SEMICONDUCTOR FABRICATION

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: $p_0 = n_0 = n_i = (1.5 \text{ x } 10^{10} \text{ cm}^{-3})$, then
$\sigma = q(n_0\mu_n + p_0\mu_p) = q[n_i(\mu_n + \mu_p)]$ $(\Omega\text{-cm})^{-1}$
$\sigma = (1.602 \text{ x } 10^{-19})(1.5 \text{ x } 10^{10})(1450 + 500)$ $(\Omega\text{-cm})^{-1}$
$\sigma = (4.686 \text{ x } 10^{-6})$ $(\Omega\text{-cm})^{-1}$
Extrinsic SI with shallow donors $N_d^+ = 2.0 \text{ x } 10^{11} \text{ cm}^{-3}$:
$n_0 = 2.011 \text{ x } 10^{11} \text{ cm}^{-3}$ and $p_0 = n_i^2/n_0 = 1.119 \text{ x } 10^9 \text{ cm}^{-3}$
$\sigma = (1.602 \text{ x } 10^{-19})[(2.011 \text{ x } 10^{11})(1450) + (1.119 \text{ x } 10^9)(500)]$
$\sigma = (4.681 \text{ x } 10^{-5})$ $(\Omega\text{-cm})^{-1}$

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

Note that $\sigma_{\text{extrinsic}}(N_d^+ = 2.0 \text{ x } 10^{11} \text{ cm}^{-3}) \sim 10 \text{ x } \sigma_{\text{intrinsic}}$
For $4.994 \text{ x } 10^{22}$ Si atoms per $\text{cm}^3/2.0 \text{ x } 10^{11}$ impurity atoms per cm^{-3}
or
$2.497 \text{ x } 10^{11}$ 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

SiO_2 (solid) + C + heat –> Si (impure solid) + CO_2
Si + 4Cl –> $SiCl_4$ (impure liquid) –> $SiCl_4$ (pure liquid)
$SiCl_4 + 2H_2$ + heat –> Si (pure solid) + 4HCl

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)

- $n_{i,Si}(T) < n_{i,Ge}(T)$
  At Room Temperature $n_{i,Si} = (1.5 \times 10^{10}\ \text{cm}^{-3}) < n_{i,Ge} = (2.3 \times 10^{13}\ \text{cm}^{-3})$
  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)

Notes