the Gaussian distribution

Mathematically: $N(x) = N_p \exp\left[-\frac{(x-R_p)^2}{2(\Delta R_p)^2}\right]$, $N_p = \frac{Q}{\Delta R_p\sqrt{2\pi}}$

⇒ in statistics courses, usually see this in the form:

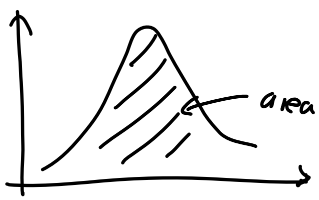
$$f_x(x) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right] \qquad -\infty < x < \infty$$

μ = mean, σ = std. dev.

This form is normalized so that the area under the whole Gaussian distribution curve = 1

↳ For doping, the area under the curve is the dose Q.

Thus, in this equation: $1 \rightarrow Q$, $\sigma \rightarrow \Delta R_p$, $\mu \rightarrow R_p$



half Gaussian Diff.

$$N(x) = \frac{Q}{\sqrt{\pi(Dt)}}\exp\left[-\frac{1}{2}\frac{x}{\sqrt{Dt}}\right]^2$$

Why is $(Dt)_{eff} = \frac{\Delta R_p^2}{2}$ for implantation?

For I/I completely contained in the Si:

$$Q = \sqrt{2\pi}N_p\Delta R_p \rightarrow N_p = \frac{Q}{\sqrt{2\pi}\Delta R_p} = \frac{D_I}{\sqrt{2\pi}\Delta R_p}$$

(Q = total implant dose = D_I)

Rearrange to the form of the limited source diffusion Gaussian:

$$N_p = \frac{Q}{\Delta R_p\sqrt{2\pi}} = \frac{D_I}{\Delta R_p\sqrt{2\pi}} = \frac{\frac{D_I}{2}}{\frac{\Delta R_p}{2}\sqrt{2\pi}} = \frac{\frac{D_I}{2}}{\sqrt{2\pi(\Delta R_p/2)^2}} = \frac{D_I/2}{\sqrt{\pi(Dt)_{eff}}}$$

$$(Dt)_{eff} = \frac{(\Delta R_p)^2}{2}$$

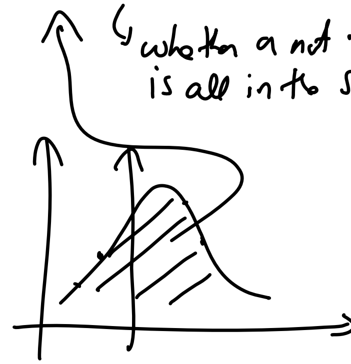
To summarize:

① For I/I, we use a two-sided Gaussian expression:

$$N(x) = \frac{Q}{\sqrt{2\pi}\Delta R_p}\exp\left[-\frac{1}{2}\frac{(x-\Delta R_p)^2}{R_p^2}\right]$$

where Q = implanted dose, D_I $(Q = D_I)$

↳ whether or not the implantation is all in the Si



② For limited source diffusion, use a one-sided Gaussian expression:

$$N(x) = \frac{Q}{\sqrt{\pi(Dt)}} \exp\left[-\frac{1}{2}\frac{x}{\sqrt{Dt}}\right]^2$$

where if

$x_{so} \triangleq$ initial peak dopant depth (before diffusion)

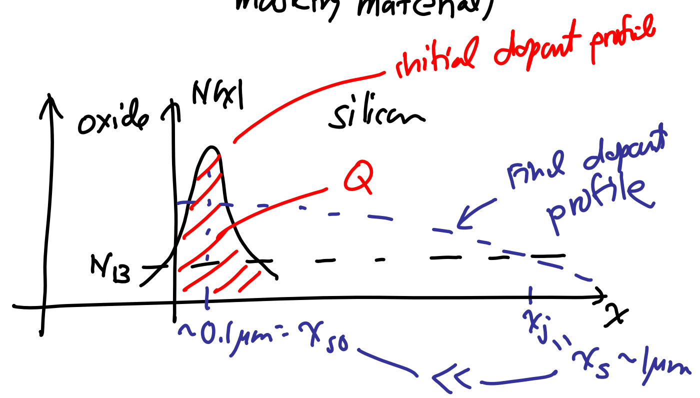
$x_s \triangleq$ final dopant depth (after diffusion)
↳ this often = junction depth, x_j

then

(i) Case: $x_{so} \ll x_s$ & there's a diffusion barrier above the Si surface (e.g., oxide)

Q = total dose into the silicon (not including dopants in the masking material)

Ex:



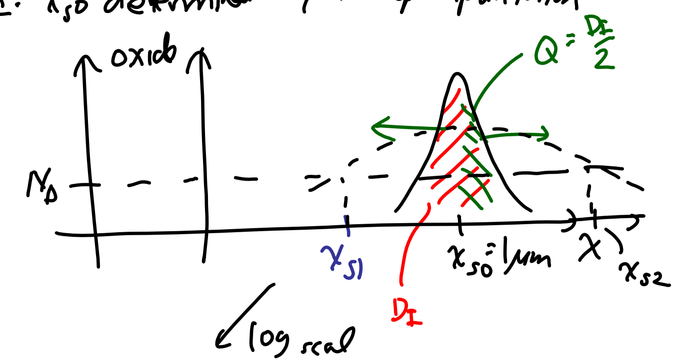
(ii) Case: $x_{so} \geq x_s$ w/ diffusion barrier above Si surface

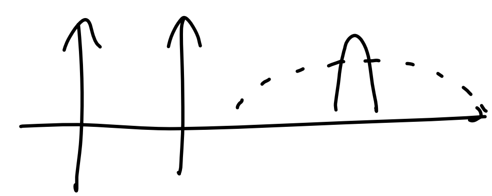
then $Q = \frac{1}{2}D_I$ (where D_I = total implanted dose)

and $N(x) = \frac{Q}{\sqrt{\pi(Dt)}} \exp\left[-\frac{1}{2}\frac{(x-x_{so})}{\sqrt{Dt}}\right]^2$

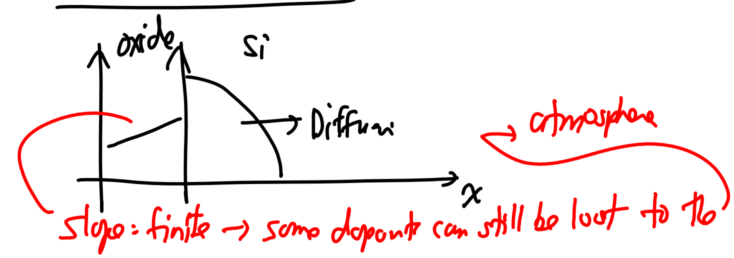
should be used.

Ex. x_{so} determined by a deep implantation





③ Practical Considerations:



- Diffusivity in oxide is usually << than in silicon, so oxide is usually a good diffusion barrier
- But it does depend upon a few factors:
  - Thickness of the encapsulating layer
  - Segregation coefficient, when oxide is being grown; we discussed this before
  - $D_{oxide}/D_{silicon}$ should be very small; normally it is, but there are cases when it is not, e.g., when H_2 is present

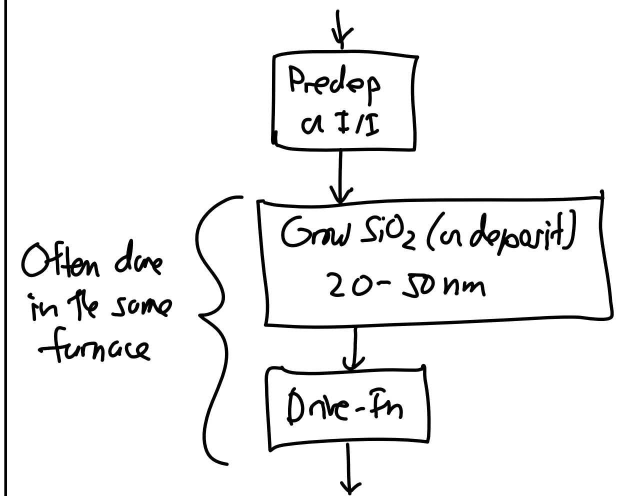
Impurity	m	D in SiO_2
B	<0.3 (small)	Small
B (oxidation w/H_2)	<0.3 (small)	Large
P, Sn, As	~10 (large)	Small
Ga	20 (large)	Large

Normally, oxide is a good diffusion barrier.

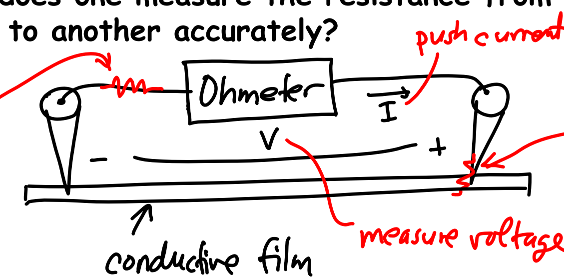
But not always!

- Go through Module 6 pp. 17-25

The doping process generally always follows this flow:



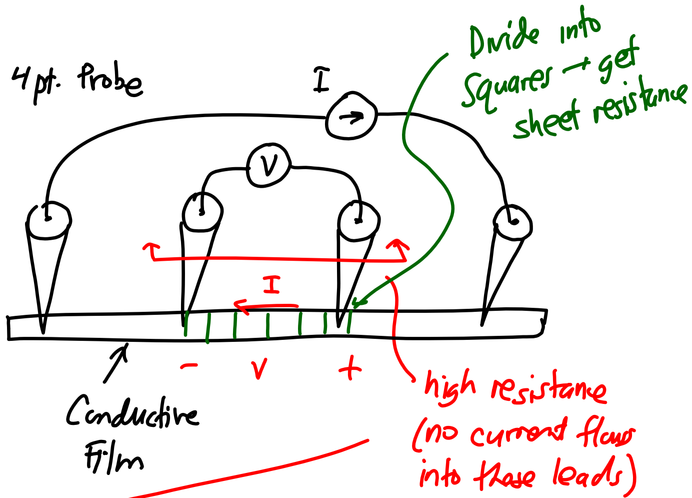
- How does one measure the resistance from one point to another accurately?



Problem: What about:
① the resistance in the leads?
② the contact resistance (which can be high)?

↳ How can you tell your film's resistance vs. these?

Soln: 4pt. Probe



→ Get the R between the two inner probes, and only the inner probes (even contact R nulled out)