Lecture 7: Surface Micromachining I

- **Announcements**:
- HW#1B due tomorrow; HW#2 online soon
- I will be traveling tomorrow (Thursday)
    - ↳ Thursday lecture will be an online video
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- **Today**:
- Reading: Senturia, Chpt. 3; Jaeger, Chpt. 2, 3, 6
    - ↳ Example MEMS fabrication processes
    - ↳ Photolithography
    - ↳ Etching
    - ↳ Oxidation
    - ↳ Film Deposition
    - ↳ Ion Implantation
    - ↳ Diffusion
- Reading: Senturia Chpt. 3, Jaeger Chpt. 11, Handout: "Surface Micromachining for Microelectromechanical Systems"
- Lecture Topics:
    - ↳ Polysilicon surface micromachining
    - ↳ Stiction
    - ↳ Residual stress
    - ↳ Topography issues
    - ↳ Nickel metal surface micromachining
    - ↳ 3D "pop-up" MEMS
    - ↳ Foundry MEMS: the "MUMPS" process
    - ↳ The Sandia SUMMIT process
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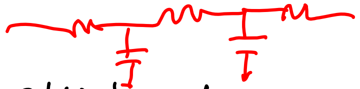
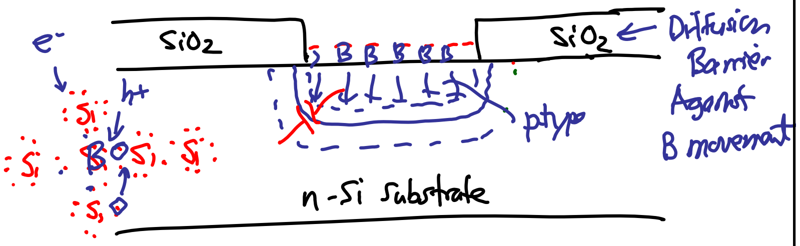
- **Last Time**:
- Going through process modules (quickly)

- **Diffusion**:
- Process of introducing dopants into selected areas on an IC
- **Example**:



diborane gas → B_2H_6 + O_2 @ high temperature ~ 800°C — 1200°C



① Form borosilicate glass w/ high B concentration

② Boron diffuses in → this becomes p-type

⇒ diffusion requires:

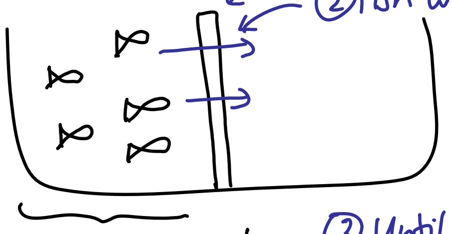
① concentration gradient

② movement (velocity)

→ Example. Fish Tank

① When separator removed...

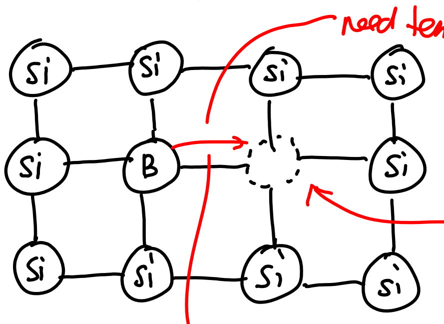
② Fish will go to the other side



③ Until the concentration is the same on both sides

But they can't if they're dead!

It's similar for an impurity in silicon:



need temperature for this to happen

Need higher T for this vacancy to exist.

Just one mechanism for diffusion → we'll look at others, too

Substitutional diffusion:

⇒ impurity moves along vacancies in the lattice

⇒ substitutes for a Si atom in the lattice

For movement to occur:

① Vacancies must exist.

② The B must have enough energy to move.

Both require high temperature!

→ must heat to induce diffusion of impurities in Si!

Definitions:

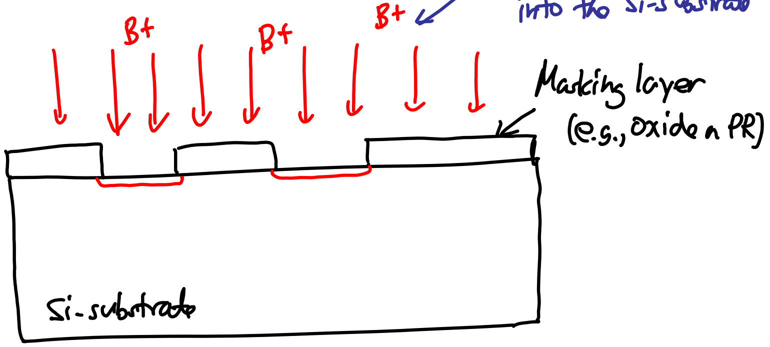
① Predeposition: diffusion w/ dopant source present

② Drive-in: diffusion in an inert ambient, e.g., N_2 w/ no dopant gases present

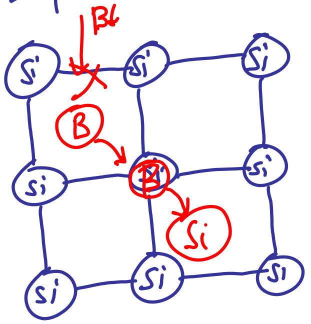
Ion Implantation

⇒ a more accurate way to introduce dopants before drive-in

① Accelerate B^+ ions into the Si-substrate



② B+ punches into the Si



③ Raise T to move the B into the lattice → only when it's in the lattice is it active & can contribute to the doping level

④ Keep T up to drive the dopants in to the desired depth.

Advantages:

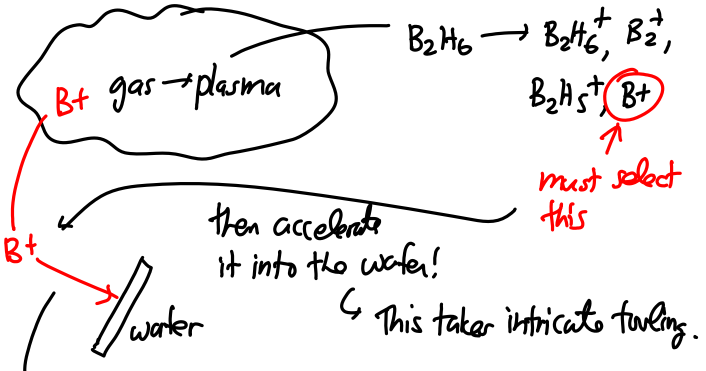
① accurate dose ✓

② change depth by setting ion energy ✓

③ ~~no~~ smaller need for high temperature

Problem: COST!

An ion implanter is quite a sophisticated piece of equipment! → and expensive! (> $1 million)



$B_2H_6 \rightarrow B_2H_6^+, B_2^+, B_2H_5^+, \boxed{B^+}$

must select this

then accelerate it into the wafer!

↳ This takes intricate tooling.

Energy Range: 20keV – 100keV

Penetration Depth: fraction of a μm ← not so useful for MEMS

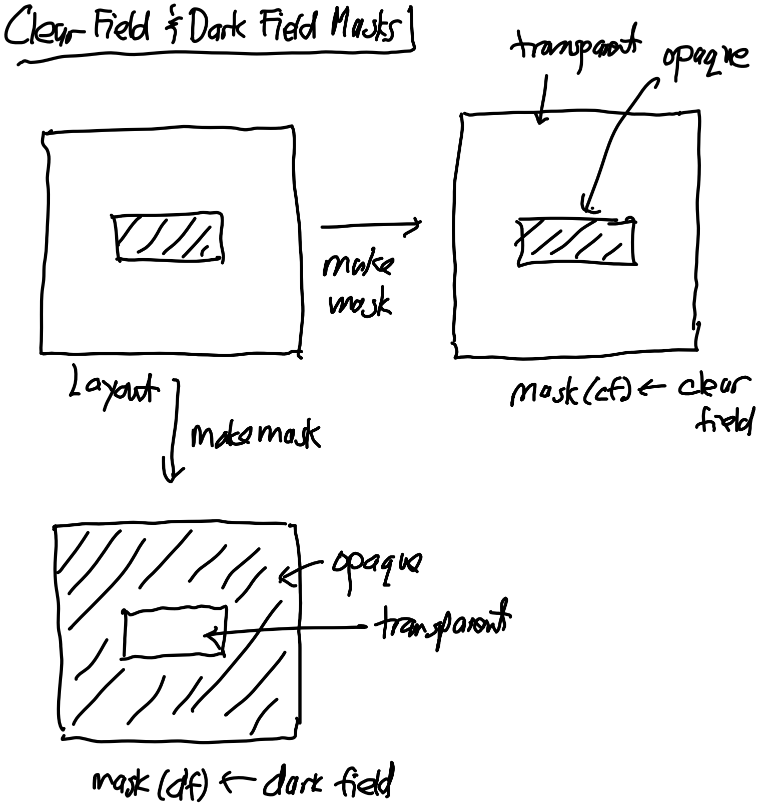
⇒ larger ions don't go as far as smaller

(heavier ions penetrate shallower than smaller)

Dose: $10^{11} - 10^{15}\ cm^{-2}$

- Now, start going through Module 5 on Surface Micromachining

Clear Field & Dark Field Masks

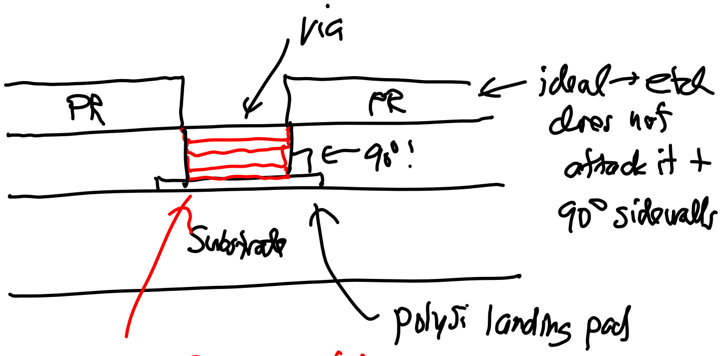


- Now, start going through Module 5 on Surface Micromachining

- **Straight or Sloped Sidewalls**:
- Often want sloped sidewalls in order to reduce the sharpness of corners
  - Easier to deposit over
  - Sharp corners concentrate stresses
  - High stress can weaken structures creating a reliabilty concern
  - High stress can dissipate energy, lowering Q
- When you want straight sidewalls (e.g., for lateral electrostatic drive), use a hard mask
  - PR can't last for thick structures
  - A hard mask suppresses angle transfer

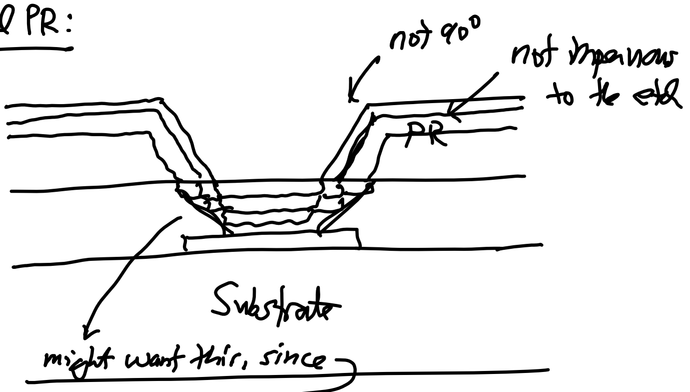
Etching for a Desired Sidewall Slope

Ideal Case:



Assume RIE w/ perfect anisotropy.

Real PR:



might want this, since ⇒ easier to deposit over sloped sidewall → than straight sidewall