Physics 607 (Fall 2014)

- Course map: Finish in site doping, wafer characterization, SiO₂ growth.
- Review of growth technique & doping.
- Float-zone or zone-refining growth.

\[ C_0 = \text{initial uniform doping of rod (Mass/m³)} \]
\[ S = \text{amount of dopant in zone} \]
\[ \int \text{Amount of dopant added to leading edge} = C_0 \cdot A \cdot dX \]
\[ \int \text{Amount of dopant removed from trailing edge} = K_e \cdot dM \]
\[ = K_e \cdot \frac{S}{V} \cdot dV \]
\[ = K_e \cdot S \cdot \frac{dx}{L} \]
So differential change in dopant is

\[ ds = C_0 \phi Adx - \frac{k_s S}{L} \cdot dx \]

or

\[ \frac{ds}{dx} = C_0 \phi A - \frac{k_s S}{L} \]

Solve differential Eq.

\[ C_s(x) = C_0 \left[ 1 - (1 - k_s) e^{-\frac{k_s x}{e}} \right] \]

Depreciation end:

Flow: Refined wafers have low impurities:
- Good for ultrapure Si (low dopant)
- Starting material for uniform doping (i.e., via neutron irradiation)

\[ Si_{30} + \text{Neutron} \rightarrow Si_{31}^{31} + \beta^{+} \]

\[ \text{Half-life: 2.5 hrs} \]

\[ \beta^{+} + \gamma \]

\[ \text{Remove Impurities!} \]
Flow-zone for uniform doping:

\[ C_5 = K_c C_1 e^{-\frac{K_a x}{L}} \]

When \( \frac{K_a}{L} \ll 1 \), then \( C_5 = K_c C_1 \)

- Go As Growth
- Wafer shaping & characteristics
- Growth of thermal oxide

To fabricate devices & integrated circuits, thin films are needed.

- Insulating oxide thin films
  - Field oxide
  - Gate oxide
- Dielectrics (SiO_2, Si_N_x, etc.) for insulation, "masks", passivation, etc.
- Polysilicon; gate, vias, S-D contacts
- Metal; wire interconnects

Ability to make smooth, insulating oxide w/ chemical stability @ high T is crucial for Si device performance & the cornerstone of Si planar processing.
Ways to Grow Oxide:

1. Thermal oxidation (Most important technologically)
2. Electrochemical Oxidation
3. Plasma reaction (O₂ plasma)
4. PVD, MBE, CVD

Thermal oxidation of Si:
Exposure to O₂ or H₂O @ elevated temperature => oxide on Si surface.

\[ E_0 = 9 \text{ eV} \]
\[ \rho_{dc} = 10^{16} \Omega \cdot \text{cm} \]
\[ \sigma_{th} = 0.014 \text{ W/cm}^2 \text{°C} \]
\[ n = 1.46 \]
\[ T_{null} = 1700 \text{°C} \]

- Etch with BHF (4:1:1) = 100nm/min

Tube furnace is used for thermal oxidation of Si.

PID control to within ±1°C

- Furnace Quartz Tube
  - \( T = 900 - 1200 \text{°C} \)
  - \( \text{O}_2/\text{H}_2 \text{O} \) gas @ 1L/min
  - Mass Flow Controllers
Kinetics of Growth

- Reactions:

  \[ \text{Si} \ (s) + O_2 \ (g) \rightarrow \text{SiO}_2 \ (s) \quad \text{Dry} \]

  \[ \text{Si} \ (s) + 2H_2O (g) \rightarrow \text{SiO}_2 \ (s) + 2H_2 (g) \quad \text{Wet} \]

- \( \text{Si} - \text{SiO}_2 \) interface moves into water

\[ \varphi_{\text{SiO}_2} < \varphi_{\text{Si}} \rightarrow \text{Sparging effect} \]

\[ \varphi_{\text{Si}} = 0.44 \varphi_{\text{SiO}_2} \]

i.e., \( 1 \) mm \( \text{SiO}_2 \) consumes 0.44 mm \( \text{Si} \)

- Structure

  \[ 2.37 \text{Å} \rightarrow 1.6 \text{Å} \]

  Tetrahedron