Section 4: Diffusion
part 2

Jaeger Chapter 4

Example: High Concentration Arsenic diffusion profile becomes “box-like”
**Summary of High-Concentration Diffusion**

If doping conc $< n_i$:

Use constant diffusivity solutions (profile is erfc or half-gaussian)

If doping conc $> n_i$:

*Solution requires numerical techniques*

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**Transient Enhanced Diffusion (TED)**

Dopant Implantation

Si substrate

Implantation creates large number of excess Si interstitials and vacancies. (1000X than thermal process). After several seconds of annealing, the excess point defects recombine.

Implantation induced excess point defects

900°C, several sec (TED)
Extremely rapid diffusion due to excess point defects

900°C, several minutes (After excess point defects recombine, slower diffusion)

C(x)

no annealing

X
**Diffusion: p-n Junction Formation**

- \( x_j = \) Metallurgical Junction Depth
- P-n junction occurs at the point \( x_j \) where the net impurity concentration is zero
- (i.e. p-type doping cancels out n-type doping)

Gaussian Profile:  
\[
x_j = 2 \sqrt{D t \ln \left( \frac{N_o}{N_B} \right)}
\]

Error Function profile:  
\[
x_j = 2 \sqrt{D t} \text{erfc} \left( \frac{N_o}{N_B} \right)
\]

**Sheet Resistance**

- \( A = W \cdot t \)
- \( R = \left( \frac{\rho}{t} \right) \left( \frac{L}{W} \right) = R_s \left( \frac{L}{W} \right) \)
- \( R_s = \frac{\rho}{t} = \) Sheet Resistance [Ohms per Square]
Resistivity vs. Doping

\[ \rho = \sigma^{-1} = \left[ q\left(\mu_n n + \mu_p p\right) \right]^{-1} \]

n-type: \( \rho \approx \left[q\mu_n (N_D - N_A)\right]^{-1} \)

p-type: \( \rho \approx \left[q\mu_p (N_A - N_D)\right]^{-1} \)

Resistivity Measurement: Four-Point Probe

\[ \rho = 2\pi s \frac{V}{I} \] [\(\Omega \cdot \text{m}\)] for \( t \gg s \)

\[ \rho = \frac{\pi t}{\ln 2} \frac{V}{I} \] [\(\Omega \cdot \text{m}\)] for \( s \gg t \)

\[ R_S = \rho = \frac{\pi}{\ln 2} \frac{V}{I} \approx 4.53 \frac{V}{I} \] [\(\Omega / \text{square}\)]

Four Terminal Resistance Measurement
Impurity Profiling
Secondary Ion Mass Spectroscopy (SIMS)

Self-limiting approach for doping of nanostructures

Strategy:
1. Boron monolayer formation on Si
2. Capping with SiO₂ cap
3. RTA to diffuse the B atoms

Chemistry is important for nano devices!
1. Various doping profiles can be readily achieved by tuning the RTA condition.

2. Doping efficiency of ~30% for B and ~90% for P.