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: $p_0 = n_0 = n_i = (1.5 \times 10^{10}\ cm^{-3})$, then

$\sigma = q(n_0\mu_n + p_0\mu_p) = q[n_i(\mu_n + \mu_p)]$ $(\Omega\text{-cm})^{-1}$

$\sigma = (1.602 \times 10^{-19})(1.5 \times 10^{10})(1450 + 500)$ $(\Omega\text{-cm})^{-1}$

$\sigma = (4.686 \times 10^{-6})$ $(\Omega\text{-cm})^{-1}$

Extrinsic SI with shallow donors $N_d^+ = 2.0 \times 10^{11}\ cm^{-3}$:

$n_0 = 2.011 \times 10^{11}\ cm^{-3}$ and $p_0 = n_i^2/n_0 = 1.119 \times 10^{9}\ cm^{-3}$

$\sigma = (1.602 \times 10^{-19})[(2.011 \times 10^{11})(1450) + (1.119 \times 10^{9})(500)]$

$\sigma = (4.681 \times 10^{-5})$ $(\Omega\text{-cm})^{-1}$

Number of Si atoms per unit volume

(8 atoms per unit cell)(1 cell per a^3) = $[8/(0.5431 \times 10^{-9}\ m)^3]$

$= 4.994 \times 10^{22}$ atoms per cm^3

Note that $\sigma_{extrinsic}(N_d^+ = 2.0 \times 10^{11}\ cm^{-3}) \sim 10 \times \sigma_{intrinsic}$

For 4.994×10^{22} Si atoms per cm^3/2.0×10^{11} impurity atoms per cm^{-3}

or

2.497×10^{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 $n_{i,Si} = (1.5 \times 10^{10}\ cm^{-3}) < n_{i,Ge} = (2.3 \times 10^{13}\ cm^{-3})$
  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