EE 143: Microfabrication Technology
Lecture 17c: Diffusion

CTN 3/16/10

Lecture 17: Diffusion I

- **Announcements:**
- Need volunteers for Cal Day (April 17):
  - Alumni & prospective students visit Cal
  - If interested, sign up with your lab TA
- Midterm Exam: coming Thursday, March 18
  - It'll be during lecture HW#6 due 10p.m.
  - Review Session Time: Tu 6-8 p.m., in 293 Cory
  - TA's will be running the review session
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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:**

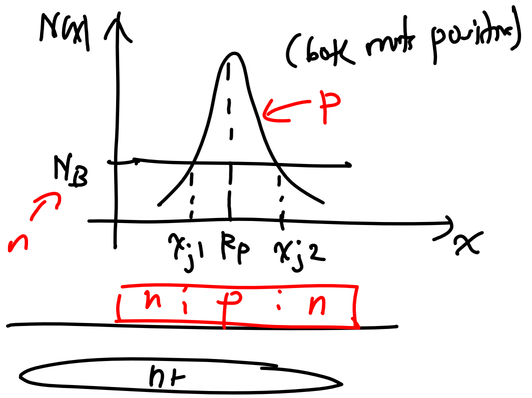
$\boxed{\text{Junction Depth}}$

⇒ defined as the depth @ which the implanted dose = N_B (the background conc.)

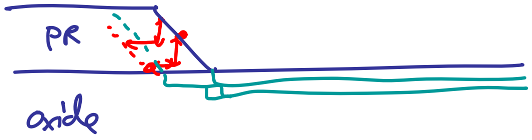
$$N_p \exp\left[\frac{-(x_j - R_p)^2}{2\Delta R_p^2}\right] = N_B$$

$$\Rightarrow \boxed{x_j = R_p \pm \Delta R_p \sqrt{2 \ln\left(\frac{N_p}{N_B}\right)}}$$

both roots may be meaningful for deep implantations:

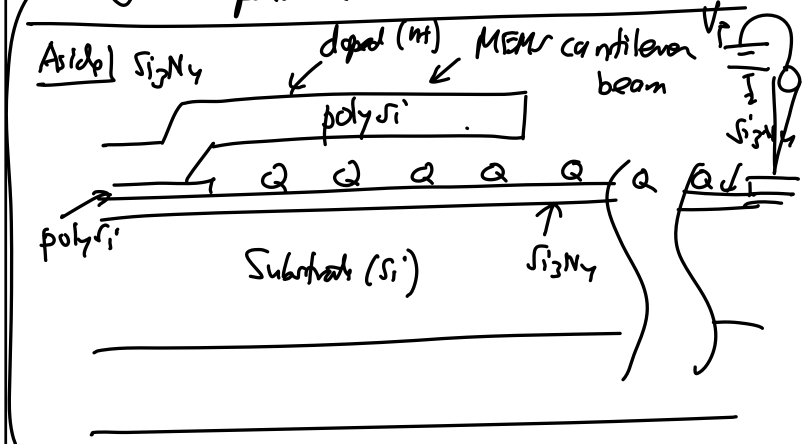


Problem 2 (a)

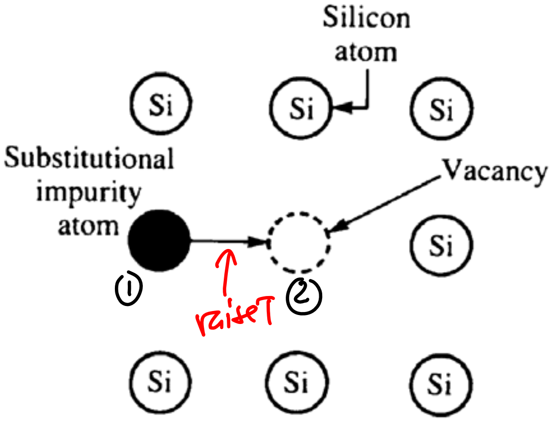


Diffusion

⇒ movement of dopants within the Si @ high temperatures



Three mechanisms: (in Si)



(a)

Substitutional Diffusion:

E_A: activation energy

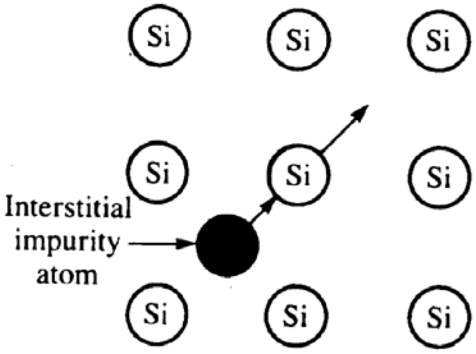
⇒ raise T → impurity moves along vacancies in the lattice

⇒ it substitutes for a Si-atom in the lattice

Interstitialcy Diffusion:

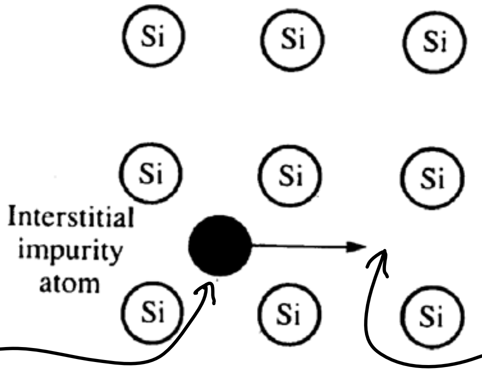
⇒ impurity atom replaces a Si atom in the lattice

⇒ Si displaced to an interstitial site



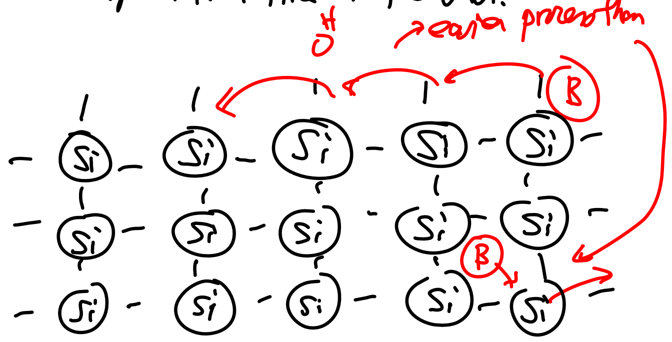
(b)

Interstitial Diffusion

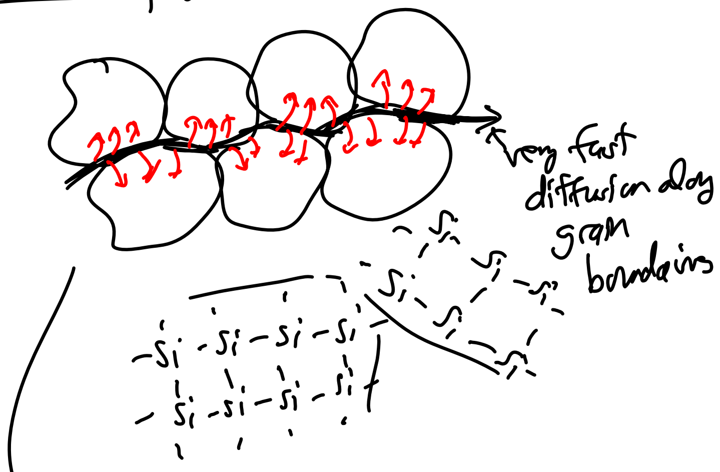


⇒ impurity atoms jump from one interstitial site to another

⇒ do not replace Si atoms in the lattice
∴ get rapid diffusion
hard to control
impurity not in lattice during transport, but often eventually ends up in the lattice in the end.



Diffusion in poly Si

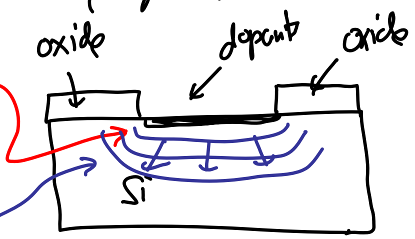


Result: overall faster diffusion in poly Si versus Si → more than 10X

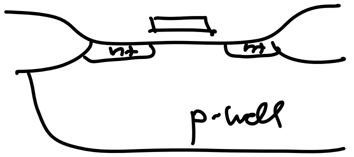
Basic Process for Selective Doping

① Introduce the dopants (introduce a fixed dose Q of dopants)

(i) ion implantation
(ii) predeposition



② Drive-in dopants to the desired depth
high temp. > 900°C in N_2 or N_2/O_2



Predeposition-

⇒ furnace-tube system using solid, liquid, or gaseous dopant sources

⇒ used to introduce a controlled amount of dopant

→ for predep, control is not as good as I/I

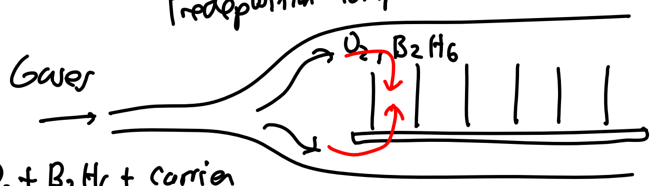
Predep: dose (Q) range: $10^{13}-10^{16} \pm 20\%$

for ref: w/ ion implantation: $\underbrace{10^{11}-10^{16}}_{\text{larger range}} \pm 1\%$

larger range & more accurate

Example. Boron predeposition

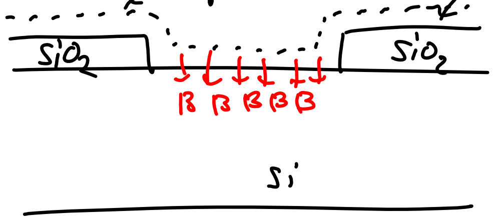
Predeposition Temp: 800-1100°C



$O_2 + B_2H_6 +$ carrier gas (inert gas: N_2 or Ar)

Diborane

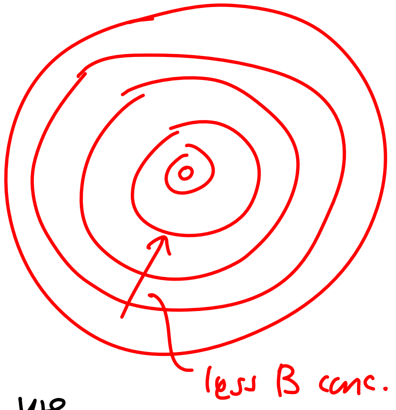
① deposit B_2O_3 glass



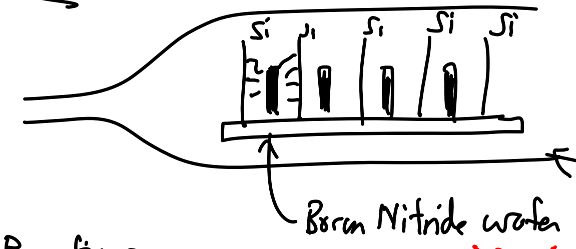
diffusion barrier (masks out the dopant)

② B diffuses from $B_2O_3 \rightarrow Si$

⇒ difficult to control dose



For better uniformity, use solid source:



⇒ 2% uniformity

Reactions:

$B_2H_6 + 3O_2 \rightarrow 3H_2O + B_2O_3$

$Si + O_2 \rightarrow SiO_2$

General Comments on Predeposition:

① Higher doses only: $Q = 10^{13} - 10^{16}\ cm^{-2}$ (I/I is $10^{11}-10^{16}$) but better for

② Dose not well-controlled for gaseous source: ±20%

③ Uniformity not so good:

±10% w/ gas source; ±2% for solid source

④ Max. conc. possible limited by solid solubility

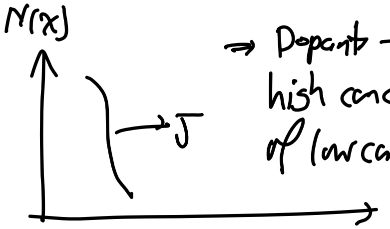
(limit is $\sim 10^{20}\,\mathrm{cm}^{-3}$, but depends on temp.)

↳ look up in chart

(no limit for I/I → just force it in!)

↳ for these reasons, I/I preferred

Modeling



→ Dopants f/ points of high conc. move to points of low conc. w/ flux $\underline{\underline{J}}$

Question: What's $N(x,t)$?

↑ fcn of time & temperature

Fick's Law of Diffusion – (First Law)

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

↗ flux [#/cm²·s]

↖ Diffusion Coefficient

Continuity Equation for Particle Flux –

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

↗ rate of increase of conc. w/ time

↑ negative of the divergence of the particle flux

⇒ we're interested in the one-dimensional form:

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

[$\frac{\partial}{\partial x}$(1) and substitute (2) in (1)]

$$\frac{\partial N(x,t)}{\partial t} = D\,\frac{\partial^2 N(x,t)}{\partial x^2}$$

[Fick's 2nd Law of Diffusion in 1-D]

Solutions: → dependent upon boundary conditions

↳ use variable separation & Laplace Xform techniques