Lecture 7: Surface Micromachining I

Announcements:
- HW#1 due tomorrow; HW#2 online soon
- I will be traveling tomorrow (Thursday)
  - Thursday lecture will be an online video

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

Last Time:
- Going through process modules (quickly)

- Diffusion:
  - Process of introducing dopants into selected areas on an IC
  - Example:
    - B₂H₆ + O₂ @ high temperature ~ 800°C - 1200°C
    - Boron diffuses in → this becomes p-type

  => diffusion requires:
  1. concentration gradient
  2. movement (velocity)

  Example: Fish Tank
  1. When separa water...
  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 to an impurity in silicon:

Just one mechanism for diffusion well look at below for us

Substitutional diffusion:
- Impurity moves along vacancy in the lattice
- Substituted for a Si atom in the lattice

In movement to occur:
1. Vacancy must exist.
2. The B must have enough energy to move.

Both require high temperature!

Must have to induce diffusion of impurities in Si!

Definitions:
1. Pre-deposition: diffusion w/ dopant source present
2. Drive-in: diffusion in an inert ambient; e.g., N₂ w/ no dopant gases present

Ion Implantation

1. Accelerate B⁺ ions into the Si-substrate
2. B⁺ provokes 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 need for high temperature

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Now, start going through Module 5 on Surface Micromachining

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Problem: Cost!

An ion implant is quite a sophisticated piece of equipment! And expensive! (> $1 million)

\[ \text{B}_2\text{H}_6 \rightarrow \text{B}_2\text{H}_5^+ , \text{B}_2^+ , \text{B}_2\text{H}_5^+ \rightarrow \text{B}^+ \]

- B+ gas → plasma
- B+ gas → plasma
- B+ gas → plasma
- B+ gas → plasma
- B+ gas → plasma
- B+ gas → plasma

Then accelerate it into the wafer!

C: This takes intricate timing.

Energy Range: 20 keV - 100 keV

Penetration Depth: fraction of a pm

\[ \text{Large ions don't go as far as smaller ions; penetrates shallower than smaller ions.} \]

Duo: \(10^{-1} - 10^{-3}\) cm²

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[Diagram showing the process of making a mask for clear-field and dark-field imaging.]

Layout \[\rightarrow\text{make mask}\]

\[\text{make mask}\] \[\rightarrow\text{clear field}\]

\[\text{opaque}\] \[\rightarrow\text{transparent}\]

Mask (cf) \[\leftarrow\text{clear field}\]

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- **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 reliability 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:**

![Diagram showing etching process and desired sidewall slopes.](image-url)