Requirements for Semiconductor Device Fabrication
(Assume elemental semiconductor homostructure)

- Elemental Material, e.g. Si not SiO$_2$
- High-Purity Material (no unintentional impurities)
- Crystalline Material
- Controlled Doping for Concentration and Location

Example: Silicon

Purity of Just-Extrinsic Silicon at Room Temperature
(Impurity level that effects conductivity, level that effects lifetime is much lower)

Intrinsic Si: $p_0 = n_0 = n_i = (1.5 \times 10^{10} \text{ cm}^{-3})$, then
\[
\sigma = q(n_0\mu_n + p_0\mu_p) = q[n_i(\mu_n + \mu_p)] \quad (\Omega\text{-cm})^{-1}
\]
\[
\sigma = (1.602 \times 10^{-19})(1.5 \times 10^{10})(1450 + 500) \quad (\Omega\text{-cm})^{-1}
\]
\[
\sigma = (4.686 \times 10^{-6}) \quad (\Omega\text{-cm})^{-1}
\]

Extrinsic SI with shallow donors $N_d^+ = 2.0 \times 10^{11} \text{ cm}^{-3}$:
\[
n_0 = 2.011 \times 10^{11} \text{ cm}^{-3} \quad \text{and} \quad p_0 = n_i^2/n_0 = 1.119 \times 10^9 \text{ cm}^{-3}
\]
\[
\sigma = (1.602 \times 10^{-19})[(2.011 \times 10^{11})(1450) + (1.119 \times 10^9)(500)]
\]
\[
\sigma = (4.681 \times 10^{-6}) \quad (\Omega\text{-cm})^{-1}
\]

Number of Si atoms per unit volume
(8 atoms per unit cell)(1 cell per a$^3$) = $[8/(0.5431 \times 10^{-9} \text{ m})^3]$
\[
= 4.994 \times 10^{22} \text{ atoms per cm}^3
\]

Note that $\sigma_{\text{extrinsic}}(N_d^+ = 2.0 \times 10^{11} \text{ cm}^{-3}) \sim 10 \times \sigma_{\text{intrinsic}}$
For $4.994 \times 10^{22}$ Si atoms per cm$^3$/2.0 x $10^{11}$ impurity atoms per cm$^3$
or
2.497 x $10^{11}$ Si atoms per one impurity atom
249.7 billion Si atoms per one impurity atom
EXAMPLE: SILICON MATERIAL

Elemental and High-Purity Si Material

Example Process
\[ \text{SiO}_2 \text{ (solid)} + \text{C} + \text{heat} \rightarrow \text{Si (impure solid)} + \text{CO}_2 \]
\[ \text{Si} + 4\text{Cl} \rightarrow \text{SiCl}_4 \text{ (impure liquid)} \rightarrow \text{SiCl}_4 \text{ (pure liquid)} \]
\[ \text{SiCl}_4 + 2\text{H}_2 + \text{heat} \rightarrow \text{Si (pure solid)} + 4\text{HCl} \]

Crystalline Si Material

Typical Process
Czochralski Method
- Liquid High-Purity Si in an SiO\(_2\) Container
- Seed Crystal dipped into Si Liquid
- Seed Crystal pulled as Si Layers are Deposited
  Requires
  1) Appropriate Temperature
  2) Appropriate Pull Rate
  3) Seed Crystal determines Crystal Orientation

Czochralski Boules (cylinders)
- X-rayed to Verify Crystallographic Quality
- “Flat” Ground on Side to Indicate Orientation
- Wafers are Cut

Controlled Doping of Si Material

Typical Processes
Doping of Czochralski Liquid
  Good for Background Doping
  Impractical for Device Structural Doping

Ion Implantation of Dopants
  Must be annealed to make dopants active and “heal” damage

Diffusion
  High-temperature process to diffuse dopants into material
  Good control, but graded concentrations

Epitaxy
  Layer by layer deposition upon a substrate
  Expensive and slow, but excellent control and abrupt structures
SEMICONDUCTOR COMPARISON

Si and Ge Compared to Compound Semiconductors

Advantages of Elemental Semiconductors
• Elemental semiconductors are less difficult and expensive to produce

Advantages of Compound Semiconductors
• Compounds are can provide higher performance, e.g. higher-speed
• Compounds can be direct (Si and Ge are indirect) and can be used for LEDs and LDs.

Si is superior to Ge

\[ E_G(Si) > E_G(Ge) \]
\[ n_{i,\text{Si}}(T) < n_{i,\text{Ge}}(T) \]
At Room Temperature
\[ n_{i,\text{Si}} = (1.5 \times 10^{10} \text{ cm}^{-3}) < n_{i,\text{Ge}} = (2.3 \times 10^{13} \text{ cm}^{-3}) \]
At a given temperature, lower doping levels are needed to create similar extrinsic behavior.
At a given extrinsic doping level, the extrinsic behavior occurs for higher temperatures.
• Better absorption by Si in photodiode applications for visible light and common visible and NIR laser wavelengths.

SiO\(_2\) is superior to GeO\(_2\)
• Surface Passivation Characteristics:
  SiO\(_2\) provides better protection from the environment, forms a more stable “skin,” and ties up surface bonds with less electrical defects.
• Processing Characteristics:
  SiO\(_2\) is easier to grow and has better etching and masking properties as compared to GeO\(_2\).

Silicon Dioxide (SiO\(_2\))

SiO\(_2\) in Device Processes
• Surface Passivation, Electrical Insulation, and Electrical Isolation

SiO\(_2\) in Fabrication Processes
• Diffusion Masks
• Cleaning Surface (growth and etch of SiO\(_2\) removes a layer of Si which may contain damage and impurities)