Introduction to Microelectronic Fabrication

Chapter 4
Diffusion
Impurity Diffusion

• Diffusion Mechanisms
  • Substitutional
  • Interstitial

**FIGURE 4.1**
Atomic diffusion in a two-dimensional lattice. (a) Substitutional diffusion, in which the impurity moves among vacancies in the lattice; (b) interstitial mechanism, in which the impurity atom replaces a silicon atom in the lattice, and the silicon atom is displaced to an interstitial site; (c) interstitial diffusion, in which impurity atoms do not replace atoms in the crystal lattice.
Diffusion
Fick’s First Law

Particle flux $J$ is proportional to the negative of the gradient of the particle concentration

$$J = -D \frac{\partial N}{\partial x}$$

$D$ = diffusion coefficient
Diffusion

Fick’s Second Law

Continuity Equation for Particle Flux:
Rate of increase of concentration is equal to the negative of the divergence of the particle flux

\[ \frac{\partial N}{\partial t} = -\frac{\partial J}{\partial x} \]

(in one dimension)

Fick's Second Law of Diffusion:
Combine First Law with Continuity Eqn.

\[ \frac{\partial N}{\partial t} = D \frac{\partial^2 N}{\partial x^2} \]

D assumed to be independent of concentration!
Constant Source Diffusion
Complementary Error Function Profiles

Concentration: \( N(x,t) = N_0 \text{erfc}\left(\frac{x}{2\sqrt{Dt}}\right) \)

Total Dose: \( Q = \int_{0}^{\infty} N(x,t)\,dt = 2N_0 \sqrt{\frac{Dt}{\pi}} \)

\(N_0\) = Surface Concentration

\(D\) = Diffusion Coefficient

\text{erfc} = \text{Complementary Error Function}

\[ \text{erfc}(z) = 1 - \text{erf}(z) \]

\[ \text{erf}(z) = \frac{2}{\sqrt{\pi}} \int_{0}^{z} \exp\left[-x^2\right] \,dx \]
Limited Source Diffusion

Gaussian Profiles

Concentration:

\[ N(x,t) = N_0 \exp \left( -\left( \frac{x}{2\sqrt{Dt_1}} \right)^2 \right) \]

\[ N_0 = \text{Surface Concentration} \]

\[ D = \text{Diffusion Coefficient} \]

Gaussian Profile

**FIGURE 4.3**

A Gaussian distribution results from a limited-source diffusion. As theDt product increases, the diffusion front moves more deeply into the wafer, and the surface concentration decreases. The area (impurity dose) under each of the three curves is the same.
Diffusion Profile Comparison

Complementary Error Function and Gaussian Profiles are Similar in Shape

\[
erfc(z) = 1 - erf(z)
\]

\[
erf(z) = \frac{2}{\sqrt{\pi}} \int_0^z \exp[-x^2] \, dx
\]

**FIGURE 4.4**
A graph comparing the Gaussian and complementary error function (erfc) profiles. We use this curve to evaluate the erfc and its inverse.
Diffusion Coefficients

**FIGURE 4.5**

Diffusion constants in silicon for (a) substitutional diffusers (above) and (b) interstitial diffusers (next page). Copyright John Wiley & Sons, Inc.; reprinted with permission from Ref. [28].
Diffusion Coefficients

\[ D = D_0 \exp\left(-\frac{E_A}{kT}\right) \quad \text{Arrhenius Relationship} \]

- \( E_A \) = activation energy
- \( k \) = Boltzmann's constant = \( 1.38 \times 10^{-23} \) J/K
- \( T \) = absolute temperature

### Example 4.1

Calculate the diffusion coefficient for boron at 1100 °C.

**Solution:** From Table 4.1, \( D_0 = 10.5 \, \text{cm}^2/\text{sec} \) and \( E_A = 3.69 \, \text{eV} \). \( T = 1373 \, \text{K} \).

\[
D = 10.5 \exp \left(-\frac{3.69}{(8.614 \times 10^{-5})(1373)} \right) = 2.96 \times 10^{-13} \, \text{cm}^2/\text{sec}.
\]

### Table 4.1 Typical Diffusion Coefficient Values for a Number of Impurities.

<table>
<thead>
<tr>
<th>Element</th>
<th>( D_0 ) (cm(^2)/sec)</th>
<th>( E_A ) (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>10.5</td>
<td>3.69</td>
</tr>
<tr>
<td>Al</td>
<td>8.00</td>
<td>3.47</td>
</tr>
<tr>
<td>Ga</td>
<td>3.60</td>
<td>3.51</td>
</tr>
<tr>
<td>In</td>
<td>16.5</td>
<td>3.90</td>
</tr>
<tr>
<td>P</td>
<td>10.5</td>
<td>3.69</td>
</tr>
<tr>
<td>As</td>
<td>0.32</td>
<td>3.56</td>
</tr>
<tr>
<td>Sb</td>
<td>5.60</td>
<td>3.95</td>
</tr>
</tbody>
</table>
Successive Diffusions

- Successive Diffusions Using Different Times and Temperatures
- Final Result Depends Upon the Total Dt Product

\[(Dt)_{tot} = \sum_{i} D_i t_i\]
Diffusion
Solid Solubility Limits

- There is a limit to the amount of a given impurity that can be “dissolved” in silicon (the Solid Solubility Limit).

- At high concentrations, all of the impurities introduced into silicon will not be electrically active.

**FIGURE 4.6**
The solid-solubility and electrically active impurity-concentration limits in silicon for antimony, arsenic, boron, and phosphorus. Reprinted with permission from Ref. [29]. This paper was originally presented at the 1977 Spring Meeting of The Electrochemical Society, Inc., held in Philadelphia, Pennsylvania.
Diffusion

p-n Junction Formation

$x_j = $ Metallurgical Junction Depth

P - n junction occurs at the point $x_j$ where the net impurity concentration is zero
(i.e. p-type doping cancels out n-type doping)

Gaussian Profile: \[ x_j = 2\sqrt{Dt \ln \left( \frac{N_0}{N_B} \right)} \]

Error Function profile: \[ x_j = 2\sqrt{Di \operatorname{erfc}^{-1} \left( \frac{N_0}{N_B} \right)} \]

FIGURE 4.7
Formation of a pn junction by diffusion. (a) An example of a p-type Gaussian diffusion into a uniformly doped n-type wafer; (b) net impurity concentration in the wafer. The metallurgical junction occurs at the point $x = x_j$ where the net concentration is zero. The material is converted to p-type to the left of $x_j$ and remains n-type to the right of $x_j$. 
Diffusion

Resistivity vs. Doping

\[
\rho = \sigma^{-1} = \left[q\left(\mu_n n + \mu_p p\right)\right]^{1}
\]

n-type: \(\rho \approx \left[q\mu_n (N_D - N_A)\right]^{1}\)

p-type: \(\rho \approx \left[q\mu_p (N_A - N_D)\right]^{1}\)

**FIGURE 4.8**

Room-temperature resistivity in n- and p-type silicon as a function of impurity concentration. (Note that these curves are valid for either donor or acceptor impurities but not for compensated material containing both types of impurities.)

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Diffusion
Two Step Diffusion

- Short constant source diffusion used to establish dose $Q$ ("Predep" step)
- Longer limited source diffusion drives profile in to desired depth ("drive in" step)
- Final profile is Gaussian

**FIGURE 4.9**
Calculated boron impurity profiles for Example 4.2. (a) Following the predeposition step at 900 C for 15 min; (b) following a subsequent 5-hr drive-in step at 1,100 C. The final junction depth is 2.77 μm with a surface concentration of $1.1 \times 10^{18}$/cm². The initial profile approximates an impulse.
Diffusion Calculation
Example 4.3 - Boron Diffusion

- A boron diffusion is used to form the base region of an npn transistor in a 0.18 Ω-cm n-type silicon wafer. A solid-solubility-limited boron predeposition is performed at 900° C for 15 min followed by a 5-hr drive-in at 1100°C. Find the surface concentration and junction depth (a) after the predep step and (b) after the drive-in step.
Diffusion Calculation
Example 4.3 - Boron Diffusion

Predeposition step is solid-solubility limited.

\[ T_1 = 900^\circ C = 1173K \rightarrow N_0 = 1.1 \times 10^{20}/cm^3 \]

\[ D_1 = 10.5 \exp \left[ -\frac{3.69eV}{(8.614 \times 10^{-5} eV/K)173K} \right] = 1.45 \times 10^{-15} cm^2/sec \]

\[ t_1 = 15 \text{ min} = 900 \text{ sec} \quad D_1 t_1 = 1.31 \times 10^{-12} cm^2 \]

\[ N(x) = 1.1 \times 10^{20} \text{erfc} \left( \frac{x}{2.28 \times 10^{-6} cm} \right) / cm^3 \]

Dose: \[ Q = 2N_o \sqrt{D_1 t_1} = 1.42 \times 10^{14} / cm^2 \]

\[ T_2 = 1100^\circ C = 1373K \]

\[ D_2 = 10.5 \exp \left[ -\frac{3.69eV}{(8.614 \times 10^{-5} eV/K)373K} \right] = 2.96 \times 10^{-13} cm^2/sec \]

\[ t_2 = 5 \text{ hr} = 18000 \text{ sec} \quad D_2 t_2 = 5.33 \times 10^{-9} cm^2 \]

\[ N_2(x) = \frac{1.42 \times 10^{14}/cm^2}{\sqrt{\pi(5.33 \times 10^{-9} cm^2)}} \text{exp} \left( -\frac{x}{2\sqrt{D_2 t_2}} \right)^2 = 1.1 \times 10^{18} \exp \left( -\frac{x}{1.46 \times 10^{-4}} \right)^2 / cm^3 \]
Diffusion Calculation
Example 4.3 (cont.)

\[ N_1(x) = 1.1 \times 10^{20} \text{erfc}\left(\frac{x}{2.28 \times 10^{-6} \text{cm}}\right) / \text{cm}^3 \]

\[ x_{j1} = 2 \sqrt{D_{ij} t_1 \text{erfc}^{-1}\left(\frac{N_a}{N_B}\right)} = (2.28 \times 10^{-6} \text{cm}) \text{erfc}^{-1}\left(\frac{3 \times 10^{16}}{1.1 \times 10^{20}}\right) = (2.28 \times 10^{-6} \text{cm}) \text{erfc}^{-1}(2.73 \times 10^{-4}) \]

\[ x_{j1} = (2.28 \times 10^{-6} \text{cm})(2.57) = 5.86 \times 10^{-6} \text{cm} = 0.058 \]

\[ N_2(x) = 1.1 \times 10^{18} \exp\left(-\frac{x}{1.46 \times 10^{-4}}\right)^2 / \text{cm}^3 \]

\[ x_{j2} = 1.46 \times 10^{-4} \text{cm} \sqrt{\ln\left(\frac{1.1 \times 10^{18}}{3 \times 10^{16}}\right)} = 2.77 \times 10^{-4} \text{cm} = 2.77 \mu\text{m} \]
Diffusion Calculation
Example 4.3 (cont.)

Starting Wafer: $n$-type $0.18 \Omega \cdot \text{cm}$

$n$-type $0.18 \Omega \cdot \text{cm} \rightarrow N_D = 3 \times 10^{16}/\text{cm}^3$
Two Step Diffusion

- Short constant source diffusion used to establish dose $Q$ ("Predep" step)

- Longer limited source diffusion drives profile in to desired depth ("drive in" step)

- Final profile is Gaussian

\[
\text{FIGURE 4.9}
\]
Calculated boron impurity profiles for Example 4.2. (a) Following the predeposition step at 900°C for 15 min; (b) following a subsequent 5-hr drive-in step at 1,100°C. The final junction depth is 2.77 μm with a surface concentration of $1.1 \times 10^{18}$cm$^{-2}$. The initial profile approximates an impulse.
Lateral Diffusion Under Mask Edge

- Diffusion is really a 3-D process. As impurities diffuse vertically, they also diffuse horizontally in both directions.
- Diffusion proceeds laterally under the edge of the mask opening.

FIGURE 4.10
Normalized two-dimensional complementary error function and Gaussian diffusions near the edge of a window in the barrier layer. Copyright 1965 by International Business Machines Corporation; reprinted with permission from Ref. [4].
Lateral Diffusion Under Mask Edge

FIGURE 4.10
Normalized two-dimensional complementary error function and Gaussian diffusions near the edge of a window in the barrier layer. Copyright 1965 by International Business Machines Corporation; reprinted with permission from Ref. [4].
Concentration Dependent Diffusion

Second Law of Diffusion

\[ \frac{\partial N}{\partial t} = \frac{\partial}{\partial x} D(x) \frac{\partial N}{\partial x} \]

Profiles More Abrupt at High Concentrations

TABLE 4.2 Properties of High-Concentration Arsenic and Boron Diffusions

<table>
<thead>
<tr>
<th>Element</th>
<th>( x_f ) (cm)</th>
<th>( D ) (cm²/sec)</th>
<th>( N_i ) (cm⁻³)</th>
<th>( Q ) (cm⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>( 2.29 \sqrt{N_i D t / n_i} )</td>
<td>22.9 ( \exp(-4.1/kT) )</td>
<td>( 1.56 \times 10^{17} (R/kT)^{-1} )</td>
<td>0.55 ( N_i \delta_i )</td>
</tr>
<tr>
<td>Boron</td>
<td>( 2.45 \sqrt{N_i D t / n_i} )</td>
<td>3.17 ( \exp(-3.9/kT) )</td>
<td>( 2.78 \times 10^{17} (R/kT)^{-1} )</td>
<td>0.67 ( N_i \delta_i )</td>
</tr>
</tbody>
</table>

FIGURE 4.11
Diffusion profiles for concentration-dependent diffusion. Copyright 1963 by the American Physical Society. Reprinted with permission from Ref. [6].
Concentration Dependent Diffusion

**FIGURE 4.12**

Shallow phosphorus diffusion profiles for constant-source diffusions at 950 °C. Copyright 1969 IEEE. Reprinted with permission from Ref. [10].
Resistors
Sheet Resistance

\[ A = W \cdot t \]

\[ R = \frac{\rho L}{A} \]

\[ R = \frac{\rho L}{t W} = R_s \left( \frac{L}{W} \right) \]

\[ R_s = \frac{\rho}{t} = \text{Sheet Resistance [Ohms per Square]} \]

\[ \left( \frac{L}{W} \right) = \text{Number of Squares of Material} \]

**FIGURE 4.13**

Resistance of a block of material having uniform resistivity. A uniform current distribution is entering the material perpendicular to the end of the block. The ratio of resistivity to thickness is called the *sheet resistance* of the material.
Resistors

Counting Squares

- Top and Side Views of Two Resistors of Different Size
- Resistors Have Same Value of Resistance
- Each Resistor is 7 inches
- Each End Contributes Approximately 0.65 inches
- Total for Each is 8.3 inches

Figure 4.14
Resistors
Contact and Corner Contributions

- Effective Square Contributions of Various Resistor End and Corner Configurations

Figure 4.15
Sheet Resistance

Irvin’s Curves

\[ \rho = \frac{1}{\sigma} = \frac{1}{\frac{1}{x_j} \int_0^{x_j} \sigma(x)dx} \]

\[ R_S = \frac{\rho}{x_j} = \frac{1}{\frac{1}{x_j} \int_0^{x_j} \sigma(x)dx} \]

\[ R_S \equiv \left[ \int_0^{x_j} q\mu N(x)dx \right]^{-1} \]

- Irvin Evaluated this Integral and Published a Set of Normalized Curves Plot Surface Concentration Versus Average Resistivity

- Four Sets of Curves
  - n-type and p-type
  - Gaussian and erfc
Sheet Resistance
Irvin’s Curves

FIGURE 4.16
Surface impurity concentration versus the sheet resistance–junction depth product for different silicon background concentrations at 300 K. (a) $n$-type erfc distribution; (b) $n$-type Gaussian distribution; (c) $p$-type erfc distribution; (d) $p$-type Gaussian distribution. After Ref. [2]. Reprinted from Ref. [5] with permission from the AT&T Technical Journal. Copyright 1962 AT&T.
Sheet Resistance
Irvin’s Curves (cont.)

(c) $p$-type erfc

(d) $p$-type Gaussian
Two Step Diffusion
Sheet Resistance - Predep Step

Initial Profile

$N_o = 1.1 \times 10^{20} /cm^3$

$N_B = 3 \times 10^{16} /cm^3$

$x_j = 0.0587 \ \mu m$

$p-$ type erfc profile

\[
R_S x_j = 50 \ \Omega \cdot \mu m
\]

\[
R_S = \frac{32 \ \Omega \cdot \mu m}{0.0587 \ \mu m} = 850 \ \Omega/\text{Square}
\]
Two Step Diffusion
Sheet Resistance - Drive-in Step

Final Profile

\[ N_o = 1.1 \times 10^{18} / \text{cm}^3 \]

\[ N_B = 3 \times 10^{16} / \text{cm}^3 \]

\[ x_j = 2.73 \ \mu \text{m} \]

p-type Gaussian profile

\[ R_S x_j = 700 \ \Omega \cdot \mu \text{m} \]

\[ R_S = \frac{700 \ \Omega \cdot \mu \text{m}}{2.73 \ \mu \text{m}} = 260 \ \Omega / \text{Square} \]

For the exclusive use of adopters of the book
Resistivity Measurement

Four-Point Probe

\[ \rho = 2\pi s \frac{V}{I} \quad [\Omega \cdot \text{m}] \text{ for } t \gg s \]

\[ \rho = \frac{\pi t}{\ln 2} \frac{V}{I} \quad [\Omega \cdot \text{m}] \text{ for } s \gg t \]

\[ R_S = \frac{\rho}{t} = \frac{\pi}{\ln 2} \frac{V}{I} \approx 4.53 \frac{V}{I} \quad [\Omega/\text{square}] \]

Four Terminal Resistance Measurement

*FIGURE 4.17*

Four-point probe with probe spacing \( s \) used for direct measurement of bulk wafer resistivity and the sheet resistance of thin diffused layers. A known current is forced through the outer probes, and the voltage developed is measured across the inner probes. (See Eqs. (4.16) through (4.18)).
Four-Point Probe Correction Factors

Correction Factors

(a) Wafers Thick Relative to the Probe Spacing

(b) Wafers of Finite Diameter

\[ \rho = F \rho_{\text{measured}} \]
Sheet Resistance
van der Pauw’s Method

Van der Pauw’s Theory
Any Four-Terminal Region without Holes

\[ \exp \left( -\pi t \frac{R_{AB,CD}}{\rho} \right) + \exp \left( -\pi t \frac{R_{BC,DA}}{\rho} \right) = 1 \]

\[ R_{AB,CD} = \frac{V_{CD}}{I_{AB}} \quad \text{and} \quad R_{BC,DA} = \frac{V_{DA}}{I_{BC}} \]

For symmetrical structure \( R_{AB,CD} = R_{AB,CD} \)

\[ R_S = \frac{\rho}{t} = \left( \frac{\pi}{\ln 2} \right) \frac{V_{CD}}{I_{AB}} \]

Four Terminal Resistance Measurement

---

FIGURE 4.19
A simple van der Pauw test structure used to measure the sheet resistance of a diffused layer. Sheet resistance is calculated using Eq. (4.20).
Junction Depth Measurement

- Groove and Stain Method

\[ x_j = \frac{(a + b)(a - b)}{2R} \]

FIGURE 4.20
Junction-depth measurement by the groove-and-stain technique. The distances \(a\) and \(b\) are measured through a microscope, and the junction depth is calculated using Eq. (4.11).
Junction Depth Measurement

• Angle Lap Technique

\[ x_j = d \tan \theta = N \frac{\lambda}{2} \]

FIGURE 4.21
Junction depth measurement by the angle-lap and stain method. Interference fringe lines are used to measure the distance \( d \), which is related to the junction depth using Eq. (4.12).
Impurity Profiling

Spreading Resistance

- Region of Interest is Angle-Lapped
- Two-Point Probe Resistance Measurements vs. Depth
- Profile Extracted

FIGURE 4.22
Example of an impurity profile measured using the spreading resistance method.
Impurity Profiling
Secondary Ion Mass Spectroscopy (SIMS)

TABLE 4.3  SIMS Analysis in Silicon.

<table>
<thead>
<tr>
<th>Element</th>
<th>Ion Beam</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>Cesium</td>
<td>$5 \times 10^{14}/$cm$^3$</td>
</tr>
<tr>
<td>Boron</td>
<td>Oxygen</td>
<td>$1 \times 10^{13}/$cm$^3$</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Cesium</td>
<td>$5 \times 10^{15}/$cm$^3$</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Cesium</td>
<td>$1 \times 10^{17}/$cm$^3$</td>
</tr>
</tbody>
</table>

FIGURE 4.23
(a) Concept of a SIMS analysis system. (b) Example of an impurity profile measured using the SIMS analysis. Copyright 1997 IEEE. Reprinted with permission from Ref. [17].
Diffusion Simulation

After Predep

After Drive-in

SUPREM Simulation

$\text{TWO\ STEP\ DIFFUSION}$
$\text{INITIALIZE <100> PHOS}=0.18\ \text{RESISTIVITY}$
$\text{DIFFUSE TEMP}=900\ \text{TIME}=15\ \text{BORON}=1E21$

$\ldots$

$\text{DIFFUSE TEMP}=1100\ \text{TIME}=300$

$\ldots$

$\ldots$

**FIGURE 4.24**
SUPREM simulation results for two-step boron diffusion into phosphorus doped wafer from Ex. 4.3.
Diffusion Systems

Open Furnace Tube Systems

(a) Solid source in platinum source boat

(b) Liquid Source - carrier gas passing through bubbler

(c) Gaseous impurity source

Wafers in Quartz Boat

Scrubber at Output

FIGURE 4.25
Open-furnace-tube diffusion systems. (a) Solid source in a platinum source boat in the rear of diffusion tube; (b) liquid-source system with carrier gas passing through a bubbler; (c) diffusion system using gaseous impurity sources. Copyright John Wiley and Sons. Reprinted with permission from Ref. [23].
Diffusion Systems
Boron Diffusion

Surface Reaction:

\[ 2B_2O_3 + 3Si \leftrightarrow 4B + 3SiO_2 \]

Gaseous Source: Diborane \( B_2H_6 \) (Extremely Toxic)

\[ B_2H_6 + 3O_2 \xrightarrow{300^\circ C} B_2O_3 + 3H_2O \]

\[ B_2H_6 + 6CO_2 \xrightarrow{300^\circ C} B_2O_3 + 6CO + 3H_2O \]

All systems need careful scrubbing!

Solid Sources: Boron Nitride & Trimethylborate (TMB)

\[ 2(CH_3O)_3B + 9O_2 \xrightarrow{900^\circ C} B_2O_3 + 6CO_2 + 9H_2O \]

Class is using Boron Nitride Wafers

Liquid Sources: Boron Tribromide \( BBr_3 \)

\[ 4BBr_3 + 3O_2 \rightarrow 3B_2O_3 + 6Br_2 \]
Diffusion Systems
Phosphorus Diffusion

Surface Reaction:

\[ 2P_2O_5 + 5Si \leftrightarrow 4P + 5SiO_2 \]

Gaseous Source: Phosphine \( \text{PH}_3 \)  (Extremely Toxic)

\[ 2\text{PH}_3 + 4O_2 \rightarrow P_2O_5 + 3H_2O \]

Solid Sources:

- Phosphorus Pentoxide
- Ammonium monophosphate \( \text{NH}_4\text{H}_2\text{PO}_4 \)
- Ammonium diphosphate \( (\text{NH}_4)_2\text{H}_2\text{PO}_4 \)

All systems need careful scrubbing!

\[ \text{P}_2\text{O}_5 \quad \text{POCl}_3 \quad \text{Cl}_2 \]

Liquid Source: Phosphorus Oxychloride \( \text{POCl}_3 \)

\[ 4\text{POCl}_3 + 3O_2 \rightarrow 3P_2O_5 + 6\text{Cl}_2 \]
Diffusion Systems
Arsenic & Antimony Diffusion

Arsenic Surface Reaction

\[ 2\text{As}_2\text{O}_3 + 3\text{Si} \leftrightarrow 3\text{SiO}_2 + 4\text{As} \]

Solid Sources: Possible - Low Surface Concentrations

Gaseous Source: Arsine \( \text{AsH}_3 \) (Extremely Toxic)

Ion - Implantation Is Normally Used for Deposition

Antimony Surface Reaction

\[ 2\text{Sb}_2\text{O}_3 + 3\text{Si} \leftrightarrow 3\text{SiO}_2 + 4\text{Sb} \]

Liquid Source: Antimony Pentachloride \( \text{Sb}_3\text{Cl}_5 \)

Ion - Implantation Is Normally Used for Deposition
Diffusion
Toxicity of Gaseous Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>8-h exposure level (ppm)</th>
<th>Life-threatening exposure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diborane (B₂H₆)</td>
<td>0.10</td>
<td>160 ppm for 15 min</td>
<td>Colorless, sickly sweet, extremely toxic, flammable.</td>
</tr>
<tr>
<td>Phosphine (PH₃)</td>
<td>0.30</td>
<td>400 ppm for 30 min</td>
<td>Colorless, decaying fish odor, extremely toxic, flammable. A few minutes' exposure to 2000 ppm can be lethal.</td>
</tr>
<tr>
<td>Arsine (AsH₃)</td>
<td>0.05</td>
<td>6–15 ppm for 30 min</td>
<td>Colorless, garlic odor, extremely toxic. A few minutes' exposure to 500 ppm can be lethal.</td>
</tr>
<tr>
<td>Silane (SiH₄)</td>
<td>0.50</td>
<td>Unknown</td>
<td>Repulsive odor, burns in air, explosive, poorly understood.</td>
</tr>
<tr>
<td>Dichlorosilane (SiH₂Cl₂)</td>
<td>5.00</td>
<td>...</td>
<td>Colorless, flammable, toxic. Irritating odor provides adequate warning for voluntary withdrawal from contaminated areas.</td>
</tr>
</tbody>
</table>

*Data from the 1979 American Conference of Governmental Hygienists (ACGIH).
Diffusion

Gettering

- Improves Quality of Wafers
  - Removes Metallic Impurities: Cu, Au, Fe, Ni (Rapid Diffusers)
  - Removes Crystal Defects: Dislocations
- Backside Treatment
  - Surface Damage e. g. Sandblasting
  - Phosphorus Diffusion
- Argon Implantation
- Internal Stress
- Crystal Defects
- Oxygen Incorporation
  - During Growth
  - Implantation
Diffusion References


End of Chapter 4