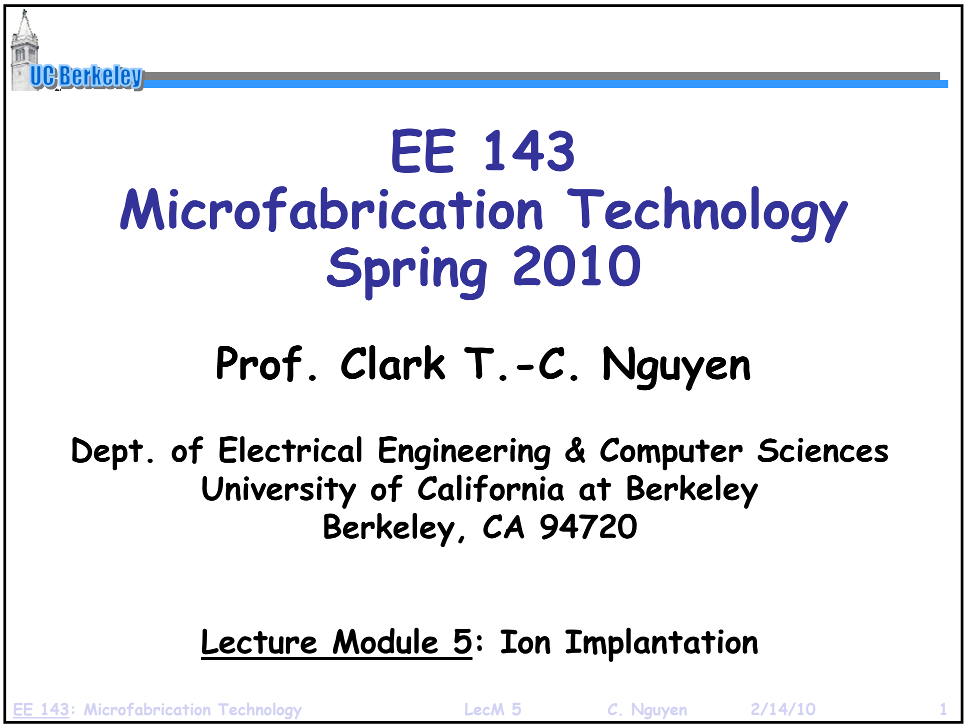

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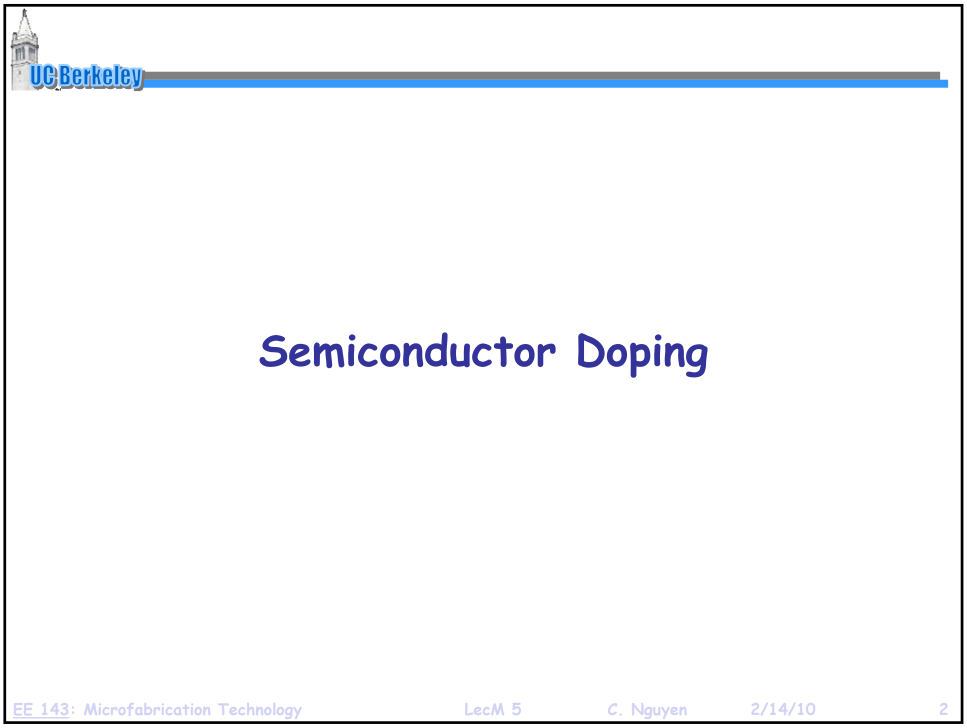
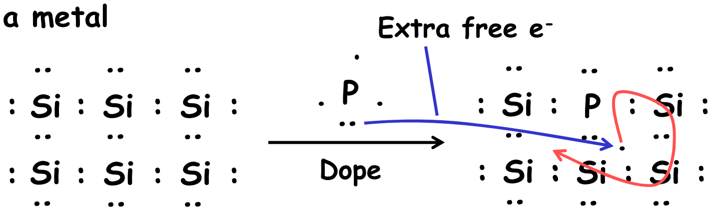
Lecture Module 5: Ion Implantation



Semiconductor Doping

Doping of Semiconductors

- Semiconductors are not intrinsically conductive
- To make them conductive, replace silicon atoms in the lattice with dopant atoms that have valence bands with fewer or more e⁻'s than the 4 of Si
- If more e⁻'s, then the dopant is a donor: P, As
  - ↳ The extra e⁻ is effectively released from the bonded atoms to join a cloud of free e⁻'s, free to move like e⁻'s in a metal



  - ↳ The larger the # of donor atoms, the larger the # of free e⁻'s → the higher the conductivity

Doping of Semiconductors (cont.)

- **Conductivity Equation:**

$$\sigma = q\mu_n n + q\mu_p p$$

conductivity

electron mobility

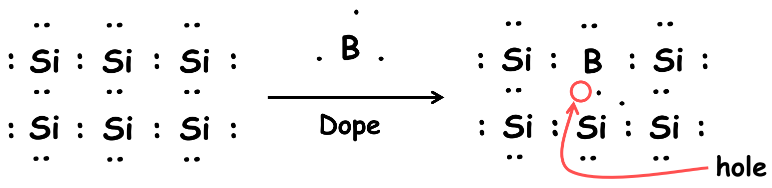
electron density

charge magnitude on an electron

hole mobility

hole density

- If fewer e⁻'s, then the dopant is an acceptor: B



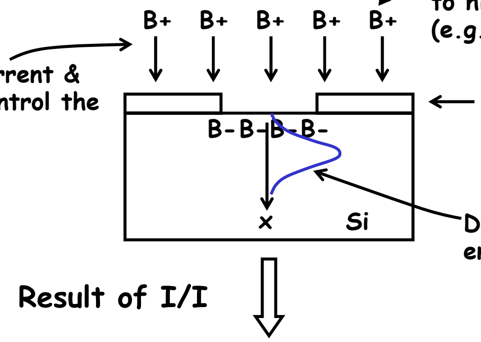
  - ↳ Lack of an e⁻ = hole = h⁺
  - ↳ When e⁻'s move into h⁺'s, the h⁺'s effectively move in the opposite direction → a h⁺ is a mobile (+) charge carrier

Ion Implantation

Ion Implantation

- Method by which dopants can be introduced in silicon to make the silicon conductive, and for transistor devices, to form, e.g., pn-junctions, source/drain junctions, …

The basic process:



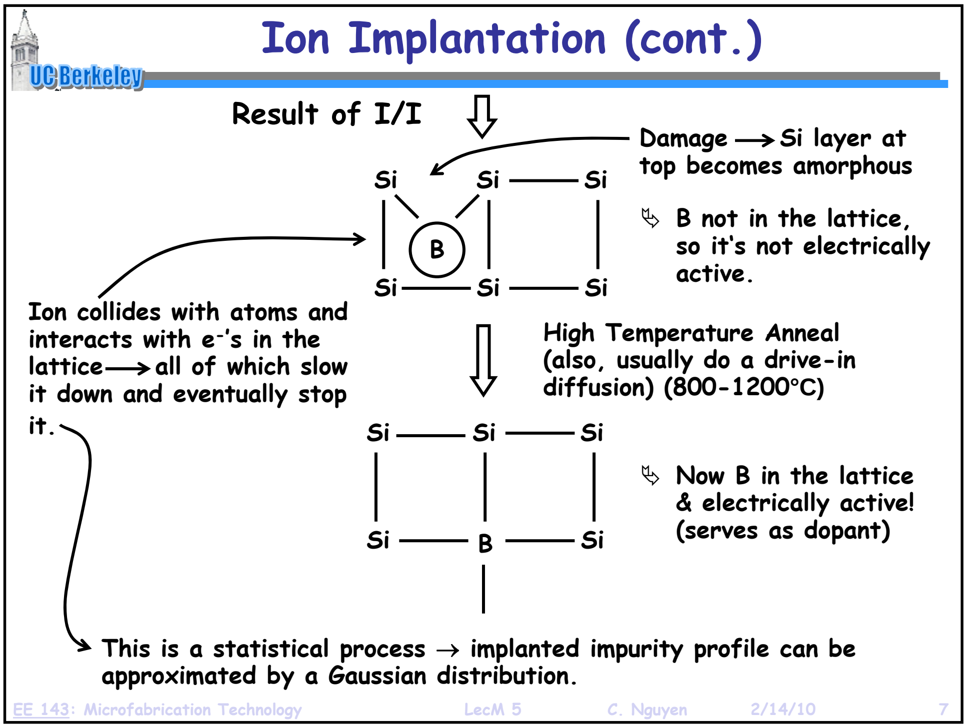
Charged dopant accelerated to high energy by an E-Field (e.g., 100 keV)

Control current & time to control the dose.

Masking material (could be PR, could be oxide, etc.)

Depth determined by energy & type of dopant

Result of I/I



Ion Implantation (cont.)

Result of I/I

Damage → Si layer at top becomes amorphous

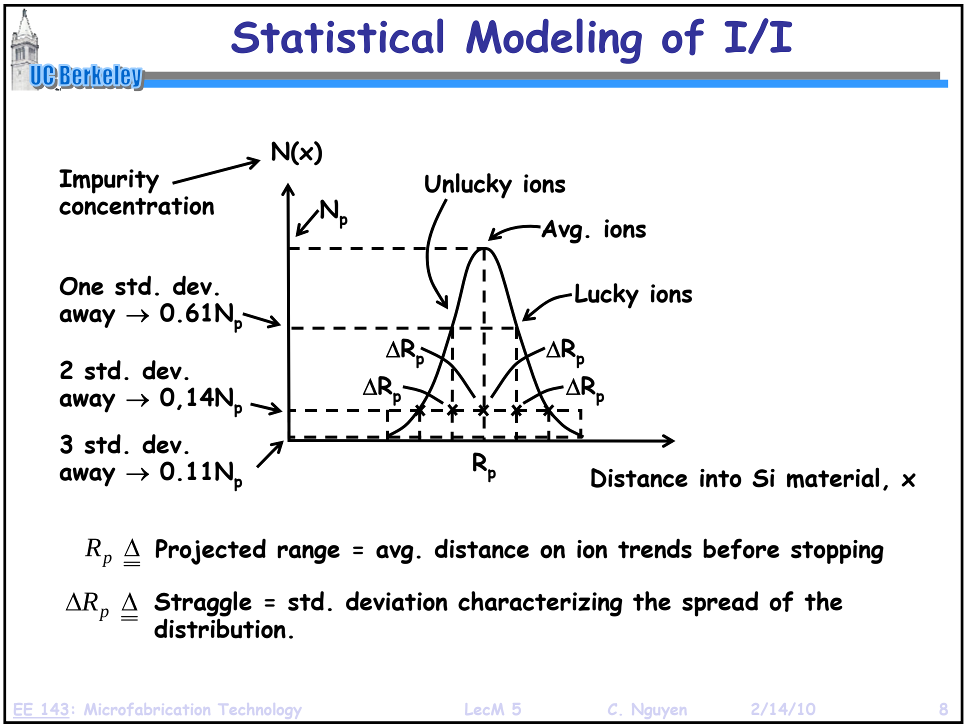
- B not in the lattice, so it's not electrically active.

Ion collides with atoms and interacts with e⁻'s in the lattice → all of which slow it down and eventually stop it.

High Temperature Anneal (also, usually do a drive-in diffusion) (800-1200°C)

- Now B in the lattice & electrically active! (serves as dopant)

This is a statistical process → implanted impurity profile can be approximated by a Gaussian distribution.



Statistical Modeling of I/I

$R_p \triangleq$ Projected range = avg. distance on ion trends before stopping

$\Delta R_p \triangleq$ Straggle = std. deviation characterizing the spread of the distribution.

Analytical Modeling for I/I

Mathematically:

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

Area under the impurity distribution curve } Implanted Dose = $Q = \int_0^\infty N(x)dx \ \left[ions/cm^2\right]$

For an implant completely contained within the Si:

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

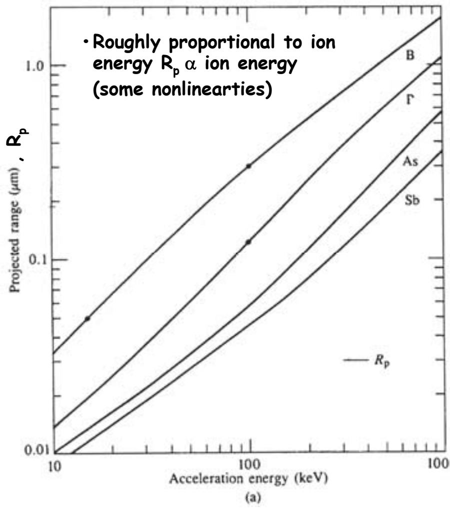
Assuming the peak is in the silicon: (putting it in one-sided diffusion form)

So we can track the dopant front during a subsequent diffusion step.

$D_I = Q$

$$N(x) = \frac{D_I/2}{\sqrt{\pi (Dt)_{eff}}} \exp\left[-\frac{(x-R_p)^2}{2(\Delta R_p)^2}\right], \text{ where } (Dt)_{eff} = \frac{(\Delta R_p)^2}{2}$$

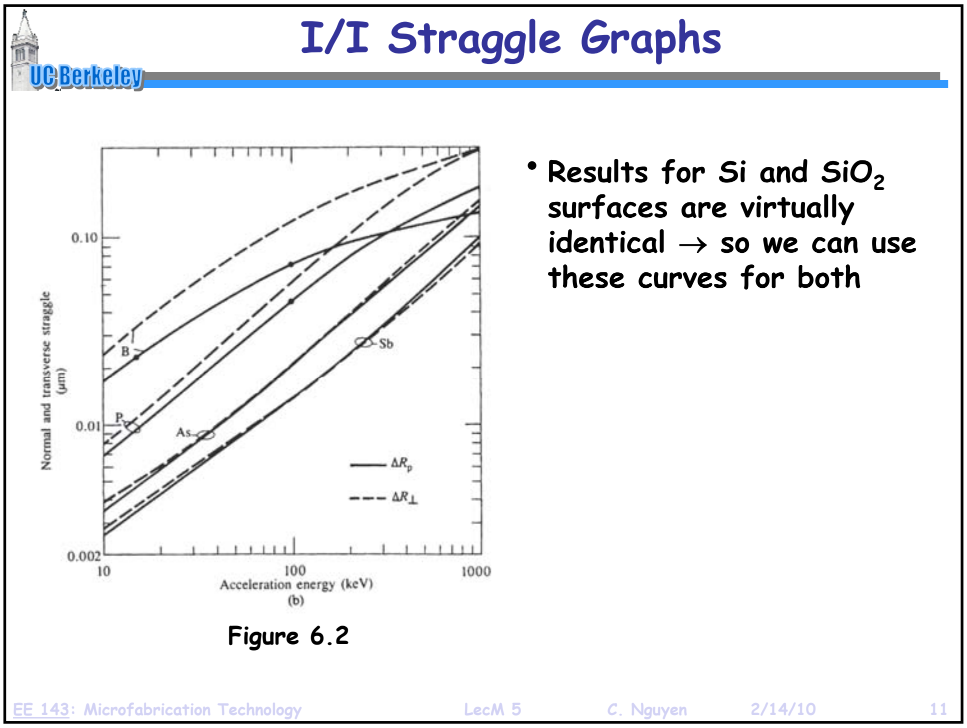
I/I Range Graphs



- Roughly proportional to ion energy R_p α ion energy (some nonlinearties)

Figure 6.1

- R_p is a function of the energy of the ion and atomic number of the ion and target material
- Lindhand, Scharff and Schiott (LSS) Theory:
- Assumes implantation into amorphous material, i.e, atoms of the target material are randomly positioned
- Yields the curves of Fig. 6.1 and 6.2
- For a given energy, lighter elements strike Si with higher velocity and penetrate more deeply



I/I Straggle Graphs

Figure 6.2

- Results for Si and SiO_2 surfaces are virtually identical → so we can use these curves for both