Engineering of Semiconductor

:Semiconductor Physics and Devices

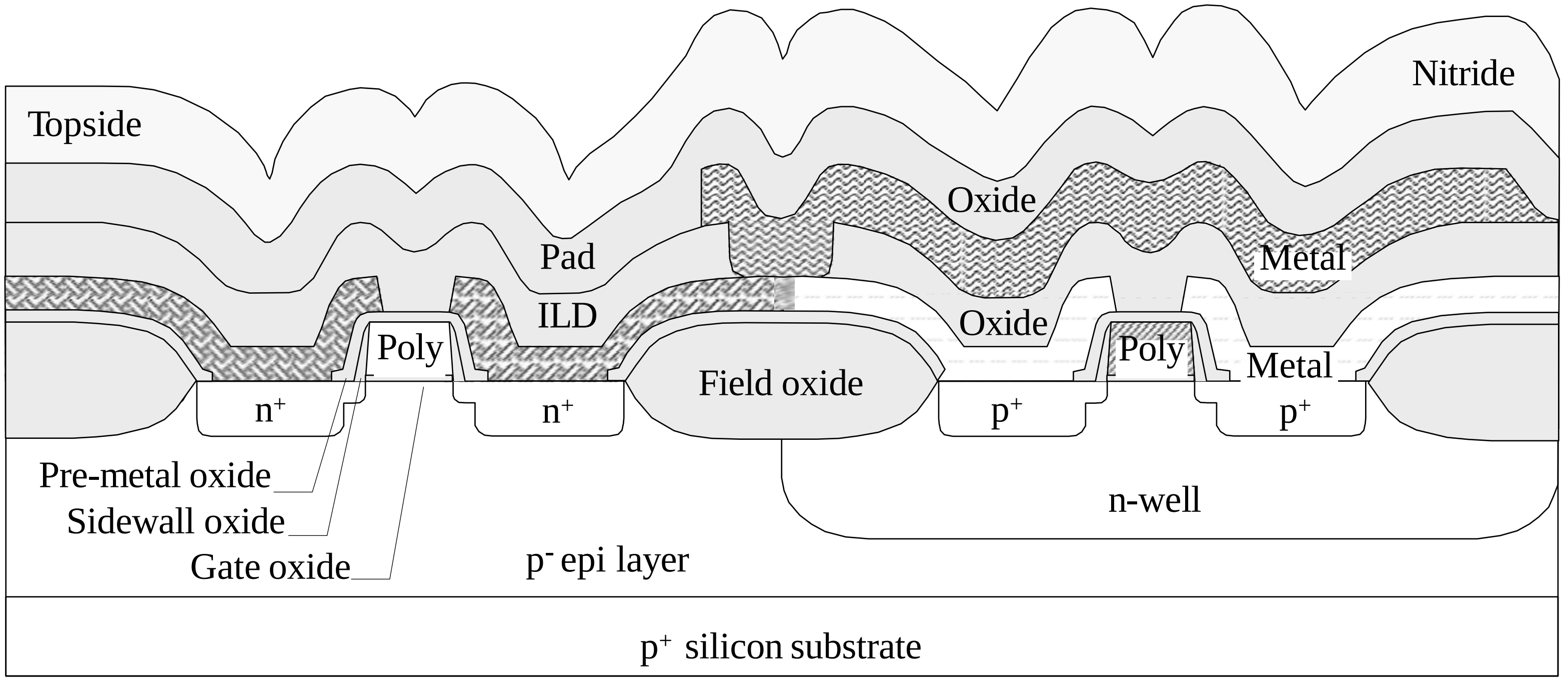
Chapter 2. Silicon Technology

Objectives

Overview of Silicon Technology

- Wafer preparation
- Lithography
- Oxidation
- Etching
- Doping
- Deposition
- Packaging

Film Layers for NMOS Transistor



Process Flow in a Wafer Fab

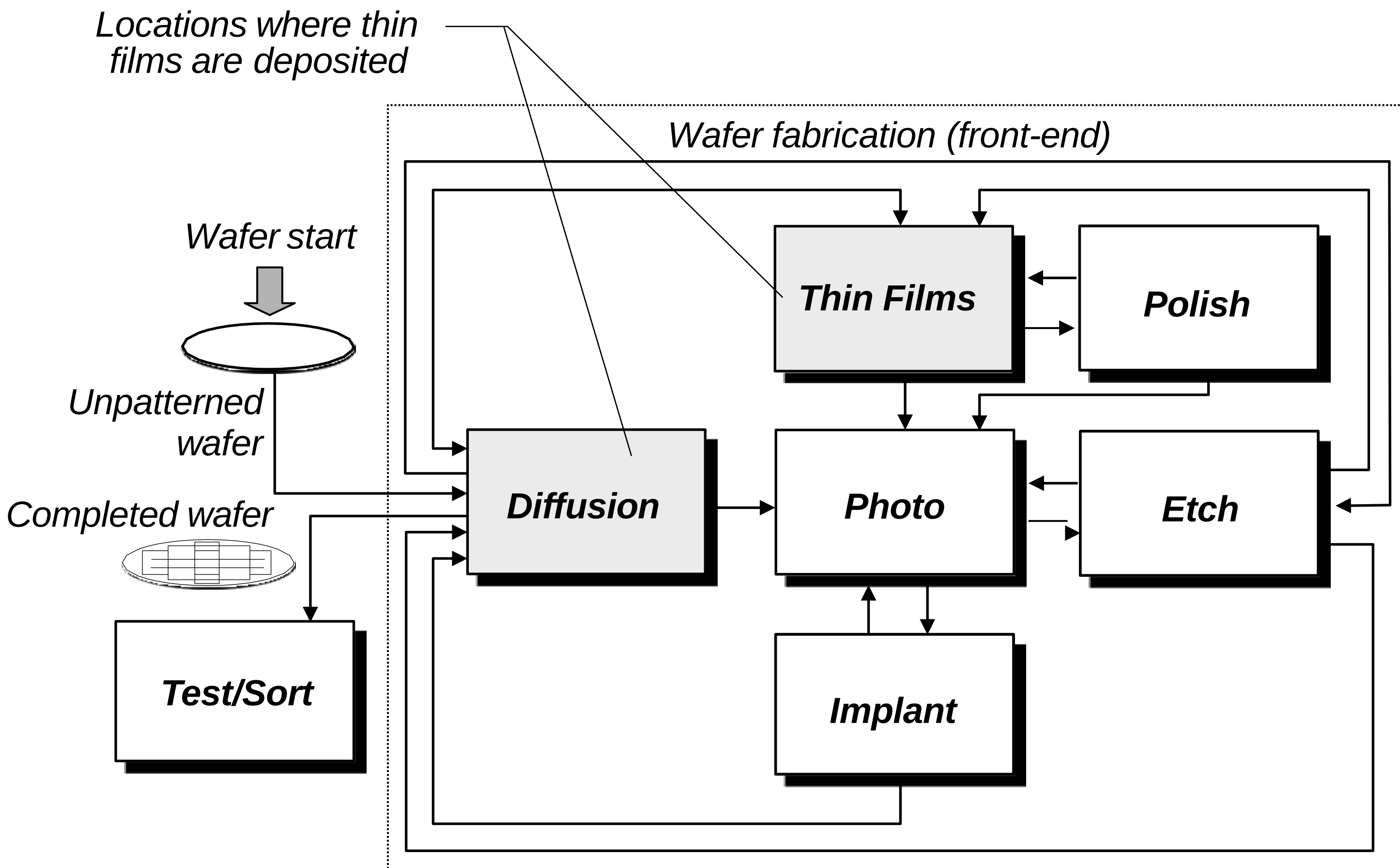


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Figure 11.2

Introduction

- Film Layering in Wafer Fab
  - Diffusion
  - Thin Films
- Film Layering Terminology
- Multilayer Metallization
  - Metal Layers
  - Dielectric Layers

Multilevel Metallization on a ULSI Wafer

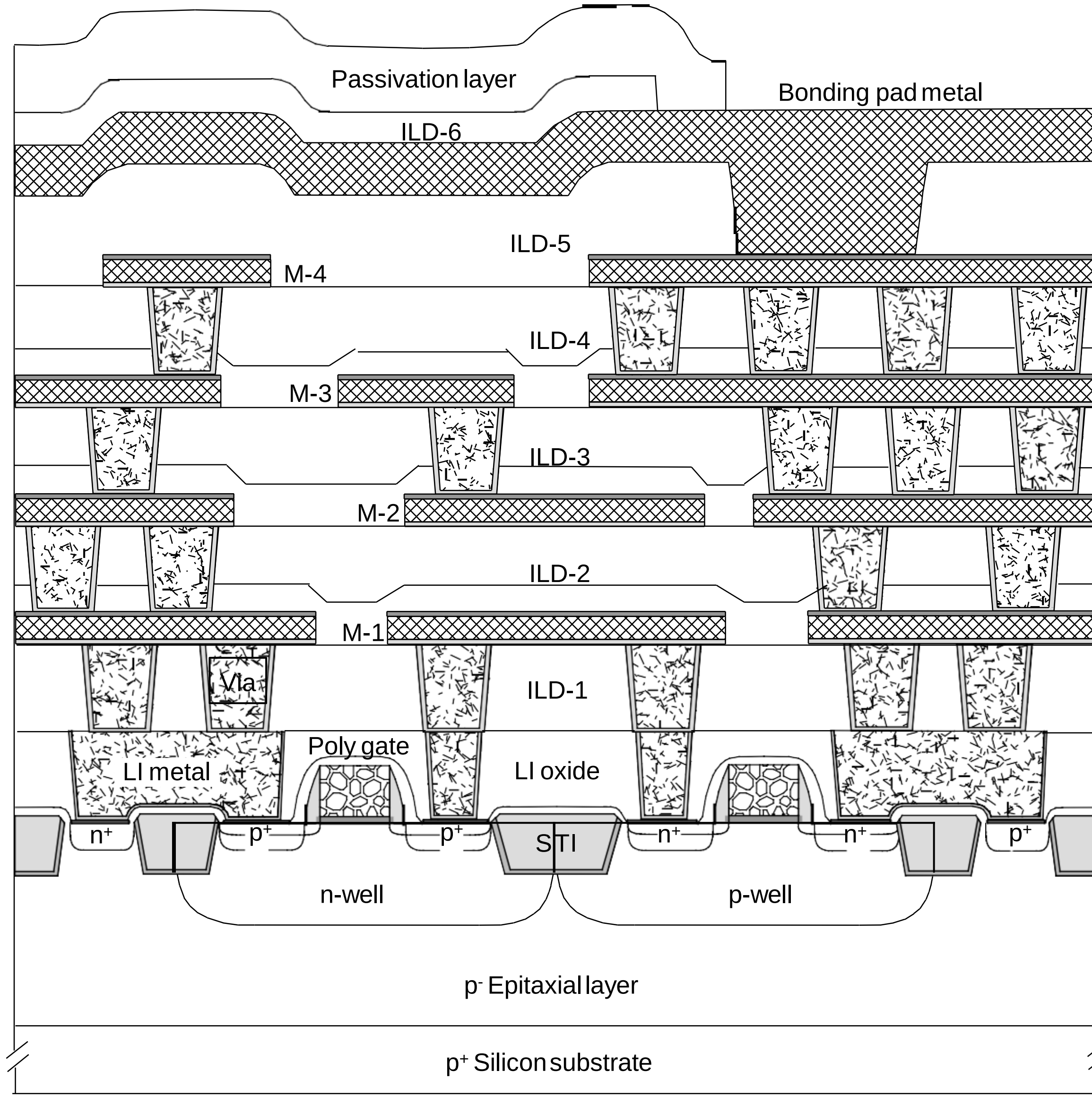
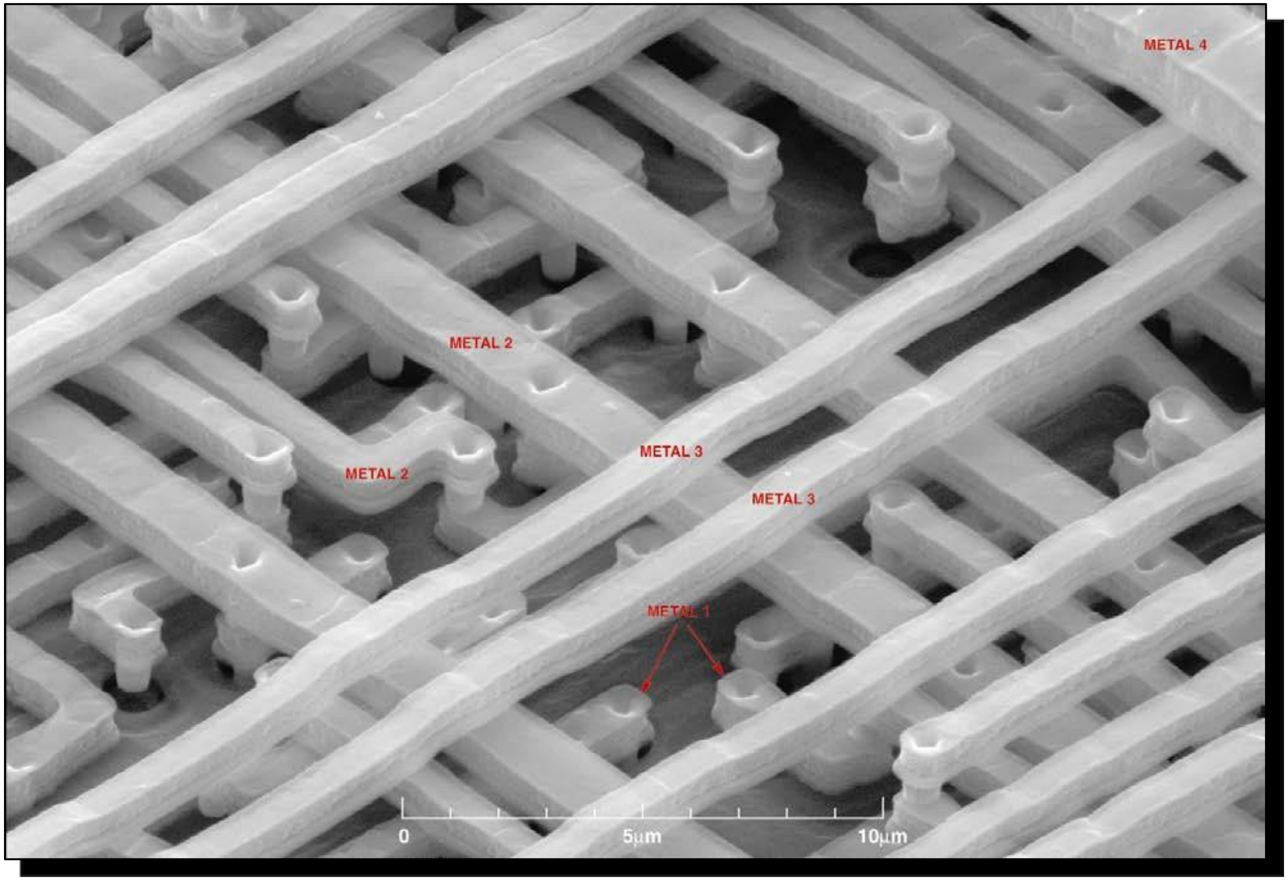


Figure 11.3

Metal Layers in a Chip



Micrograph courtesy of Integrated Circuit Engineering

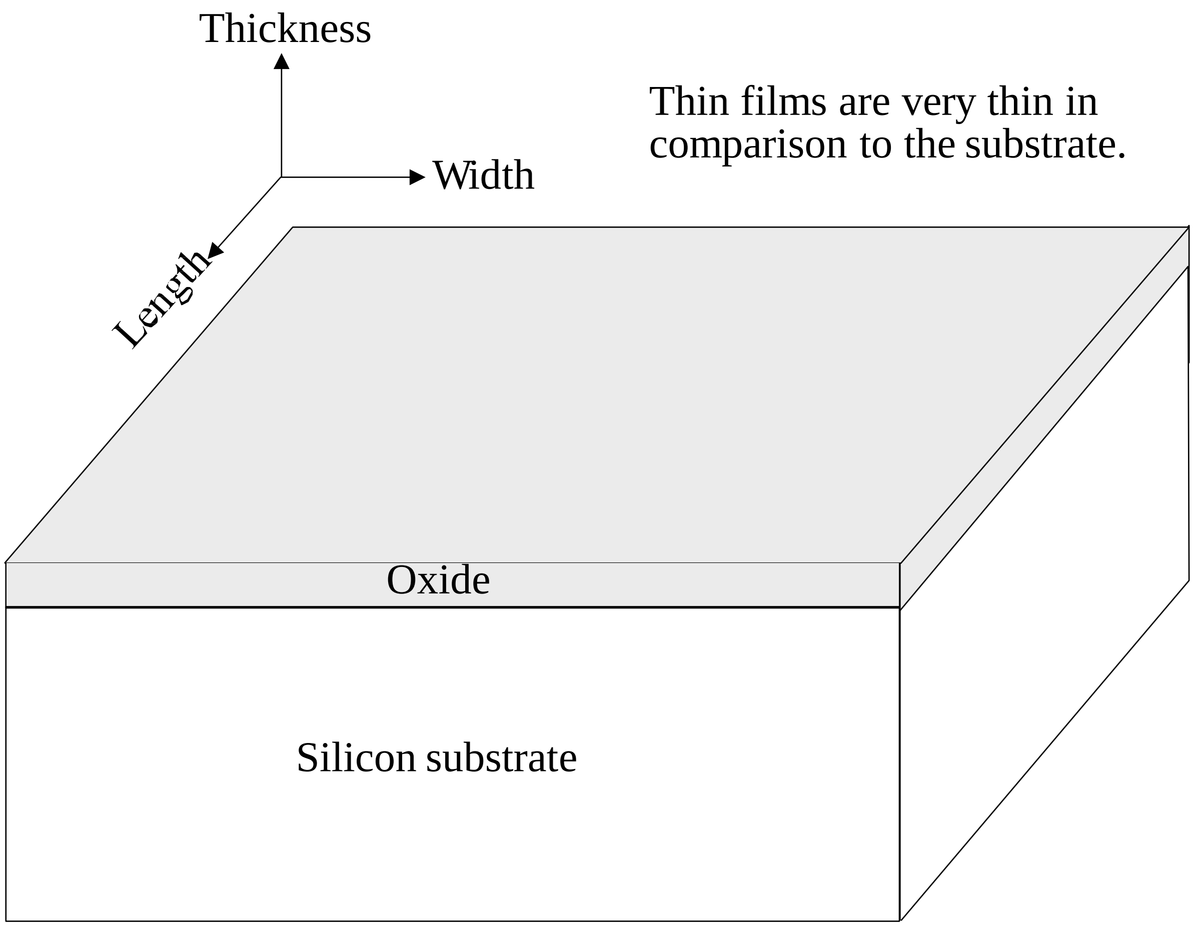
Film Deposition

Thin Film Characteristics

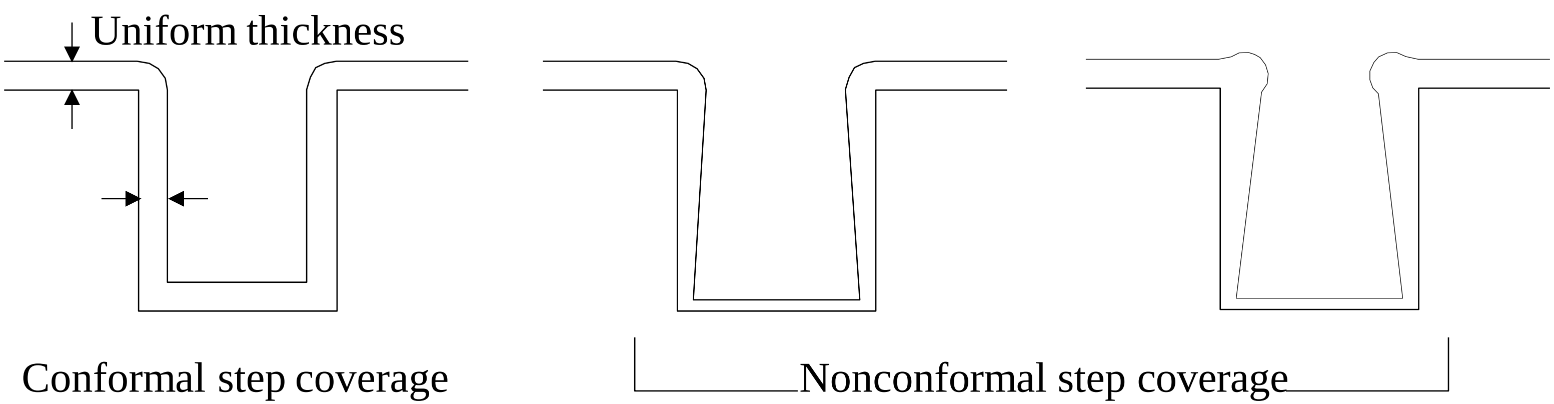
- Good step coverage
- Ability to fill high aspect ratio gaps (conformality)
- Good thickness uniformity
- High purity and density
- Controlled stoichiometries
- High degree of structural perfection with low film stress
- Good electrical properties
- Excellent adhesion to the substrate material and subsequent films

Solid Thin Film

Thin films are very thin in comparison to the substrate.

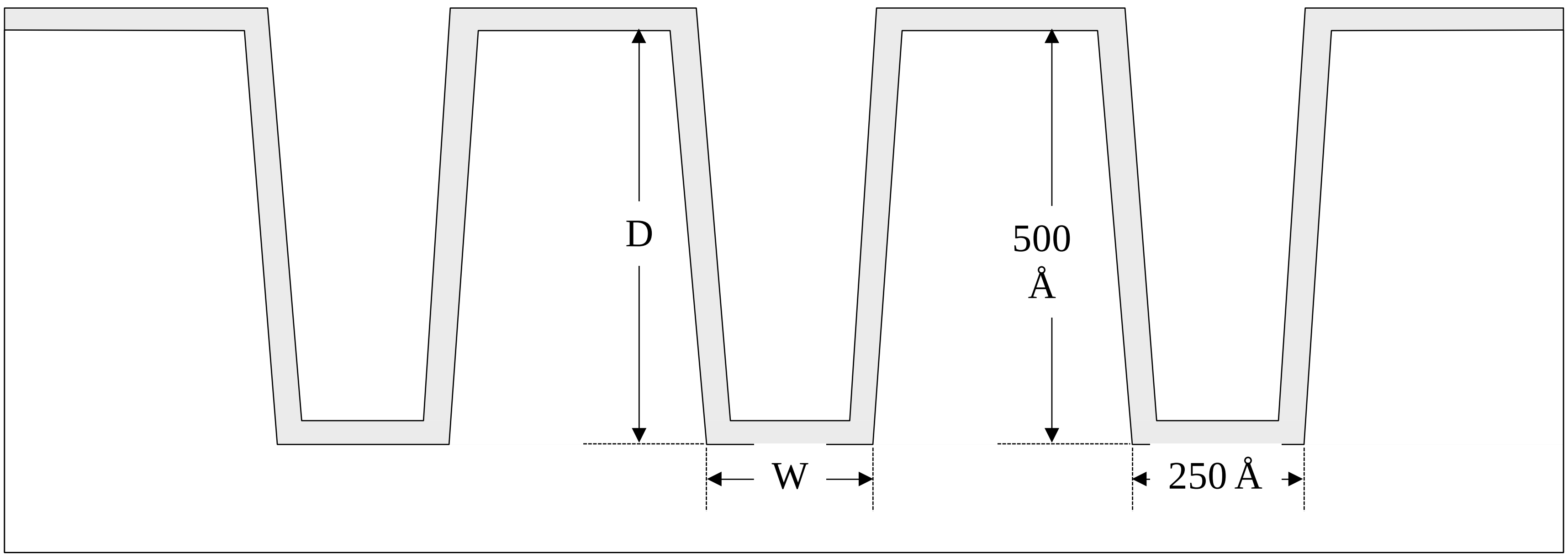


Film Coverage over Steps

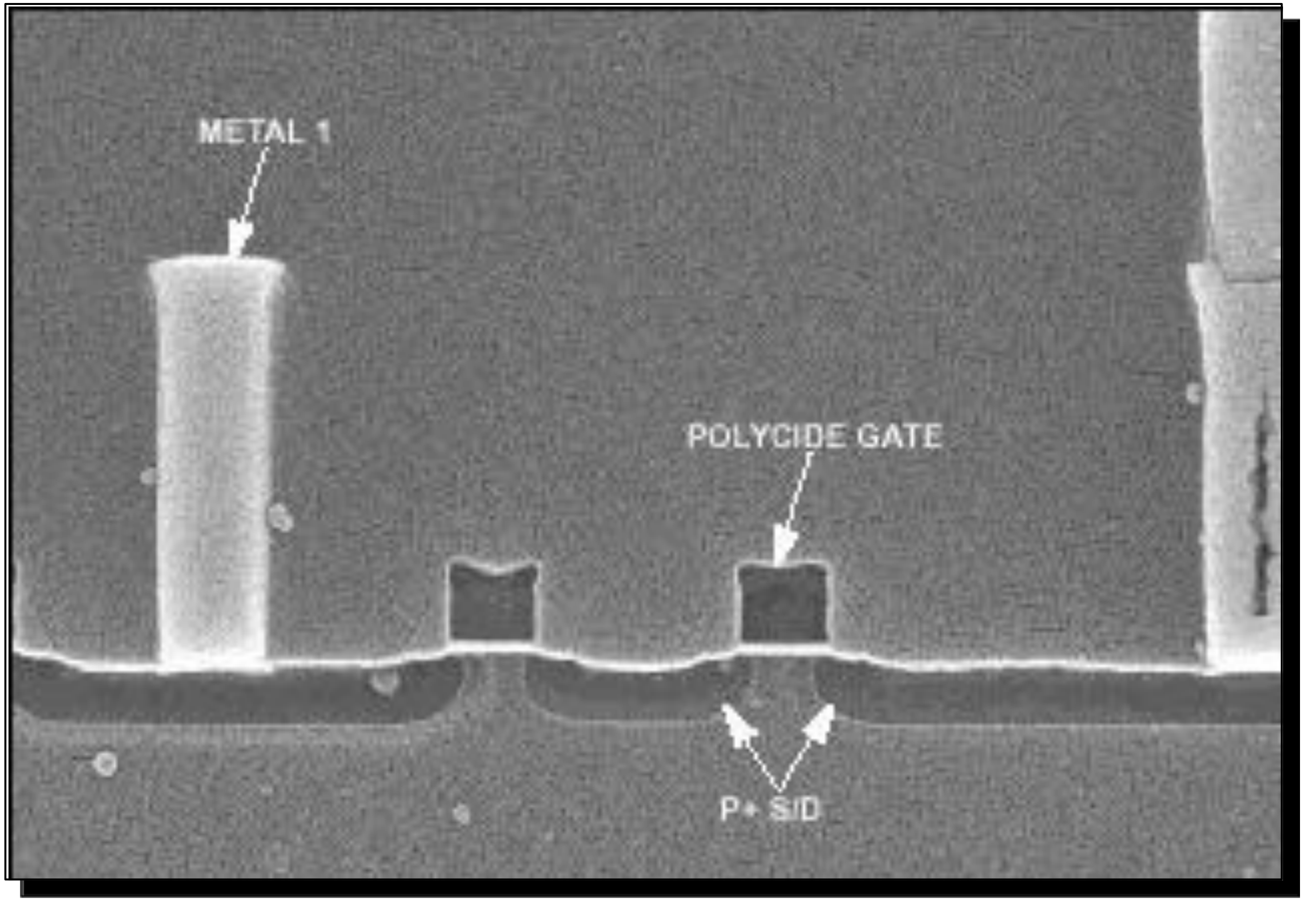


Aspect Ratio for Film Deposition

$$\text{Aspect Ratio} = \frac{\text{Depth}}{\text{Width}} \qquad \text{Aspect Ratio} = \frac{500\ \text{Å}}{250\ \text{Å}} = \frac{2}{1}$$



High Aspect Ratio Gap



Photograph courtesy of Integrated Circuit Engineering

Stages of Film Growth

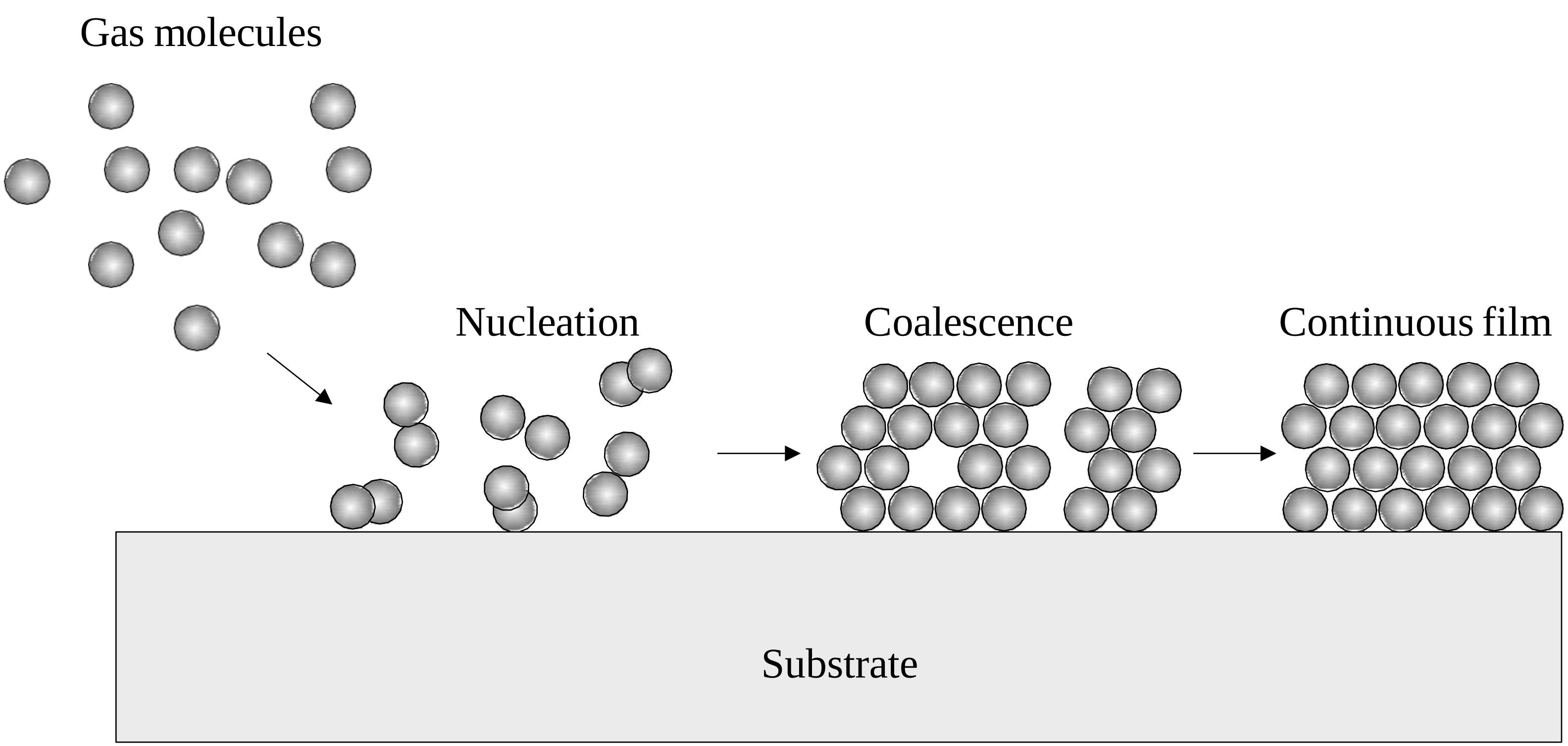


Figure 11.7

Techniques of Film Deposition

Chemical Processes		Physical Processes		
Chemical Vapor Deposition (CVD)	**Plating**	**Physical Vapor Deposition (PVD or S puttering)**	**Evaporation**	**Spin On Methods**
Atmospheric Pressure CVD (APCVD) or Sub-Atmospheric CVD (SACVD)	Electrochemical dep osition (ECD), comm only referred to as el ectroplating	DC Diode	Filament and Electron Beam	Spin on g lass (SOG)
Low Pressure CVD (LPCVD)	Electroless Plating	Radio Frequency (RF)	Molecular Beam Epitaxy (MBE)	Spin on d ielectric (SOD)
Plasma Assisted CVD: ▪ Plasma Enhanced CVD (PECVD) ▪ High Density Plasma CVD (HDPCVD)		DC Magnetron		
Vapor Phase Epitaxy (VPE) and Metal-organic CVD (MOCVD)		Ionized metal plasma (IMP)		
Dielectrics: Chapter 11 Metals: Chapter 12	Chapter 12	Chapter 12	Chapter 12	Chapter 11

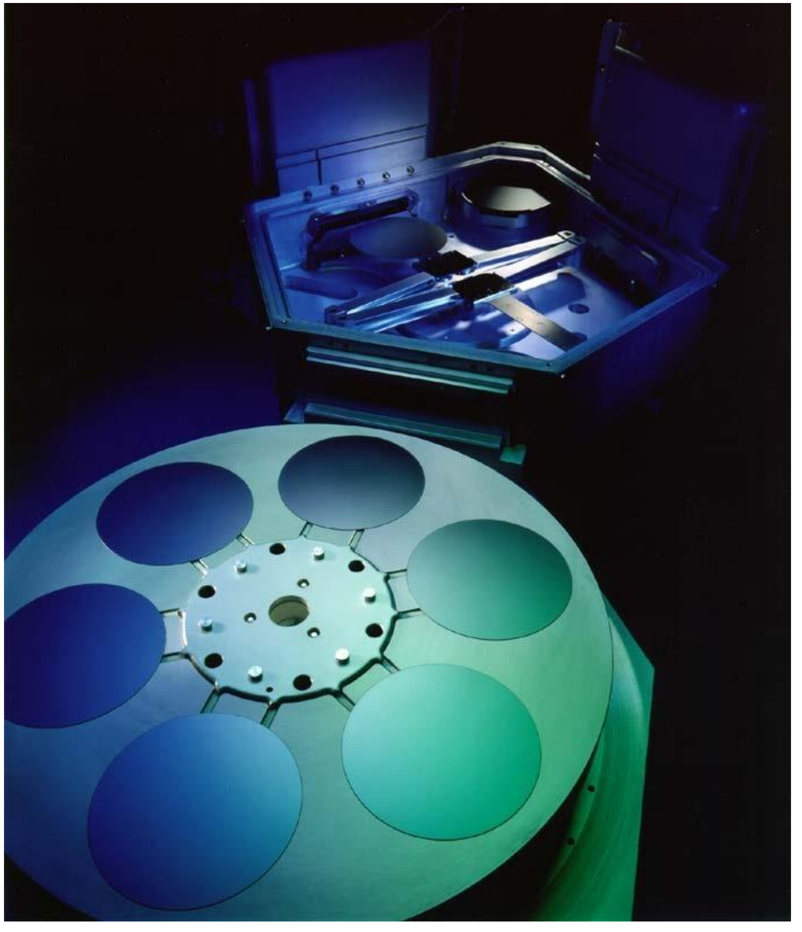
Table 11.1

Chemical Vapor Deposition

The Essential Aspects of CVD

1. Chemical action is involved, either through chemical reaction or by thermal decomposition (referred to as pyrolysis).
2. All material for the thin film is supplied by an external source.
3. The reactants in a CVD process must start out in the vapor phase (as a gas).

Chemical Vapor Deposition Tool



Photograph courtesy of Novellus, Sequel CVD

CVD Chemical Processes

1. **Pyrolosis**: a compound dissociates (breaks bonds, or decomposes) with the application of heat, usually without oxygen.

2. **Photolysis**: a compound dissociates with the application of radiant energy that breaks bonds.

3. **Reduction**: a chemical reaction occurs by reacting a molecule with hydrogen.

4. **Oxidation**: a chemical reaction of an atom or molecule with oxygen.

5. **Reduction-oxidation (redox)**: a combination of reactions 3 and 4 with the formation of two new compounds.

CVD Reaction

- CVD Reaction Steps
- Rate Limiting Step
- CVD Gas Flow Dynamics
- Pressure in CVD
- Doping During CVD
  - PSG
  - BSG
  - FSG

Schematic of CVD Transport and Reaction Steps

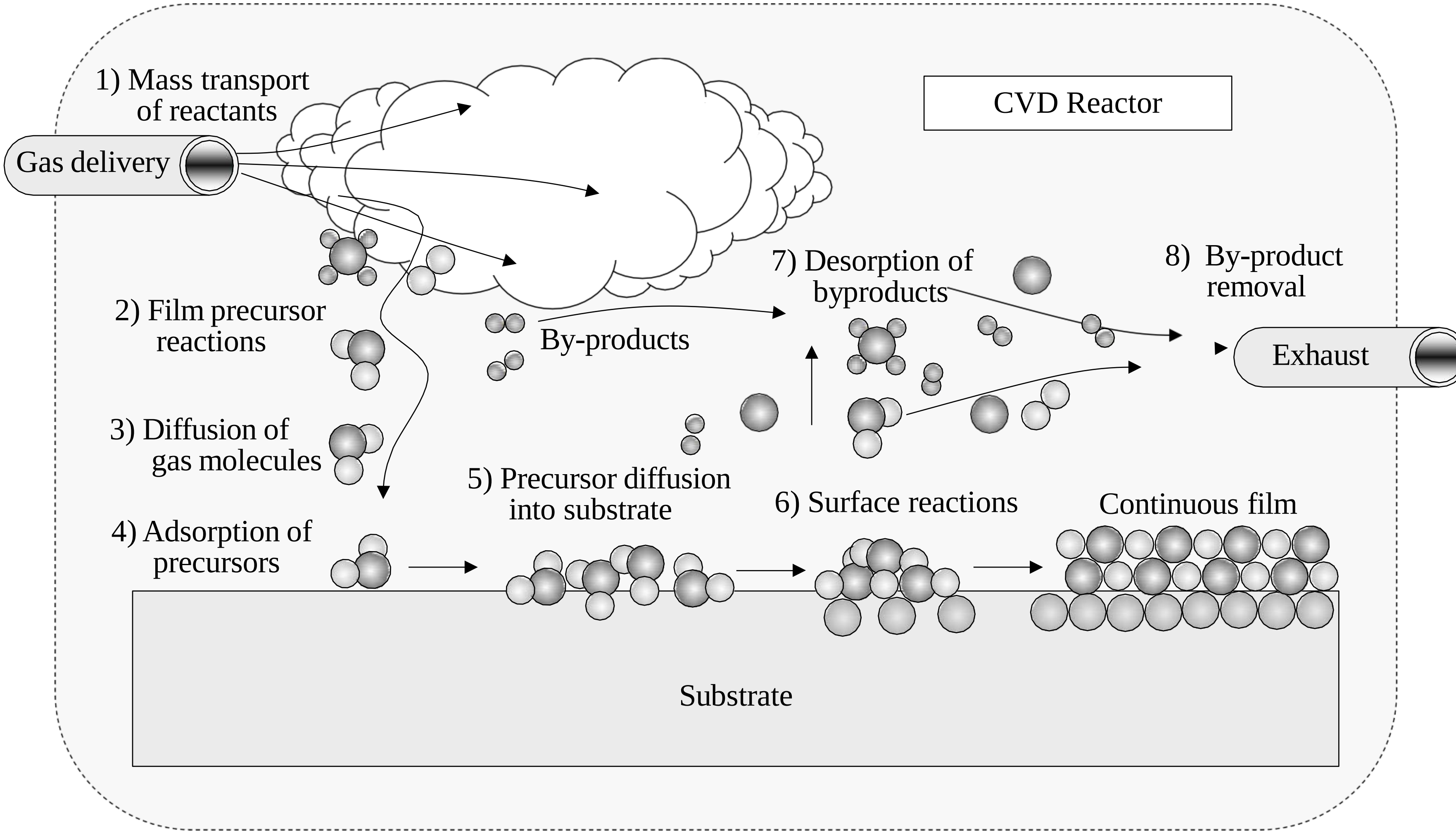


Figure 11.8

Gas Flow in CVD

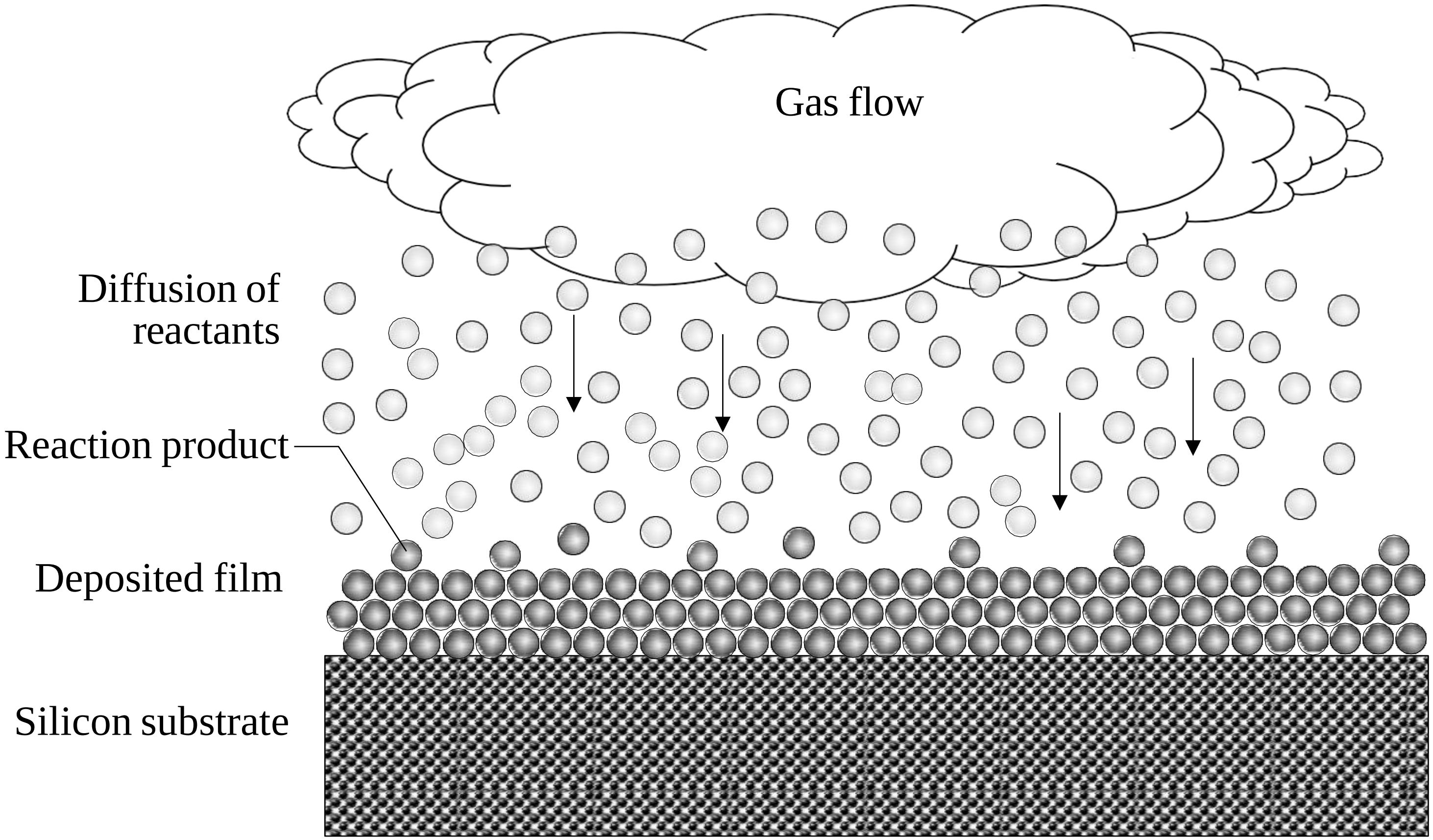
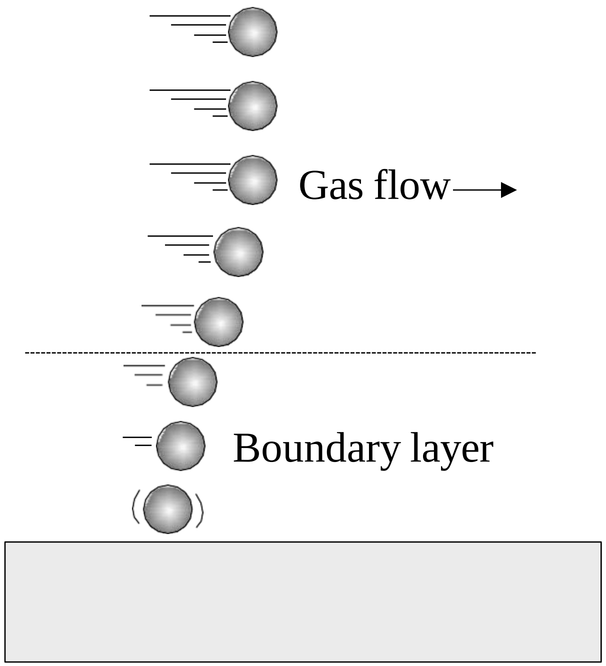
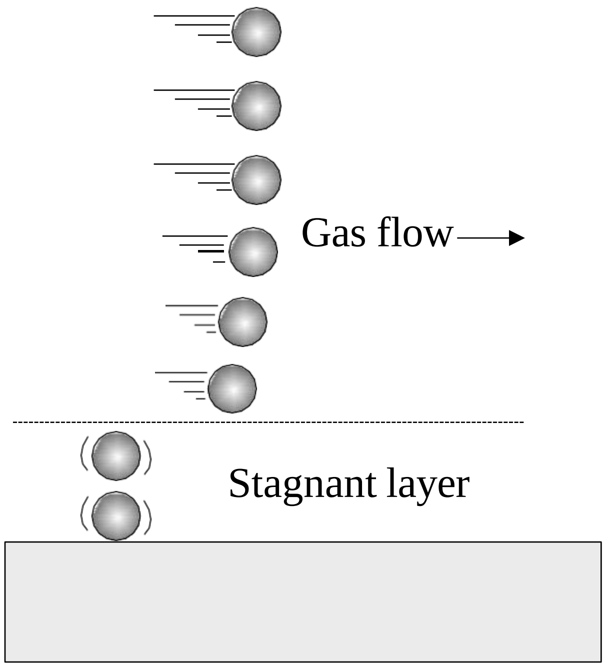


Figure 11.9

Gas Flow Dynamics at the Wafer Surface





CVD Deposition Systems

- CVD Equipment Design
  - CVD reactor heating
  - CVD reactor configuration
  - CVD reactor summary
- Atmospheric Pressure CVD, APCVD
- Low Pressure CVD, LPCVD
- Plasma-Assisted CVD
- Plasma-Enhanced CVD, PECVD
- High-Density Plasma CVD, HDPCVD

CVD Reactor Types

CVD Reactor Types	Atmospheric	Low-pressure	Batch	Single-wafer
Hot-wall	√	√	√	
Cold-wall	√	√	√	√
Continuous motion	√		√	
Epitaxial	√		√	
Plenum	√		√	
Nozzle	√		√	
Barrel	√		√	
Cold-wall planar		√	√	√
Plasma-assisted		√	√	√
Vertical-flow Isothermal		√	√	√

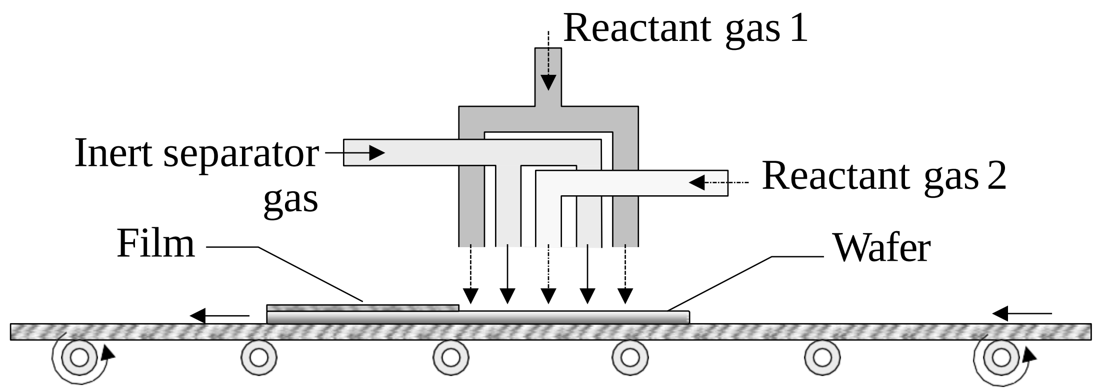
Figure 11.11

Types of CVD Reactors and Principal Characteristics

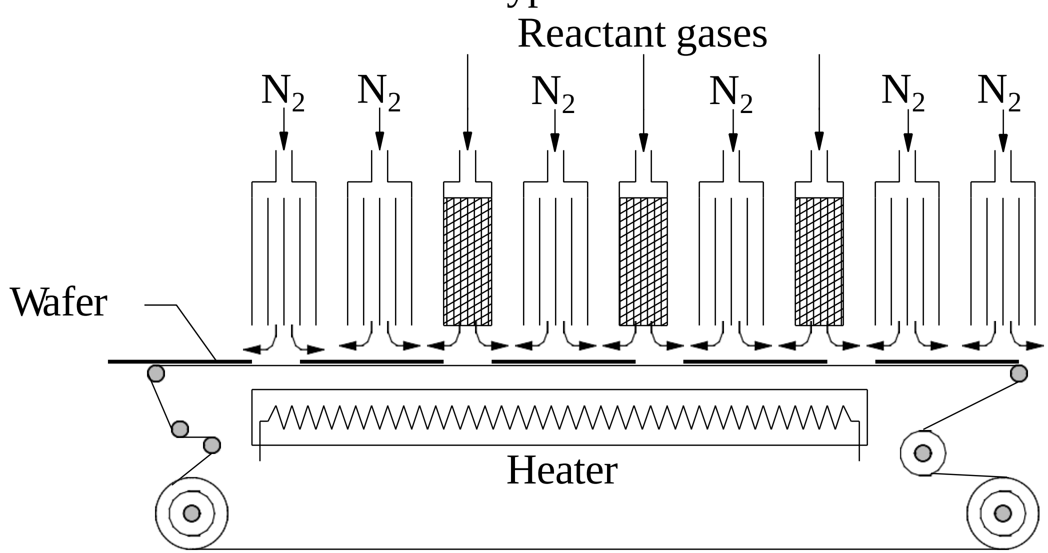
Process	Advantages	Disadvantages	Applications
APCVD (Atmospheric Pressure CVD)	Simple reactor, fast deposition, low temperature.	Poor step coverage, particle contamination, and low throughput.	Low-temperature oxides (both doped and undoped).
LPCVD (Low Pressure CVD)	Excellent purity and uniformity, conformal step coverage, large wafer capacity.	High temperature, low deposition rate, more maintenance intensive and requires vacuum system.	High-temperature oxides (both doped and undoped), silicon nitride, polysilicon, W, WSi_2.
Plasma Assisted CVD: ▪ Plasma Enhanced CVD (PECVD) ▪ High Density Plasma CVD (HDPCVD)	Low temperature, fast deposition, good step coverage, good gap fill.	Requires RF system, higher cost, stress is much higher with a tensile component, and chemical (e.g., H_2) and particle contamination.	High aspect ratio gap fill, low-temperature oxides over metals, ILD-1, ILD, copper seed layer for dual damascene, passivation (nitride).

Table 11.2

Continuous-Processing APCVD Reactors



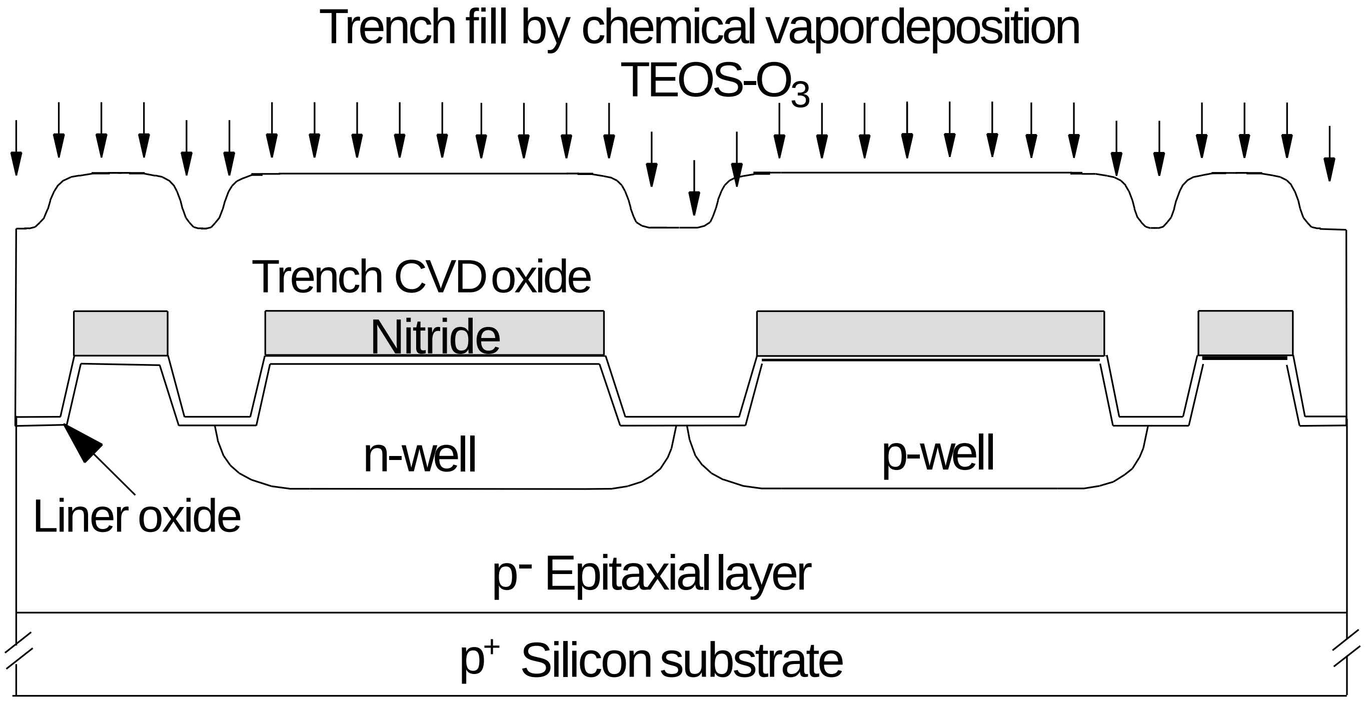
(a) Gas-injection type



(b) Plenum type

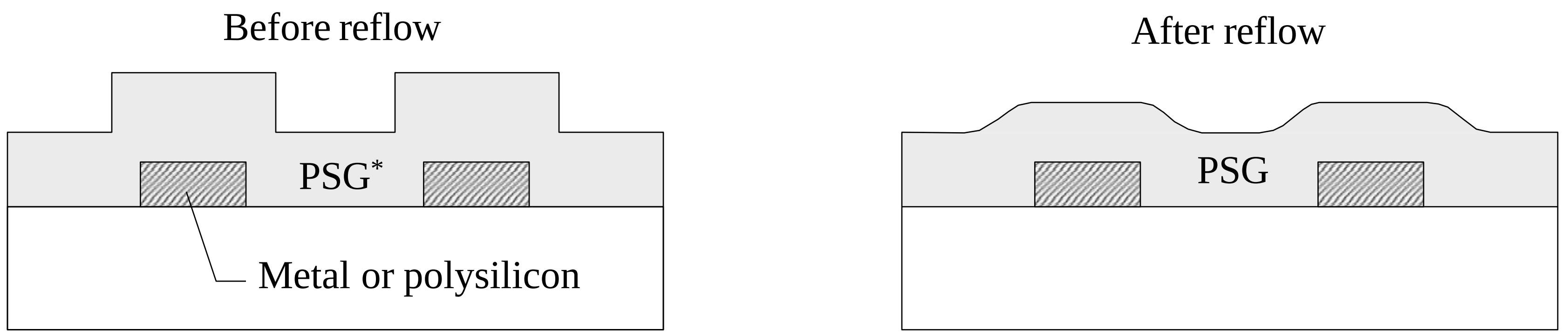
Figure 11.12

Excellent Step Coverage of APCVD TEOS-O3



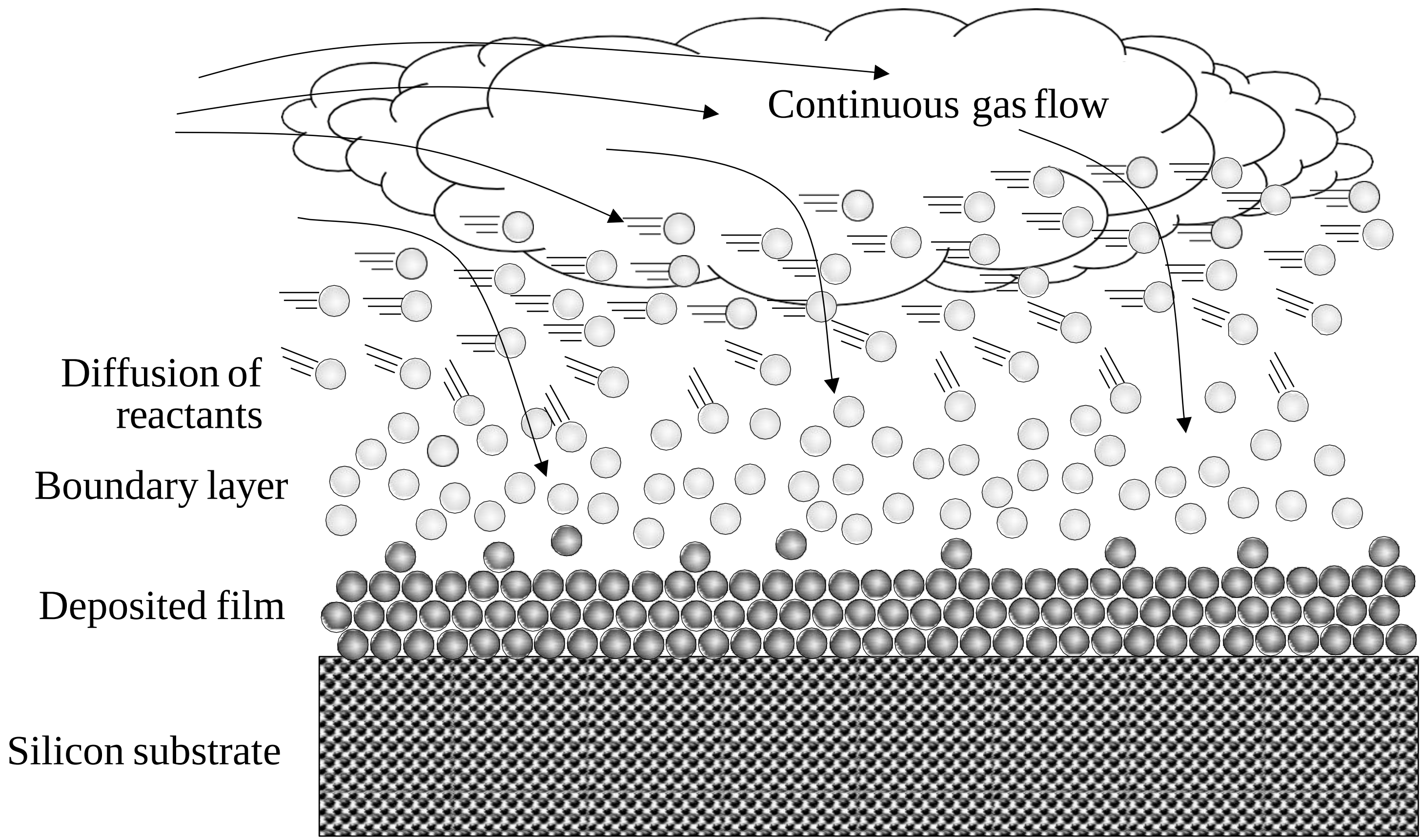
*Tetraethyl orthosilicate (TEOS)

Planarized Surface after Reflow of PSG



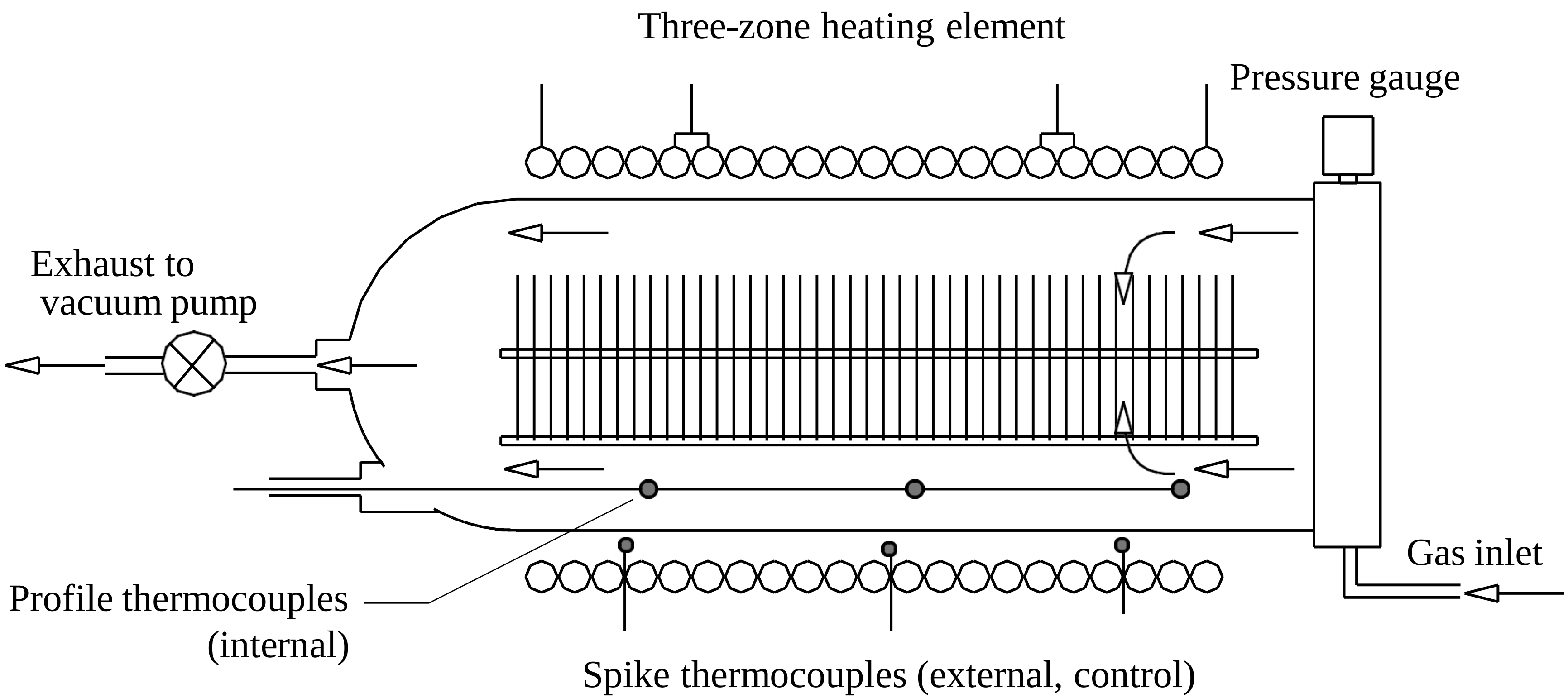
*phosphosilicate glass(PSG)

Boundary Layer at Wafer Surface

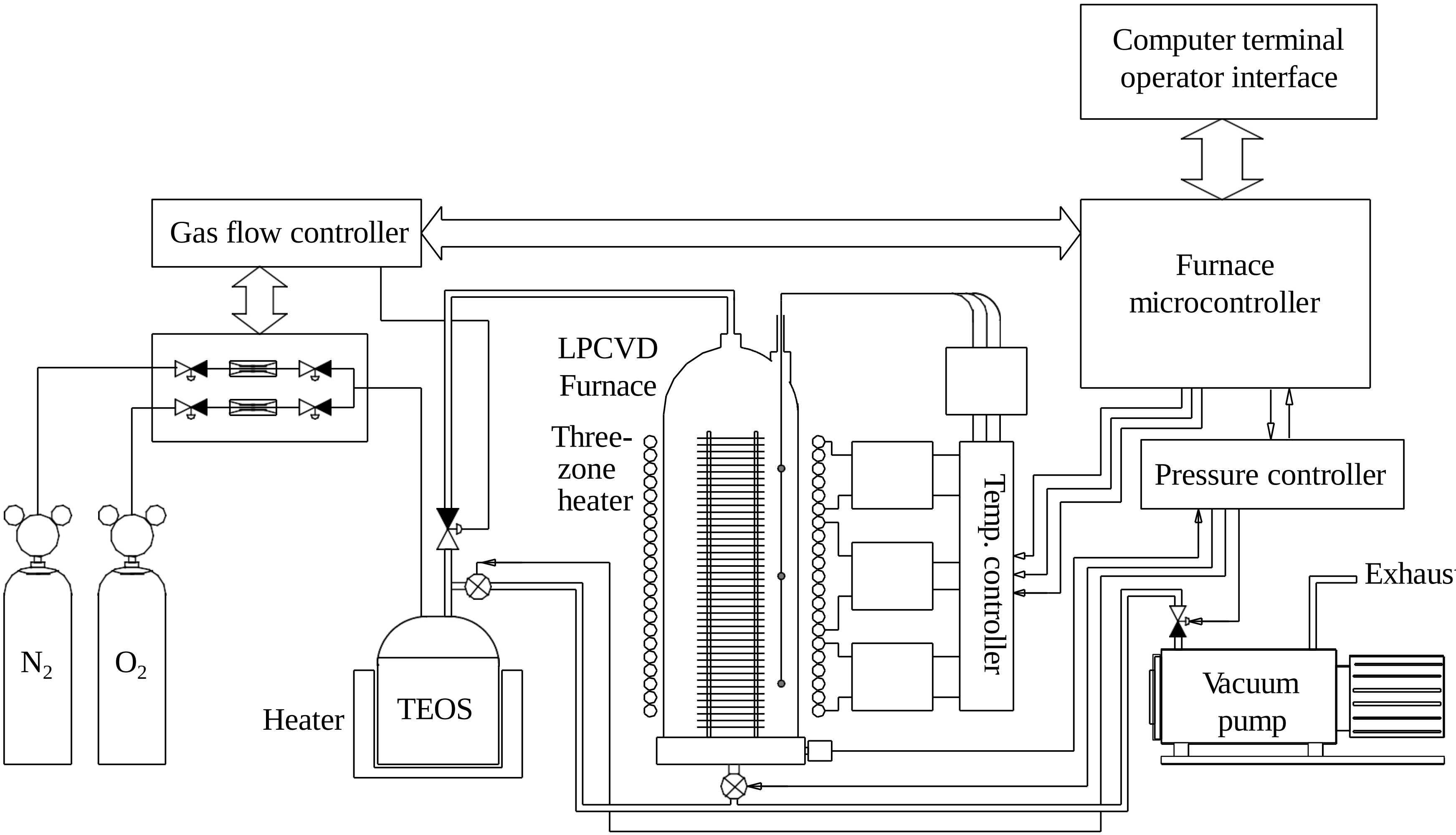


LPCVD Reaction Chamber

for Deposition of Oxides, Nitrides, or Polysilicon



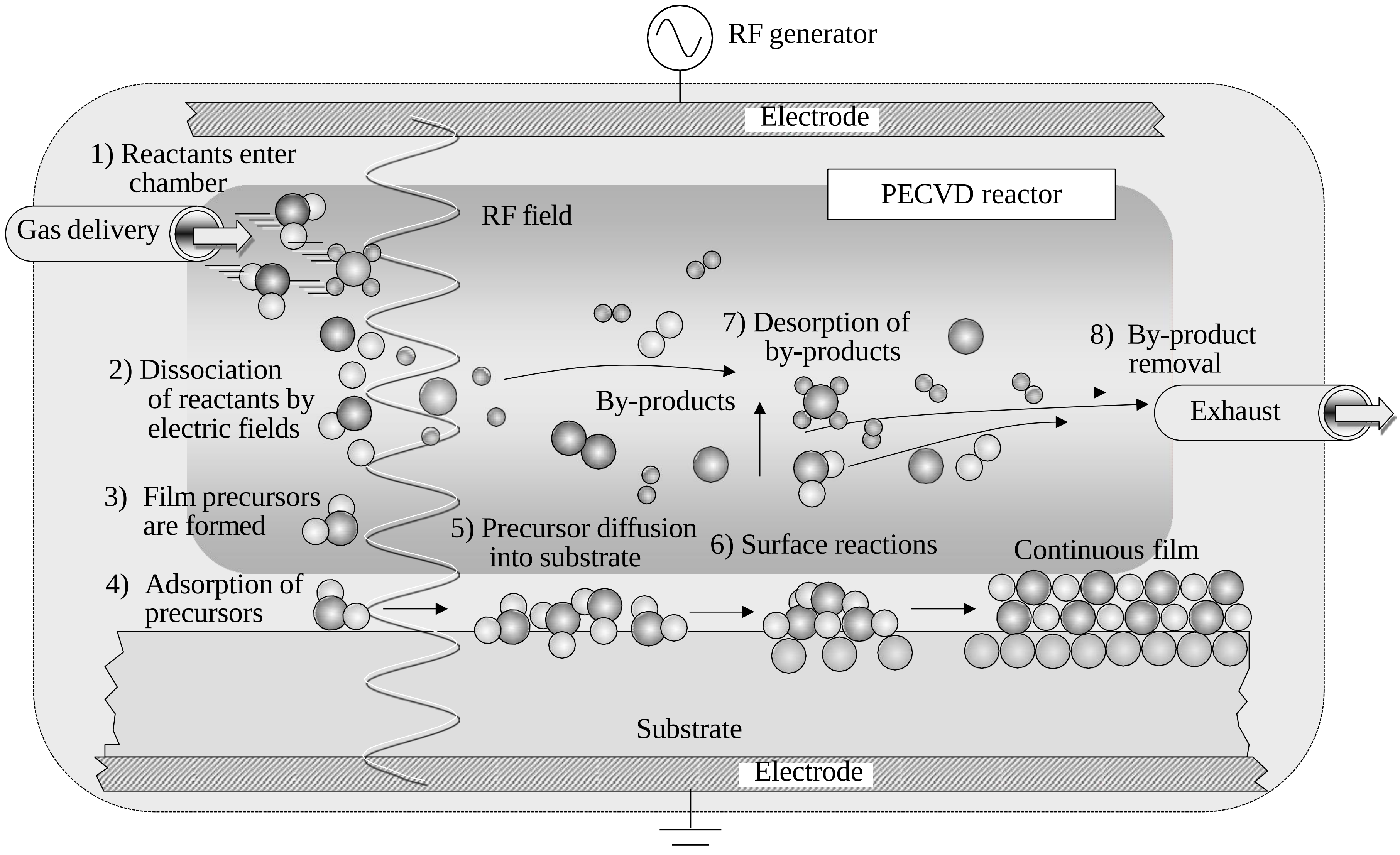
Oxide Deposition with TEOS LPCVD



Advantages of Plasma Assisted CVD

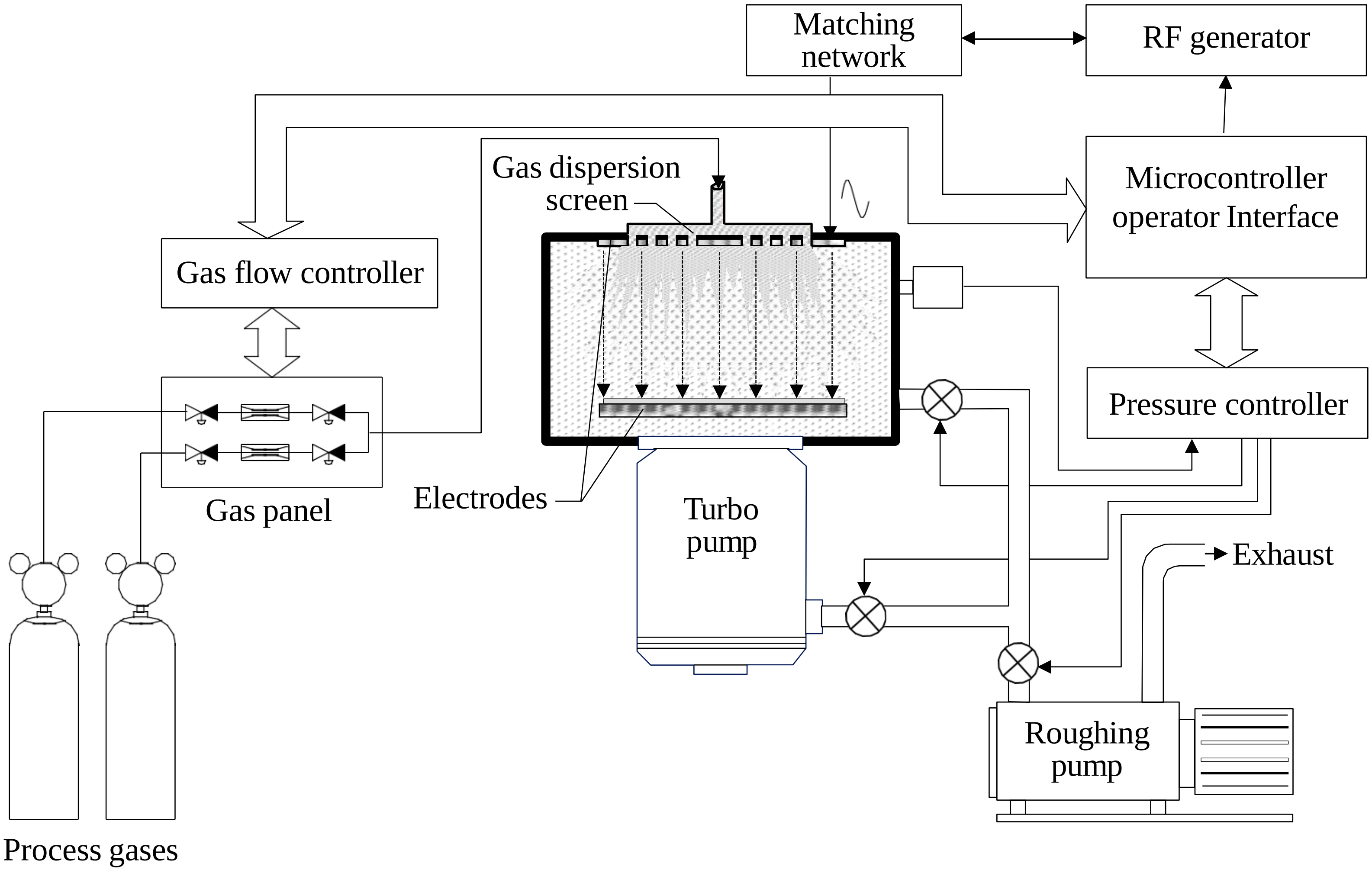
1. Lower processing temperature (250 – 450˚C).
2. Excellent gap-fill for high aspect ratio gaps (with high- density plasma).
3. Good film adhesion to the wafer.
4. High deposition rates.
5. High film density due to low pinholes and voids.
6. Low film stress due to lower processing temperature.

Film Formation during Plasma-Based CVD



General Schematic of PECVD

for Deposition of Oxides, Nitrides, Silicon Oxynitride or Tungsten



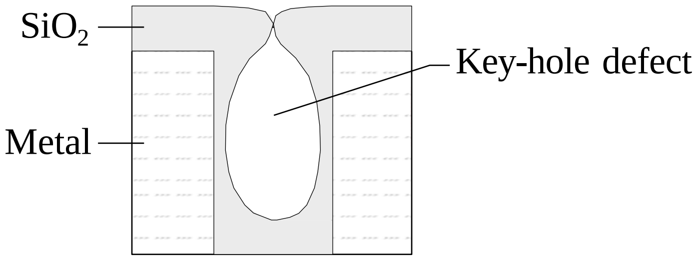
Properties of Silicon Nitride for LPCVD Versus PECVD

Property	LPCVD	PECVD
Deposition temperature (°C)	700 – 800	300 – 400
Composition	Si_3N_4	$Si_xN_yH_z$
Step coverage	Fair	Conformal
Stress at 23°C on silicon (dyn/cm^{-2})	1.2 – 1.8 x 10^{10} (tensile)	1 – 8 x 10^{9} (tensile or compressive)

Table 11.3

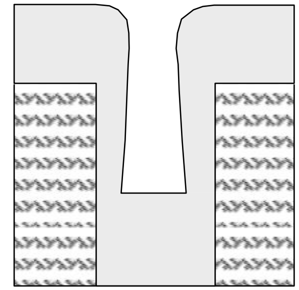
Dep-Etch-Dep Process

Bread-loaf effect

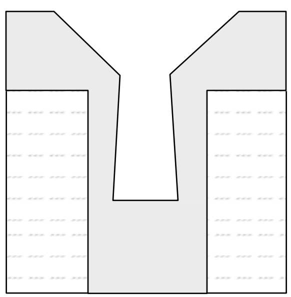


Film deposited with PECVD creates pinch-off at the entrance to a gap resulting in a void in the gap fill.

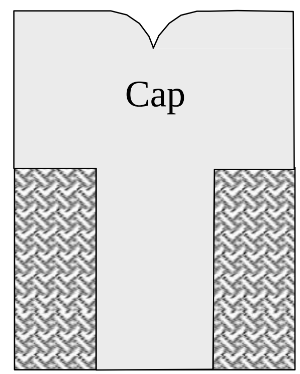
The solution begins here



1) Ion-induced deposition of film precursors



2) Argon ions sputter-etch excess film at gap entrance resulting in a beveled appearance in the film.



3) Etched material is redeposited. The process is repeated resulting in an equal "bottom-up" profile.

Epitaxy

- Epitaxy Growth Model
- Epitaxy Growth Methods
  - Vapor-Phase Epitaxy (VPE)
  - Metalorganic CVD (MOCVD)
  - Molecular-Beam Epitaxy (MBE)

a type of crystal growth or material deposition in which new crystalline layers are formed with one or more well-defined orientations with respect to the crystalline substrate.

Silicon Epitaxial Growth on a Silicon Wafer

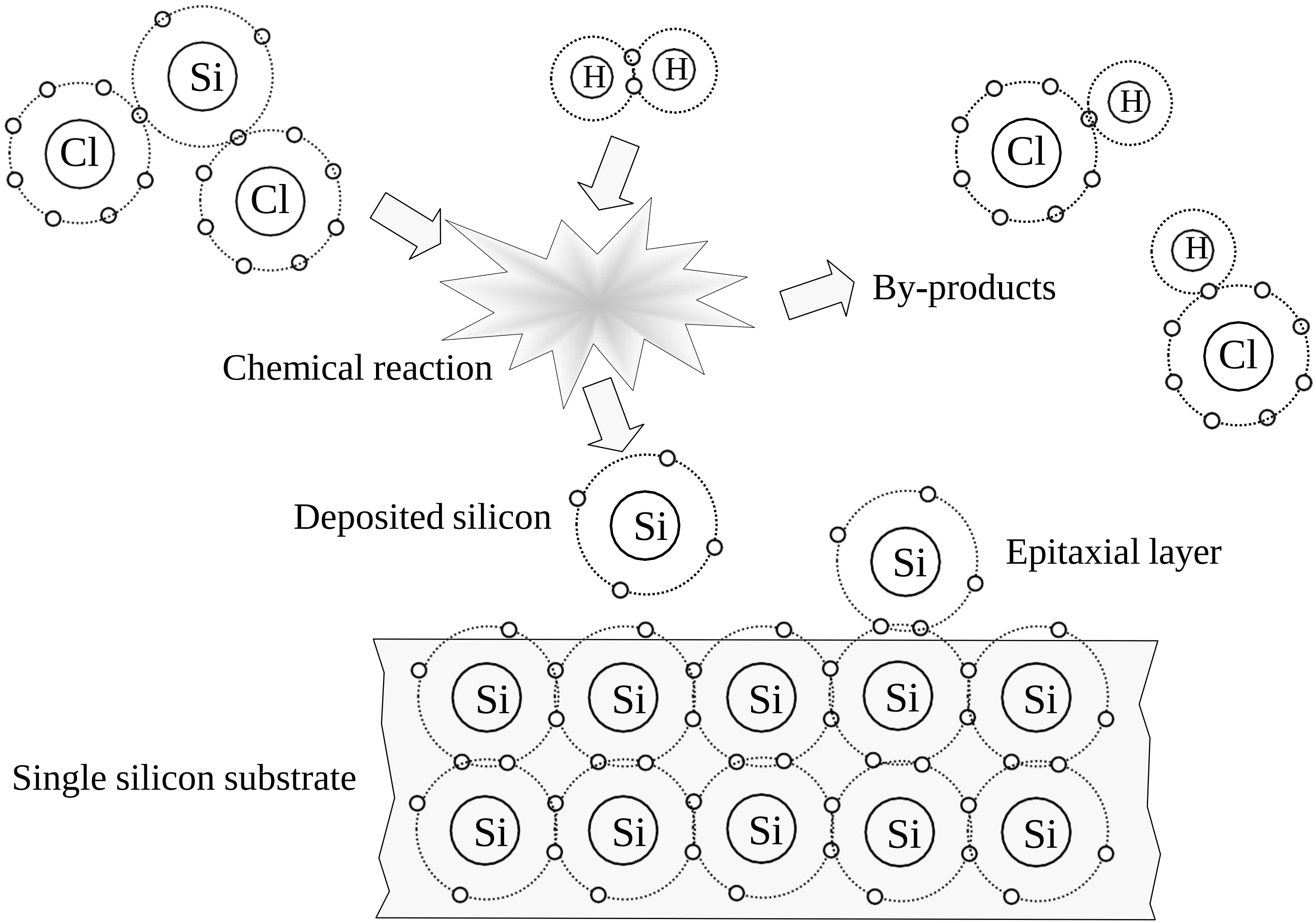
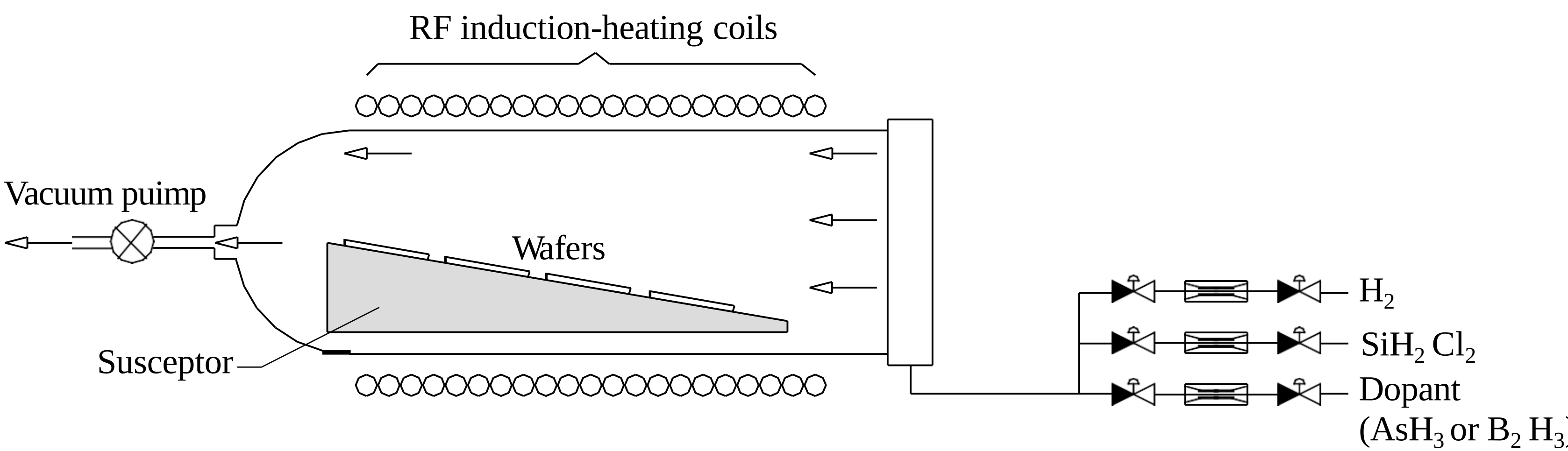
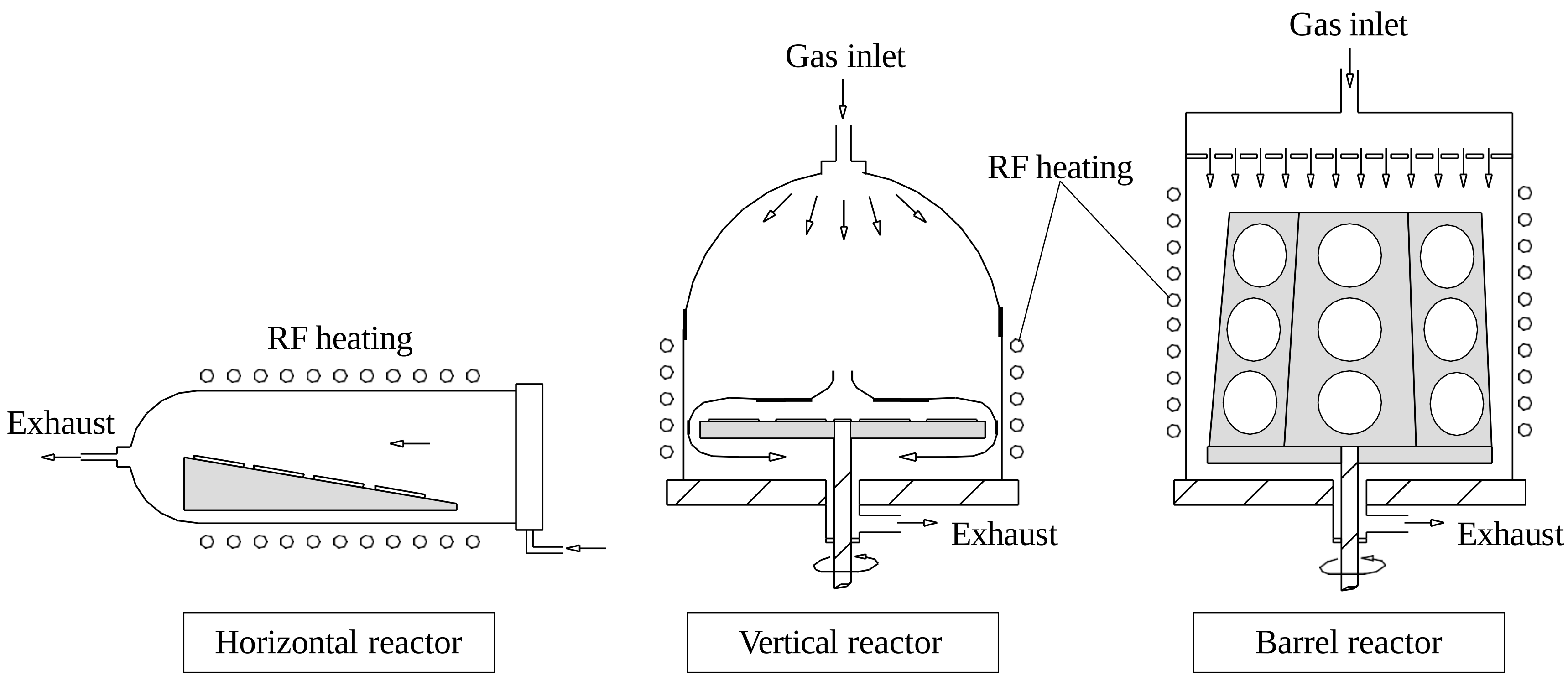


Illustration of Vapor Phase Epitaxy



Silicon Vapor Phase Epitaxy Reactors



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