Lecture 17
Ion Implantation, part 2

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Reading:
Chapter 5, Fabrication Engineering at the Micro- and Nanoscale, 4th edition, Campbell

Ion Implantation Models

- When a high-energy ion enters a solid (such as single crystal Si), what happens?
  - The positively charged ion slows down as it passes through the clouds of electrons surrounding the Si atoms
  - The ion scatters as it encounters the positively charged nuclei
- We can model these steps in various ways

Energy Loss: Drag

- Drag force is proportional to ion velocity
  \( \text{Drag force} \propto \text{velocity} \propto \sqrt{\text{Energy}} \)
- Energy loss per unit path length (s)
  \( \frac{dE}{ds} = k_e \sqrt{E} \)
- \( k_e \) depends on the masses and atomic numbers of the ion and the target atoms

Scattering

- Rutherford scattering (Coulomb scattering)
  - Mostly elastic
  - Scattered angle, path length between scatter events are probabilistic
- Monte Carlo simulation
  - Trace the path of a single ion through the target, using random numbers for the probabilistic terms
  - Repeat millions of times to get the statistical distribution of ion locations

Monte Carlo Simulation

- Simulations from www.srim.org

Gaussian Model

- We often use a simple Gaussian model for the distribution of dopants
  - Mean = \( R_p \) = projected range
  - Standard deviation = \( \Delta R_p \) = straggle
  - Dose = \( \phi \) (dopants/cm²)
- Fit to Monte Carlo results or experimental data
  \[ N(x) = \frac{\phi}{\sqrt{2\pi}\Delta R_p} e^{-\left(x-R_p\right)^2/(2\Delta R_p)^2} \]
Gaussian Fit to Monte Carlo

Lateral Scattering

- Lighter elements show more lateral scattering due to greater amounts of backscattering
  - For As, Sb: $\Delta R_L = \Delta R_p$
  - For P: $\Delta R_L = 1.2 \Delta R_p$
  - For B: $\Delta R_L = 2 \Delta R_p$

- For lateral scatter at an edge, integration of the Gaussian gives an error function

$$N(y) \propto \text{erfc} \left( \frac{y}{\sqrt{2} \Delta R_L} \right)$$

Finding the Model Parameters

- The Gaussian model can be fit either to Monte Carlo simulations or experimental data
- The straggle can be estimated from

$$\Delta R_p = \frac{2}{3} \Delta R_p \left( \frac{\sqrt{M_i M_t}}{M_i + M_t} \right)$$

- $i = \text{ion}$, $t = \text{target}$
- $M = \text{atomic mass}$

- Gaussian model becomes skewed for lighter dopants (B) due to greater backscattering
  - Pearson IV distribution is often used instead of Gauss
  - BF$_2$ is sometimes used as the dopant

Model Parameters (From Campbell)

Lecture 17: What have we learned?

- What processes affect the trajectory of an ion through a wafer?
- Explain Monte Carlo simulations of ion implantation.
- What are the parameters used in the Gaussian model of implant distribution?
- Define ‘straggle’ and ‘transverse straggle’.