CHE323/CHE384
Chemical Processes for Micro- and Nanofabrication
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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

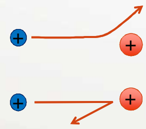
- Drag force is proportional to ion velocity
  - Drag force ∝ velocity ∝ $\sqrt{energy}$
- Energy loss per unit path length (*s*)

$$\frac{dE}{ds} = k_e\sqrt{E}$$

- k_e depends on the masses and atomic numbers of the ion and the target atoms

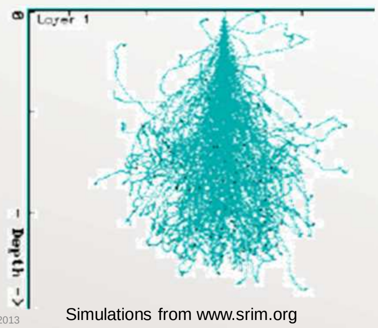
Scattering

- 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



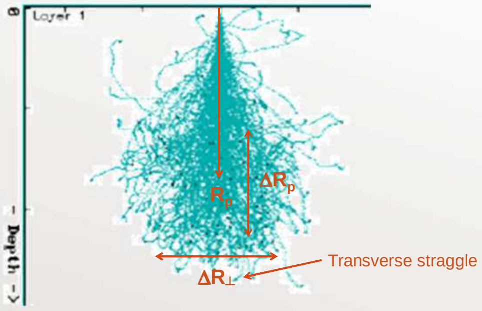
Simulations from www.srim.org

Gaussian Model

- We often use a simple Gaussian model for the distribution of dopants
  - Mean = R_p = projected range
  - Standard deviation = ΔR_p = straggle
  - Dose = ϕ (# dopants/cm^2)
- Fit to Monte Carlo results or experimental data

$$N(x) = \frac{\phi}{\sqrt{2\pi}\Delta R_p} e^{-(x-R_p)^2/2\Delta R_p{}^2}$$

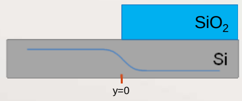
Gaussian Fit to Monte Carlo



Lateral Scattering

- Lighter elements show more lateral scattering due to greater amounts of backscattering
  – For As, Sb: $\Delta R_\perp \approx \Delta R_p$
  – For P: $\Delta R_\perp \approx 1.2\Delta R_p$
  – For B: $\Delta R_\perp \approx 2\Delta R_p$
- For lateral scatter at an edge, integration of the Gaussian gives an error function

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



Finding the Model Parameters

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

$$\Delta R_p \approx \frac{2}{3} R_p \left(\frac{\sqrt{M_i M_t}}{M_i + M_t}\right) \qquad \begin{array}{l} i = ion,\ t = target \\ M = atomic\ mass \end{array}$$

- 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)

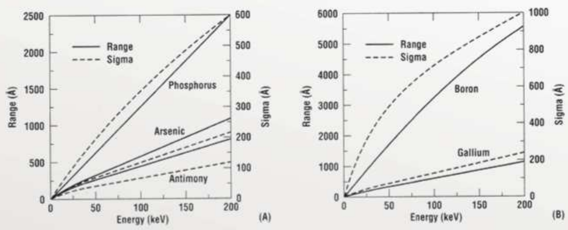


Figure 5.9 Projected range (solid lines and left axis) and standard deviation (dashed lines and right axis) for (A) n-type, (B) p-type, and (C) other species into a silicon substrate; (D) n-type and (E) p-type dopants into a GaAs substrate; and several implants into (F) SiO_2 and (G) AZ111 photoresist (*data from Gibbons* et al.).

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’.

