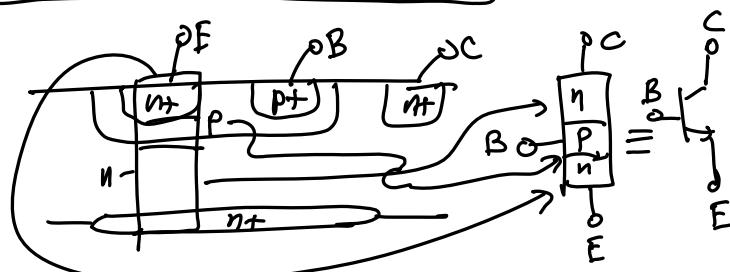


Lecture 17: Diffusion I

- Announcements:
- Midterm Exam: coming Thursday, Oct. 30
  - It'll be during lecture
  - Review Session: Tu 6:30-8:30 p.m., 293 Cory
  - TA's will be running the review session
  - Passed out old midterm exam
  - Midterm info sheet online
- 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:
- Predeposition

over

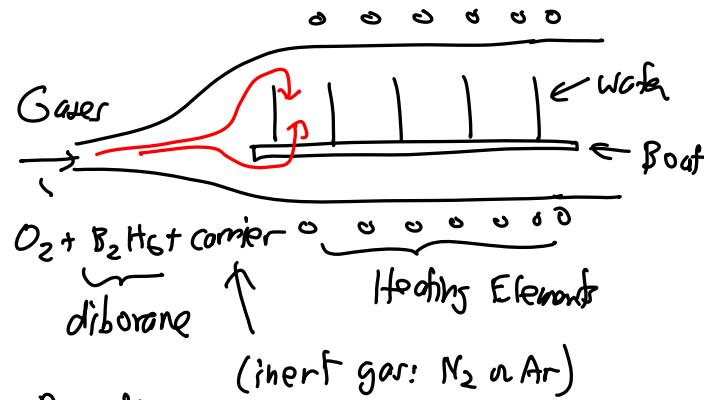
Basic Process for Selective Doping

- Introduce the dopants (a fixed dose)
  - ion implantation
  - predeposition
- Drive-in dopants to the desired depth
  - high T > 900°C in N<sub>2</sub> or N<sub>2</sub>/O<sub>2</sub>

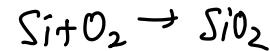
Predeposition

- ⇒ furnace-tube system using solid, liquid, or gaseous dopant sources
- ⇒ used to introduce a controlled amount of dopants
- ⇒ for pre-deposition, control not as good as I/I
- ⇒ Dose (Q) range: 10<sup>13</sup> – 10<sup>16</sup> ± 20% (pre-dep)  
(for I/I: 10<sup>11</sup> – 10<sup>16</sup> ± 19%)

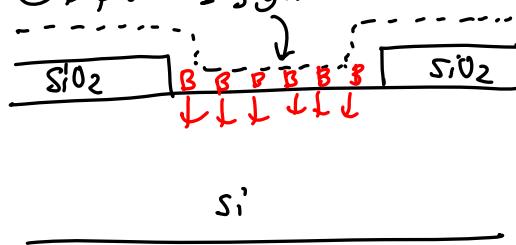
Example: Boron preposition



Reactions:

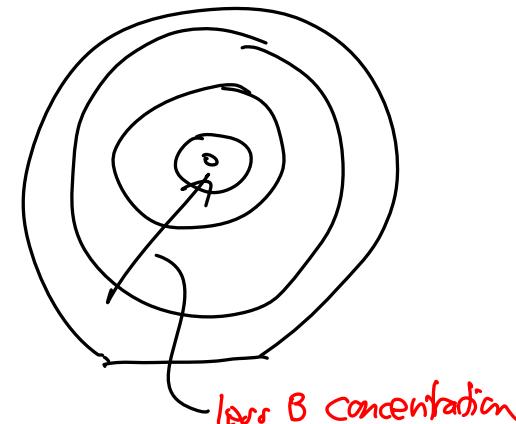


① Deposit B<sub>2</sub>O<sub>3</sub> glass



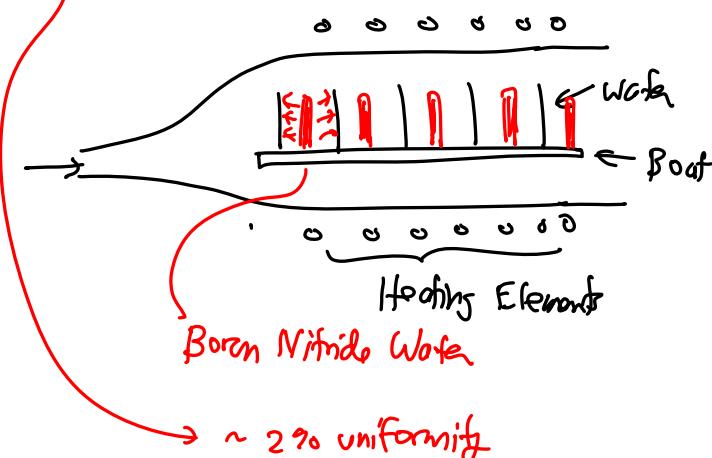
② B diffuses from B<sub>2</sub>O<sub>3</sub>  $\rightarrow$  Si

$\Rightarrow$  difficult control dose:



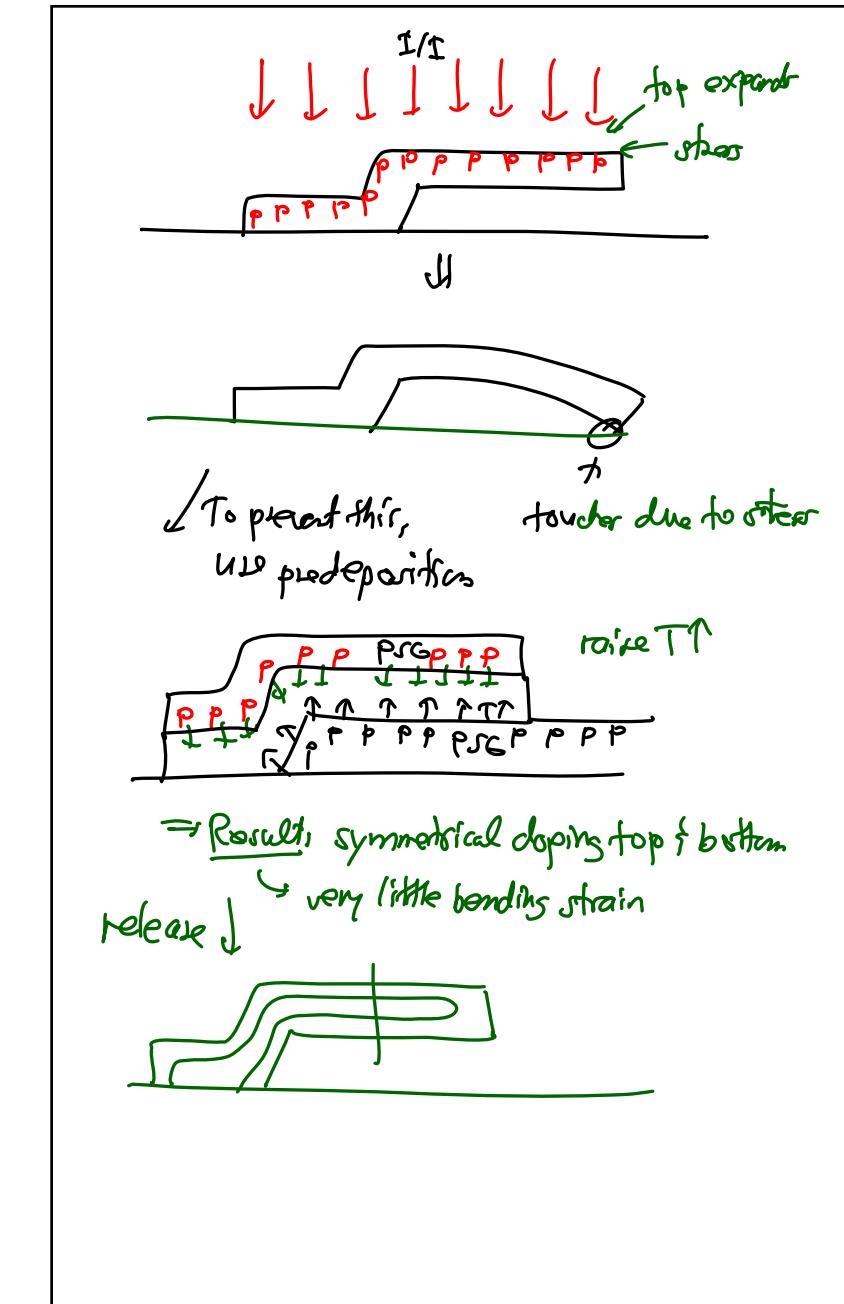
For better uniformity, use Solid Source

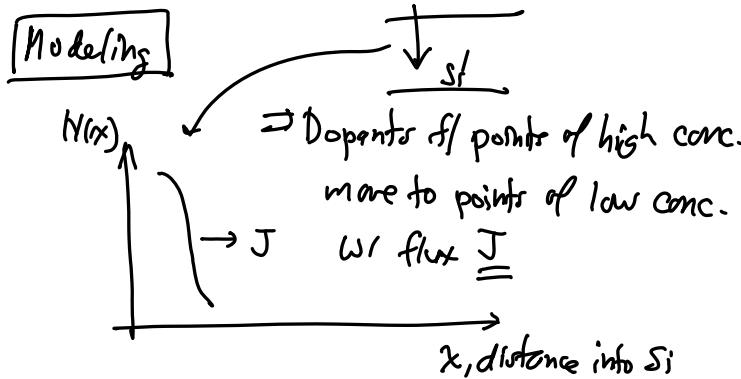
Solid Source



General Remarks on Pre-Deposition

- ① Higher doses only:  $D: 10^{13} - 10^{16} \text{ cm}^{-2}$   
( $I/I_c$  is  $10^{11} - 10^{16}$ )
- ② Dose not well-controlled for gaseous source:  $\pm 20\%$
- ③ Uniformity not so good:  
 $\pm 10\%$  w/gas source;  $\pm 2\%$  for solid source
- ④ Max conc. possible (limited by solid solubility)  
(limit is  $\sim 10^{20} \text{ cm}^{-3}$ , but depends on temp.)  
look up in chart  
(no limit for  $I/I \rightarrow$  just force it in)  
 ⇒ for the above reason,  $I/I$  is often preferred  
 ⇒ but...
 
- ⑤ Predeposition is great if one needs to dope a suspended structure conformally & uniformly on all sides (even underneath) → great for MEMS!





Question: What is  $N(x, t)$

↑  
fcn of time & temperature

Fick's Law of Diffusion - (First Law)

$$J(x, t) = -D \frac{\partial N(x, t)}{\partial x} \quad (1)$$

↑  
flux [ $\text{#}/\text{cm}^2 \cdot \text{s}$ ]      Diffusion Coefficient

Continuity Equation for Particle Flux-

General form:  $\frac{\partial N(x, t)}{\partial t} = -\nabla \cdot \vec{J}$

↑  
rate of increase of conc. w/ time      negative of the divergence of the particle flux

$\Rightarrow$  we're interested in the one-dimensional form:

$$\frac{\partial N(x, t)}{\partial t} = - \frac{\partial J}{\partial x} \quad (2)$$

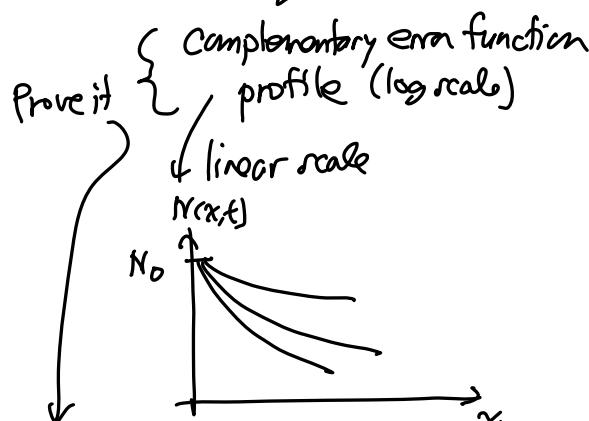
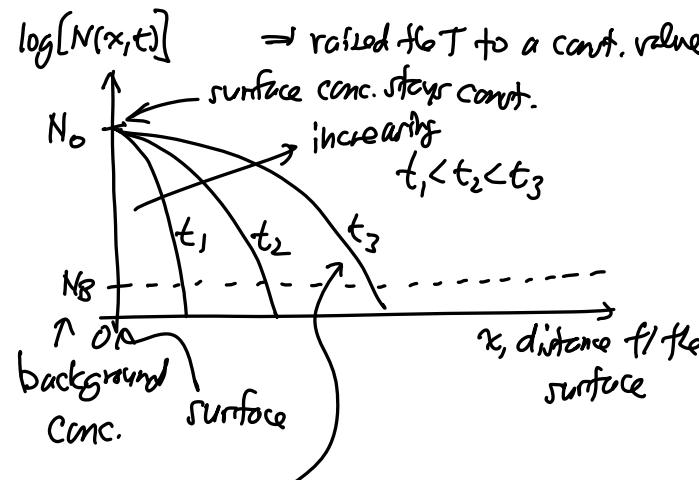
$\left[ \frac{\partial}{\partial x} (1) \text{ and substitute into (2)} \right] \Rightarrow$

\*  $\rightarrow \frac{\partial N(x, t)}{\partial t} = D \frac{\partial^2 N(x, t)}{\partial x^2}$  [Fick's 2<sup>nd</sup> Law of Diffusion]

want solutions → dependant upon boundary conditions  
 ↴ use variable separation or Laplace Xform techniques

Case I: Predeposition

↳ constant source diffusion  
 ↴ surface conc. stays the same during diffusion  
 $\Rightarrow$  dopants continuously supplied " "



Boundary Conditions: (predeposition)

(i)  $N(0,t) = N_0 \rightarrow$  by definition of

(ii)  $N(\infty,t) = 0$

\* Solve →

Get:

$$N(x,t) = N_0 \left[ 1 - \frac{1}{\sqrt{\pi}} \int_0^x \frac{x}{2\sqrt{Dt}} e^{-y^2} dy \right]$$

$$N(x,t) = N_0 \operatorname{erfc} \left( \frac{x}{2\sqrt{Dt}} \right)$$

Complementary error function

surface concentration  
(Kofr constant)

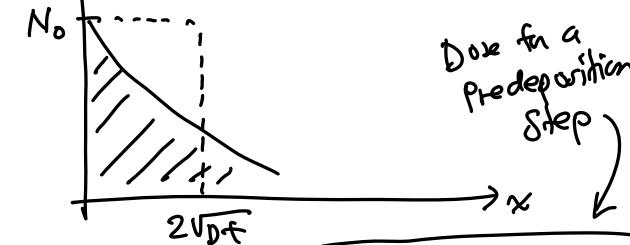
$D \triangleq$  diffusion const.

(temp. dependence is in D)

Dose,  $Q \triangleq$  total # of impurity atoms per unit area of the Si

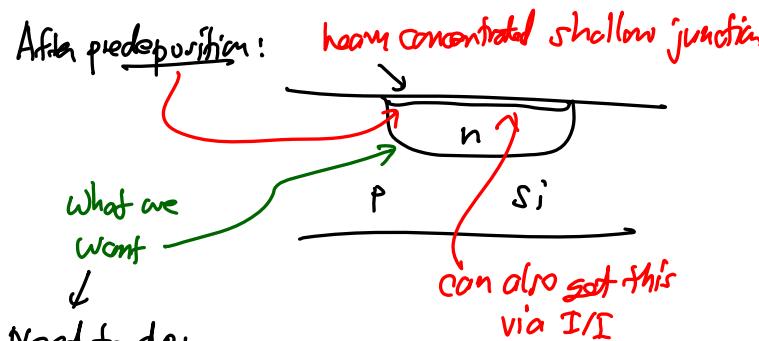
≈ area under the curve

$N(x) \leftarrow$  linear scale

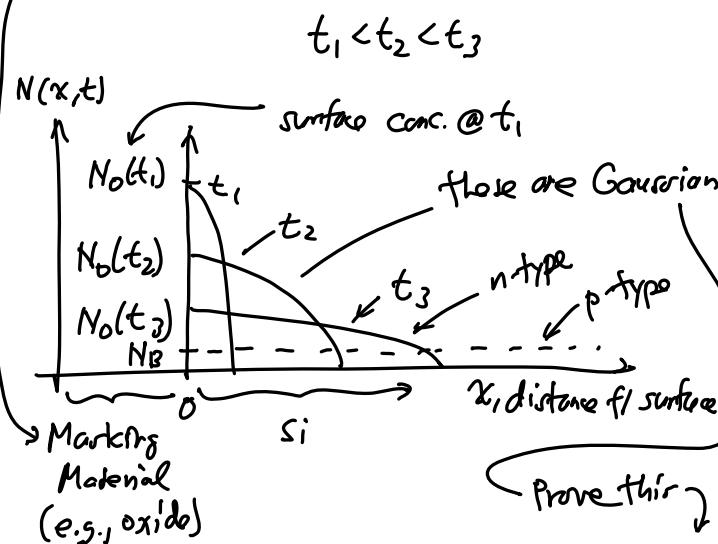


$$Q = \int_0^\infty N(x,t) dx \Rightarrow Q(t) = N_0 \frac{2\sqrt{Dt}}{\sqrt{\pi}} \text{ cm}^{-2}$$

$2\sqrt{Dt} \triangleq$  characteristic diffusion length

Lecture 18w: Diffusion II

- Case(2): Drive in  $\rightarrow$  limited source diffusion  
i.e., constant dose  $Q$
- ① dopant source turned off
  - ② add a masking material to prevent out-diffusion
  - ③ raise temp. for time  $t$

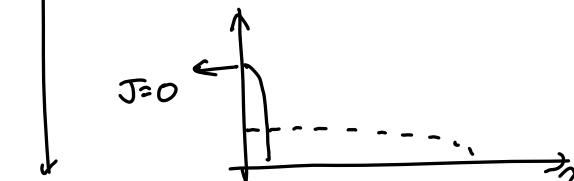
Boundary Conditions

(i)  $N(x, t) = 0$

(ii)  $\frac{\partial N(x, t)}{\partial x} \Big|_{x=0} = 0$

Constant Dose:  
 $\int_0^{\infty} N(x, t) dx = Q = \text{const.}$

This is equivalent to saying that there's no flux going out of the Si



(iii) Usually, make delta function approx:  $N(x, 0) = Q \delta(x)$

Using Fick's 2nd Law:

$\Rightarrow$  get one-sided Gaussian distribution

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

$\hookrightarrow$  corresponds to a "half Gaussian"

$$N(\text{linear})$$

