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## SEMICONDUCTOR FABRICATION

### Requirements for Semiconductor Device Fabrication

(Assume elemental semiconductor homostructure)

- Elemental Material, e.g. Si not SiO<sub>2</sub>
- 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  $N_d^+ = 2.0 \times 10^{11} \text{ cm}^{-3}$ :

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

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

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

#### Number of Si atoms per unit volume

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

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  $\text{cm}^3/2.0 \times 10^{11}$  impurity atoms per  $\text{cm}^{-3}$

or

$2.497 \times 10^{11}$  Si atoms per one impurity atom

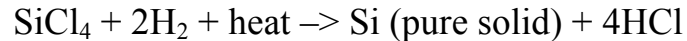
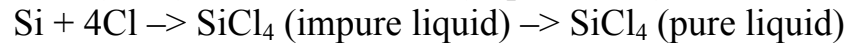
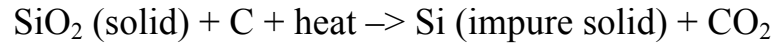
249.7 billion Si atoms per one impurity atom

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## EXAMPLE: SILICON MATERIAL

### Elemental and High-Purity Si Material

#### Example Process



### Crystalline Si Material

#### Typical Process

##### Czochralski Method

- Liquid High-Purity Si in an  $\text{SiO}_2$  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

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## 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 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

$$E_G(\text{Si}) > E_G(\text{Ge})$$

- $n_{i,\text{Si}}(T) < n_{i,\text{Ge}}(T)$

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<sub>2</sub> is superior to GeO<sub>2</sub>

- Surface Passivation Characteristics:

SiO<sub>2</sub> provides better protection from the environment, forms a more stable “skin,” and ties up surface bonds with less electrical defects.

- Processing Characteristics:

SiO<sub>2</sub> is easier to grow and has better etching and masking properties as compared to GeO<sub>2</sub>.

### Silicon Dioxide (SiO<sub>2</sub>)

#### SiO<sub>2</sub> in Device Processes

- Surface Passivation, Electrical Insulation, and Electrical Isolation

#### SiO<sub>2</sub> in Fabrication Processes

- Diffusion Masks
- Cleaning Surface (growth and etch of SiO<sub>2</sub> removes a layer of Si which may contain damage and impurities)

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## Notes