Engineering of Semiconductor

:Semiconductor Physics and Devices

Chapter 2. Silicon Technology

Objectives

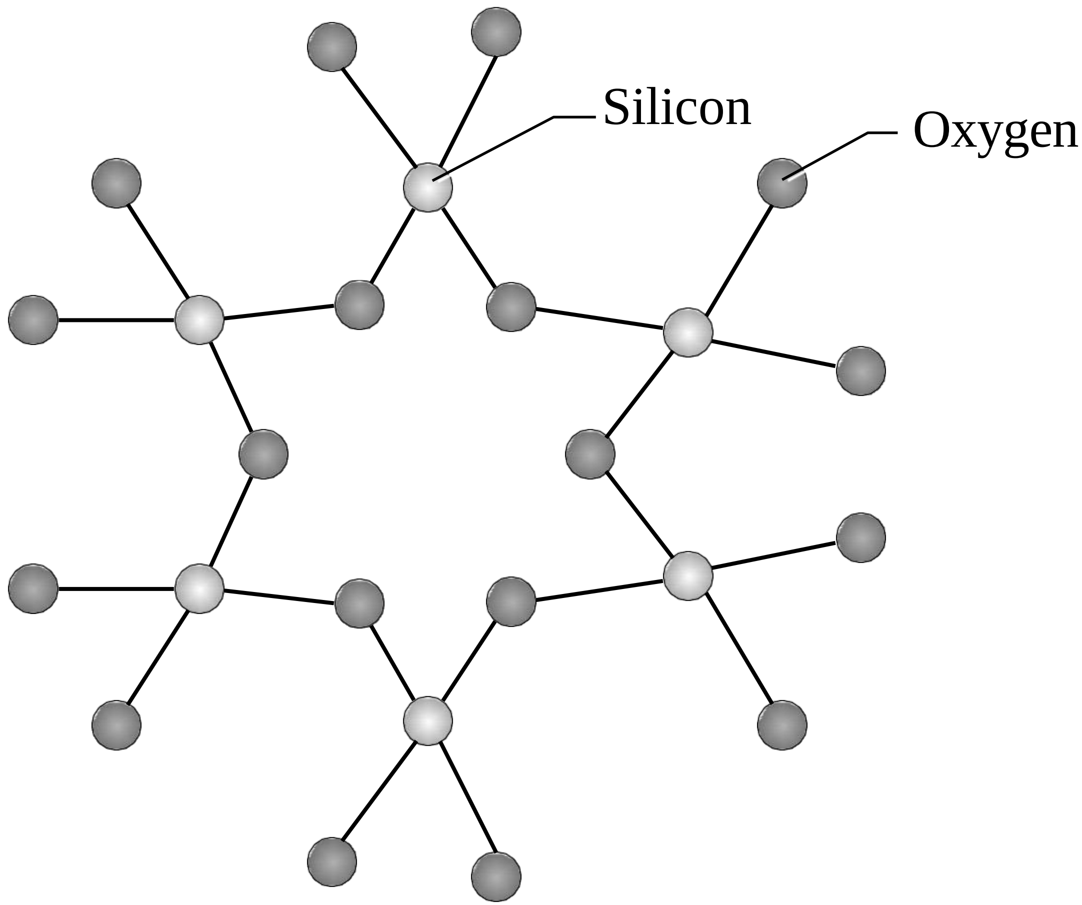
Overview of Silicon Technology

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

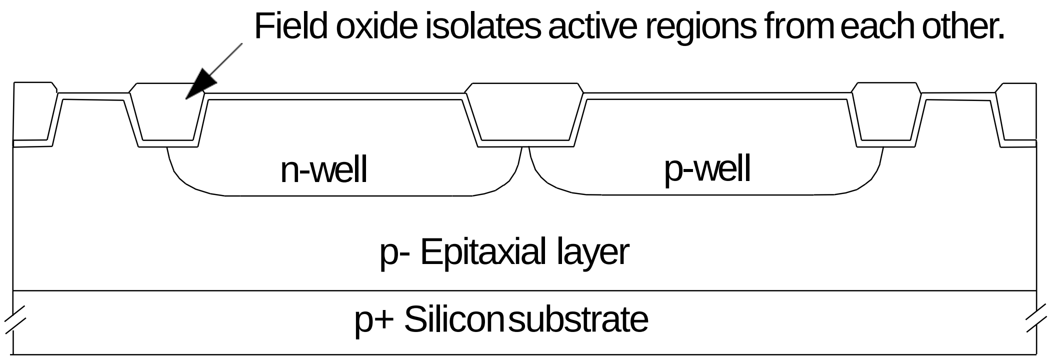
Oxide Film

- Nature of Oxide Film
- Uses of Oxide Film
  - Device Protection and Isolation
  - Surface Passivation
  - Gate Oxide Dielectric
  - Dopant Barrier
  - Dielectric Between Metal Layers

Atomic Structure of Silicon Dioxide



Field Oxide Layer



Gate Oxide Dielectric

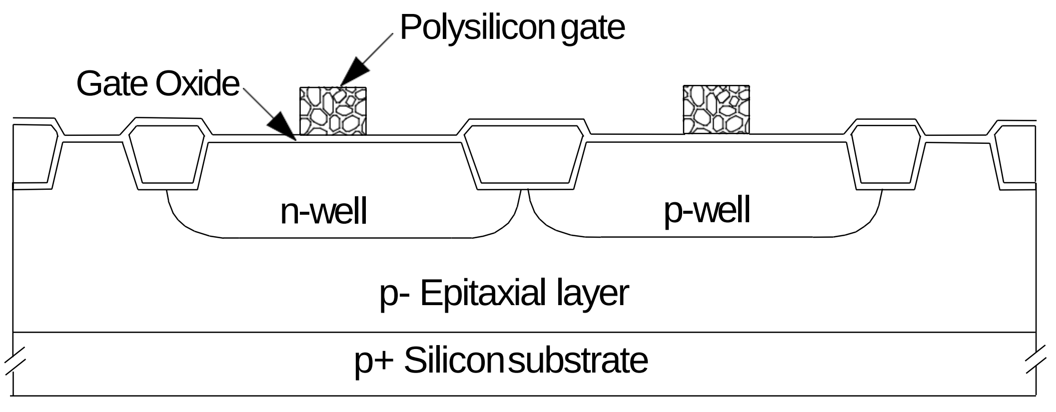
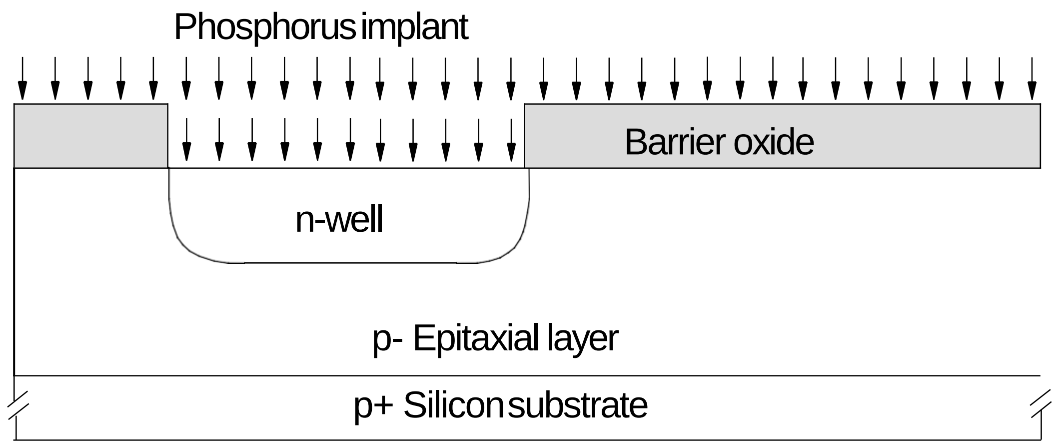


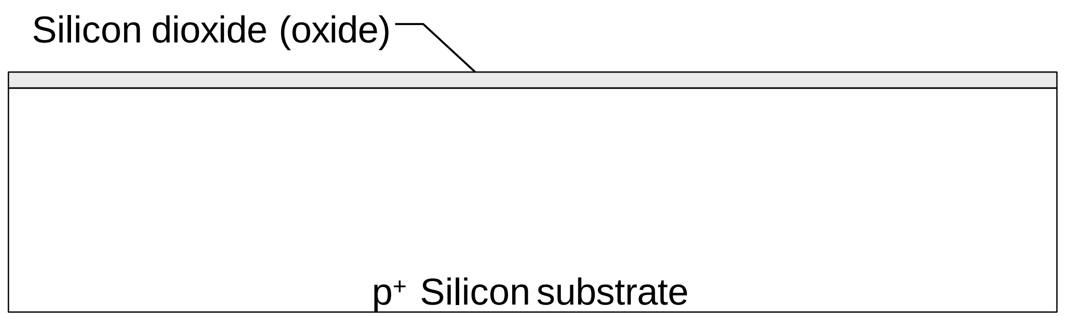
Figure 10.4

Oxide Layer Dopant Barrier



Oxide Applications: Native Oxide

Purpose: This oxide is a contaminant and generally undesira ble. Sometimes used in memory storage or film pa ssivation.

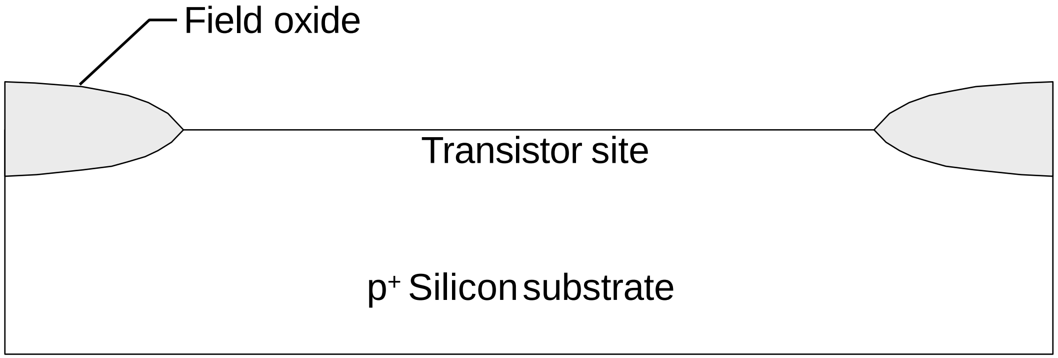


Comments: Growth rate at room temperature is 15 per hour up to about 40 Å.

Table 10.1A

Oxide Applications: Field Oxide

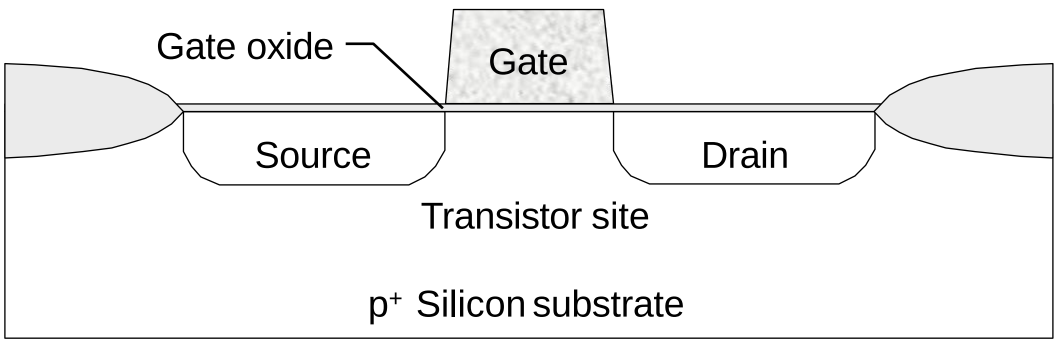
Purpose:	Serves as an isolation barrier between individual transistors to isolate them from each other.



Comments:	Common field oxide thickness range from 2,500 Å to 15,000 Å. Wet oxidation is the preferred method.

Oxide Applications: Gate Oxide

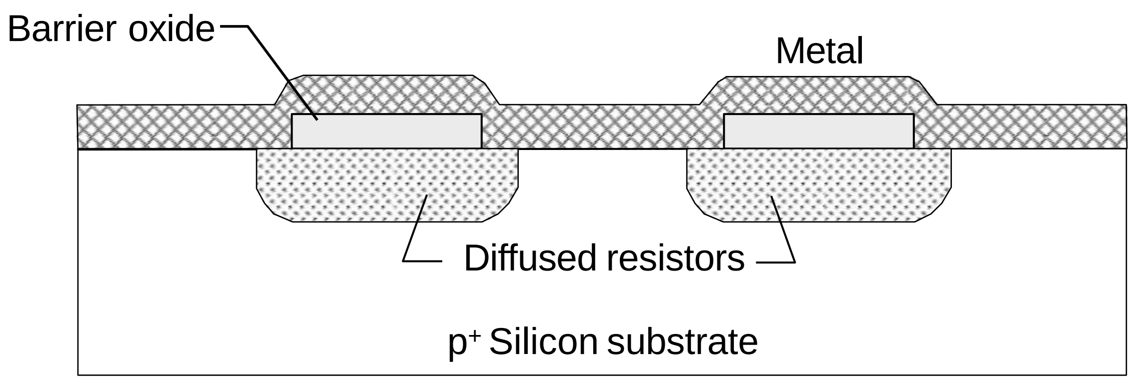
Purpose: Serves as a dielectric between the gate and source-drain parts of MOS transistor.



Comments: Growth rate at room temperature is 15 Å per hour up to about 40 Å. Common gate oxide film thick ness range from about 30 Å to 500 Å. Dry oxidat ion is the preferred method.

Oxide Applications: Barrier Oxide

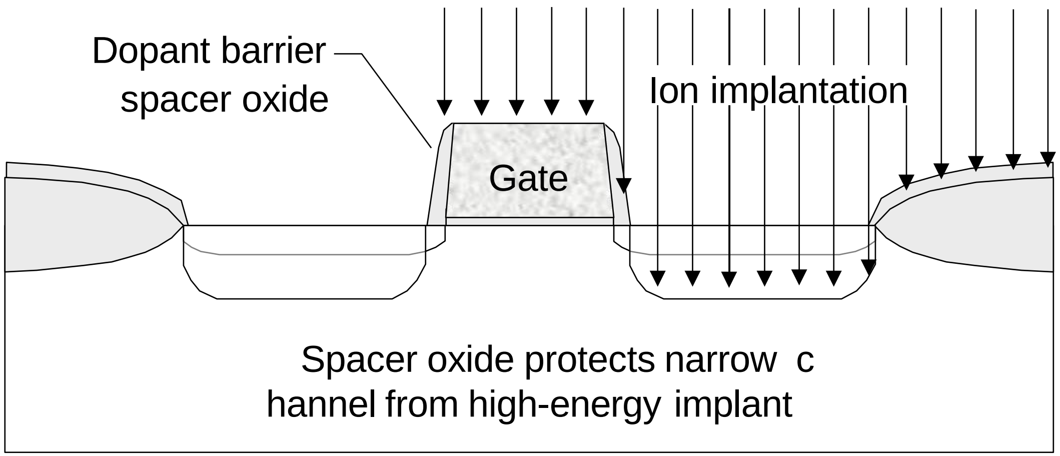
Purpose: Protect active devices and silicon from follow-on processing.



Comments: Thermally grown to several hundred Angstroms thickness.

Oxide Applications: Dopant Barrier

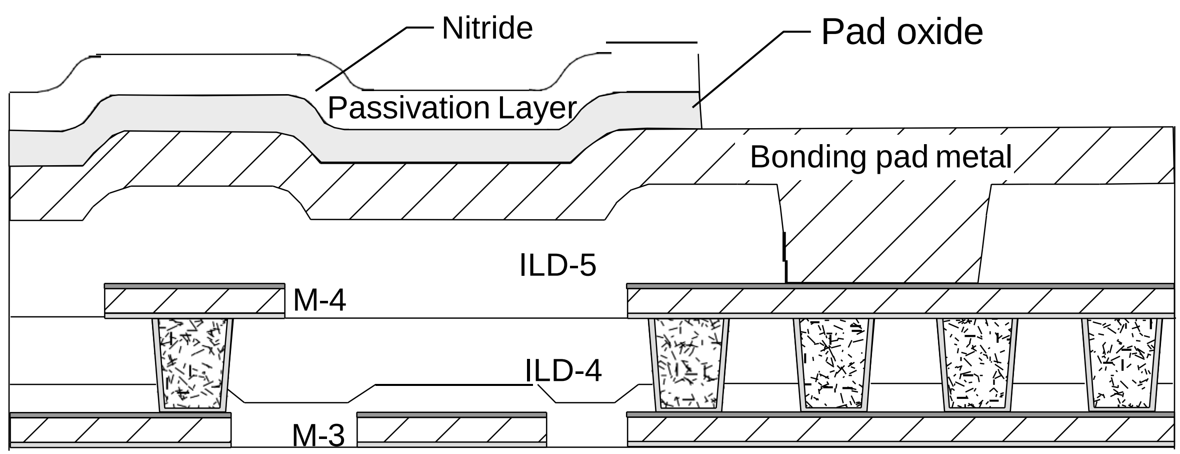
Purpose:	Masking material when implanting dopant into waf er. Example: Spacer oxide used during the im plant of dopant into the source and drain regions.



Comments:	Dopants diffuse into unmasked areas of silicon by selective diffusion.

Oxide Applications: Pad Oxide

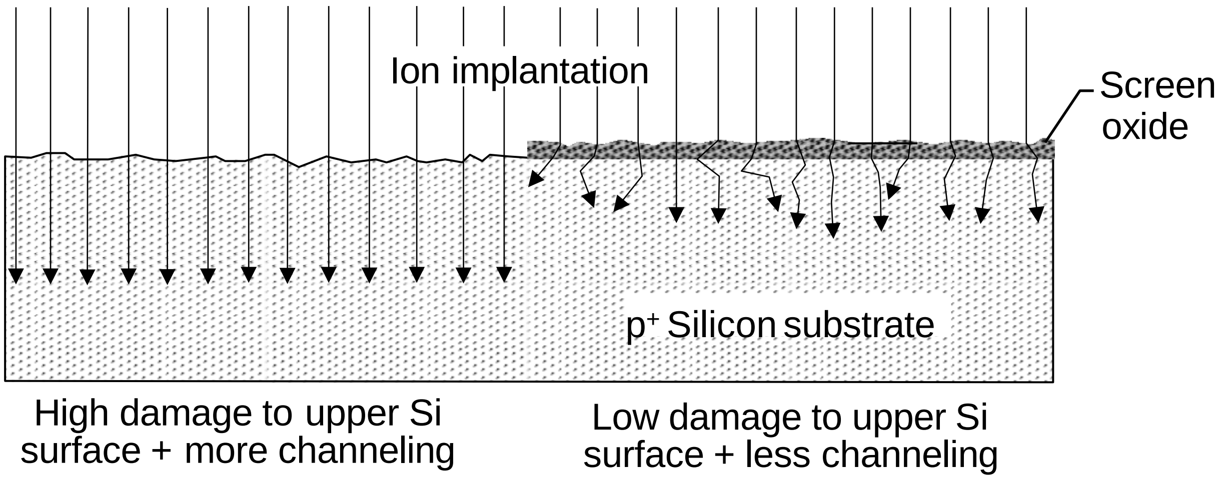
Purpose: Provides stress reduction for Si_3N_4



Comments: Thermally grown and very thin.

Oxide Applications: Implant Screen Oxide

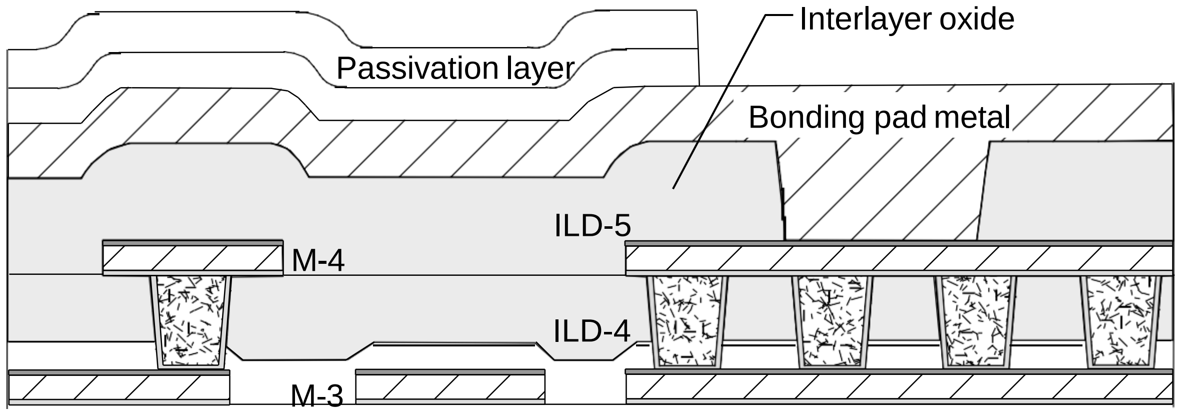
Purpose:	Sometimes referred to as "sacrificial oxide", screen oxide, is used to reduce implant channeling and da mage. Assists creation of shallow junctions.



Comments: Thermally grown

Oxide Applications: Insulating Barrier between Metal Layers

Purpose: Serves as protective layer between metal lines.



Comments: This oxide is not thermally grown, but is deposited.

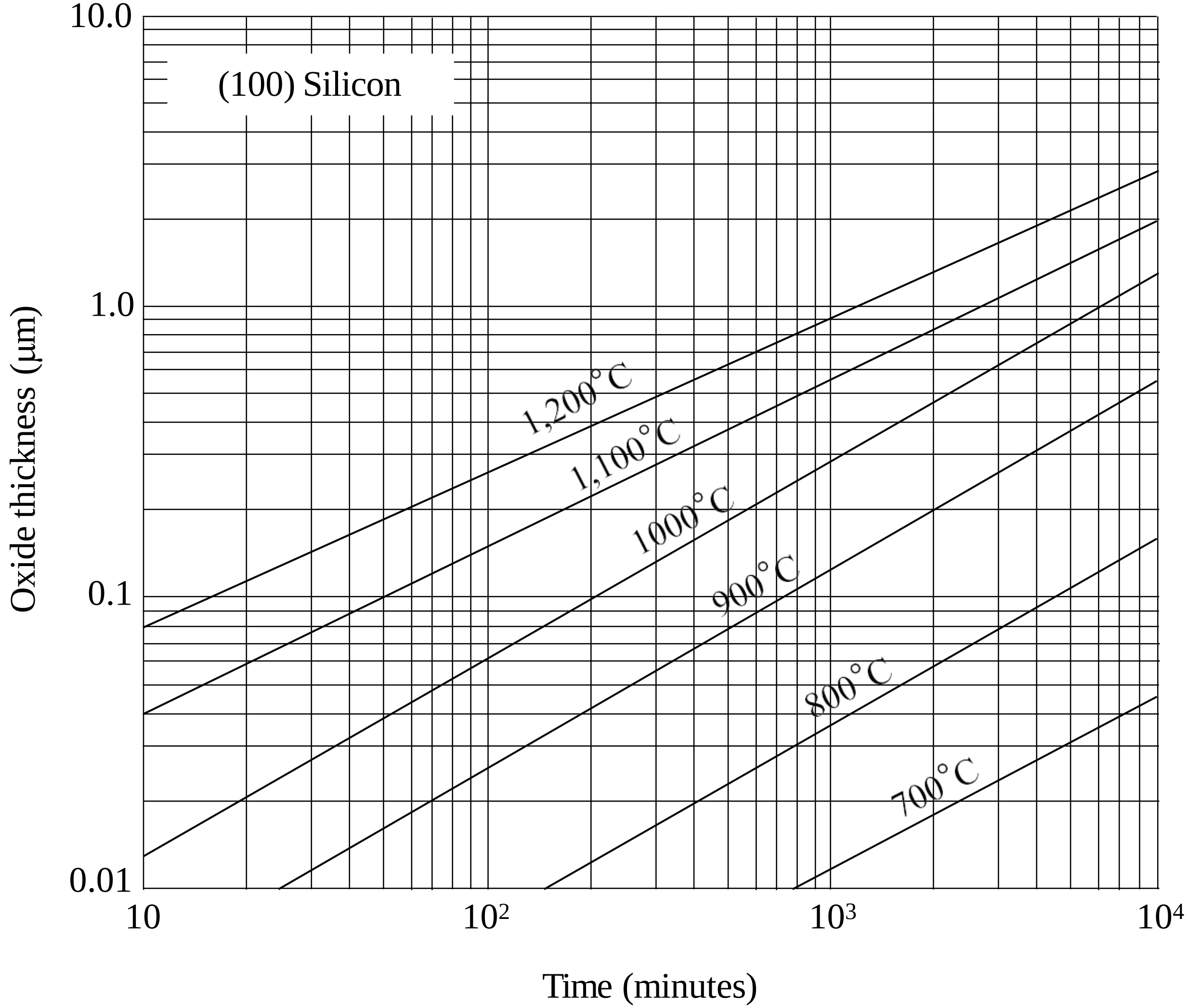
Thermal Oxidation Growth

- Chemical Reaction for Oxidation
  - Dry oxidation
  - Wet oxidation
- Oxidation Growth Model
  - Oxide silicon interface
    - Use of chlorinated agents in oxidation
  - Rate of oxide growth
  - Factors affecting oxide growth
  - Initial growth phase
  - Selective oxidation
    - LOCOS
    - STI

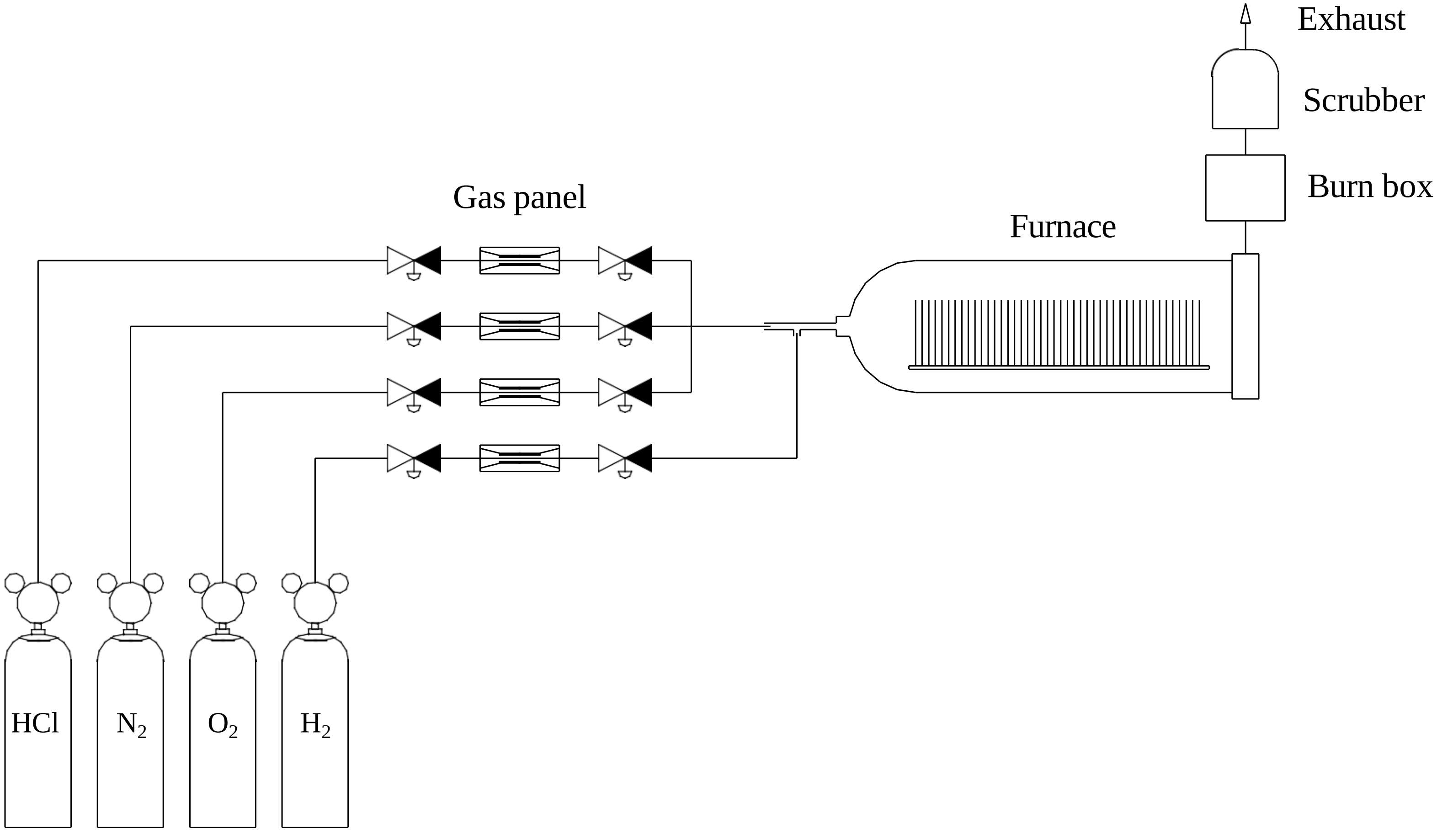
Oxide Thickness Ranges for Various Requirements

Semiconductor Application	**Typical Oxide Thickness, Å**
Gate oxide (0.18 μm generation)	20 – 60
Capacitor dielectrics	5 – 100
Dopant masking oxide	400 – 1,200 (Varies depending on dopant, implant energy, time & temperature)
STI Barrier Oxide	150
LOCOS Pad Oxide	200 – 500
Field oxide	2,500 – 15,000

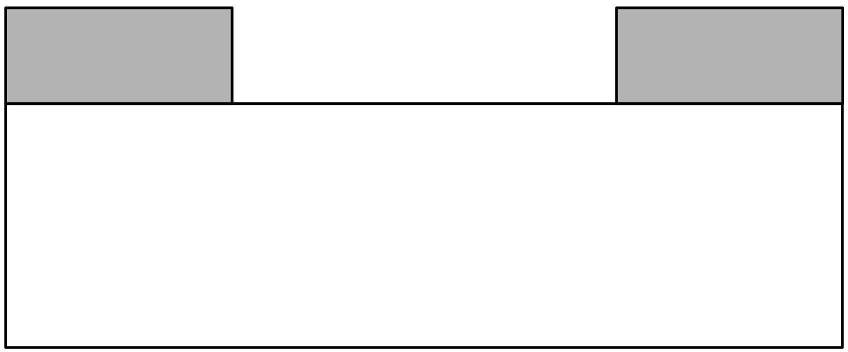
Dry Oxidation Time (Minutes)



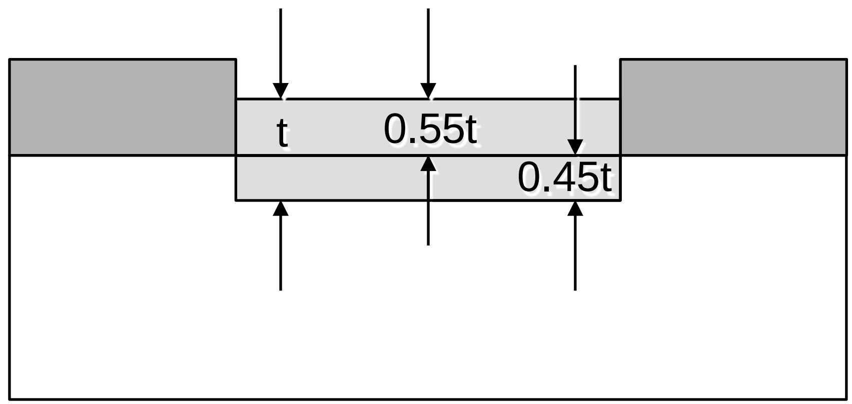
Wet Oxygen Oxidation



Consumption of Silicon during Oxidation

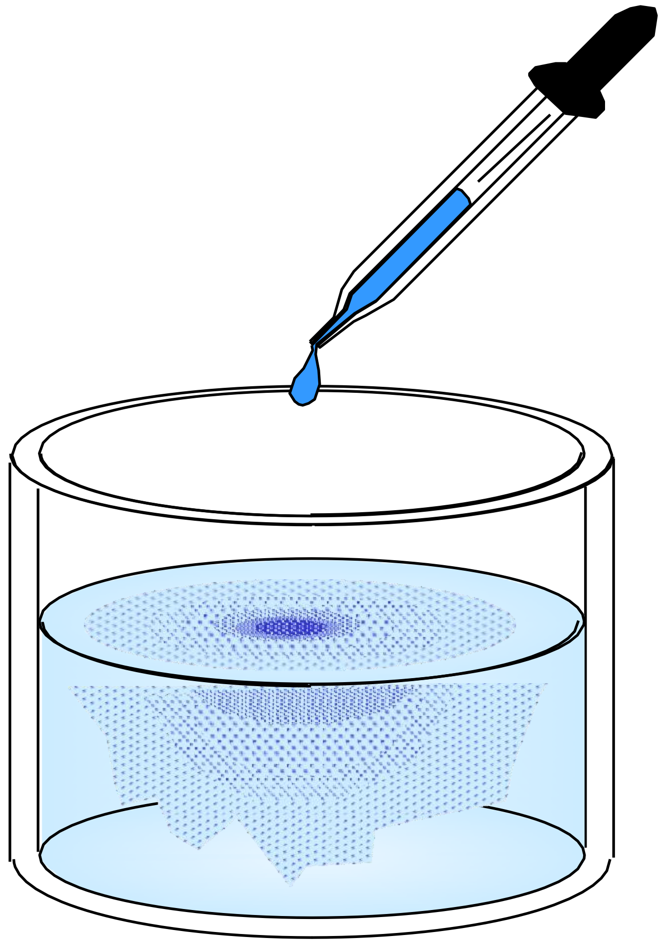


Before oxidation

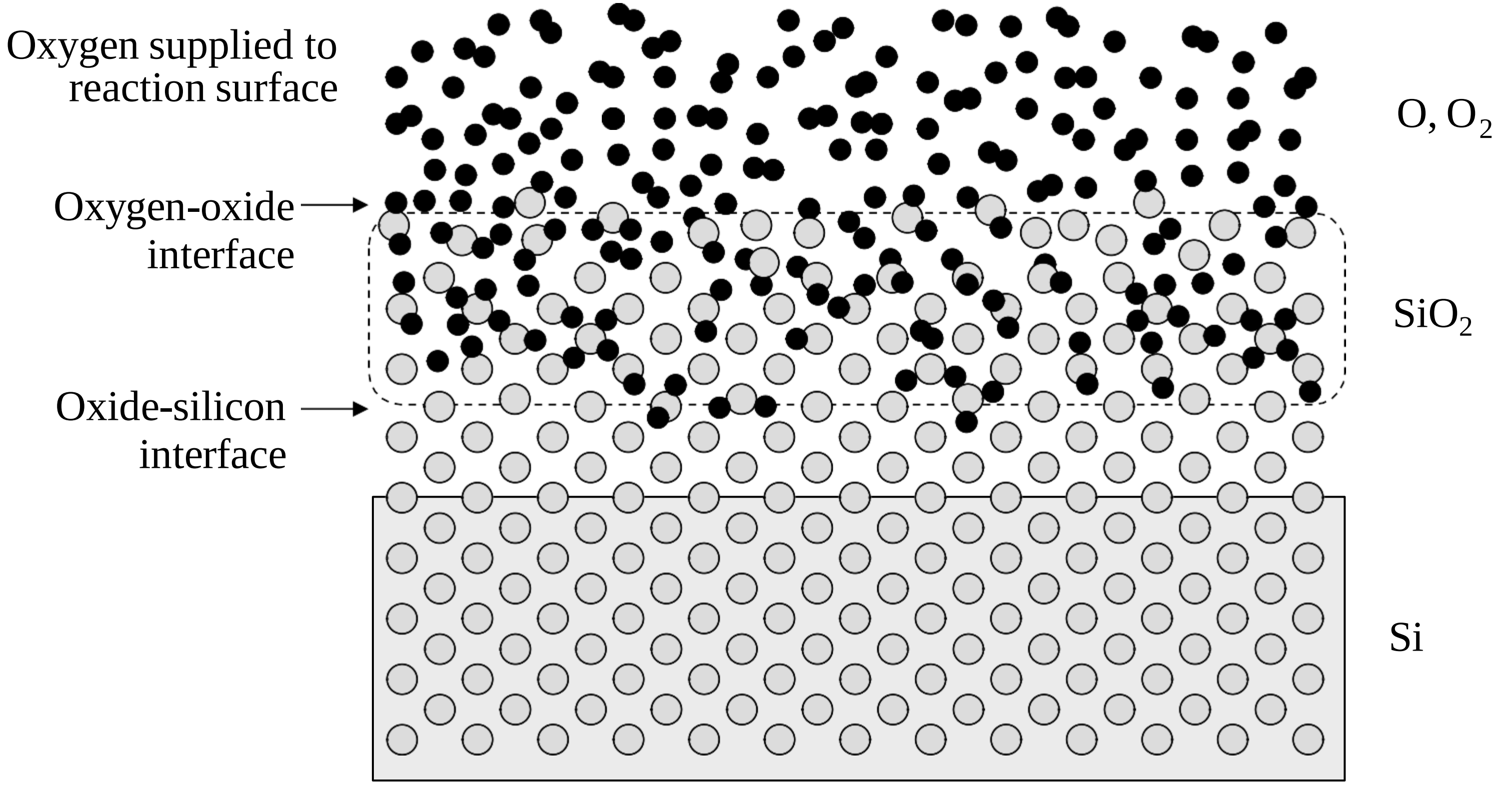


After oxidation

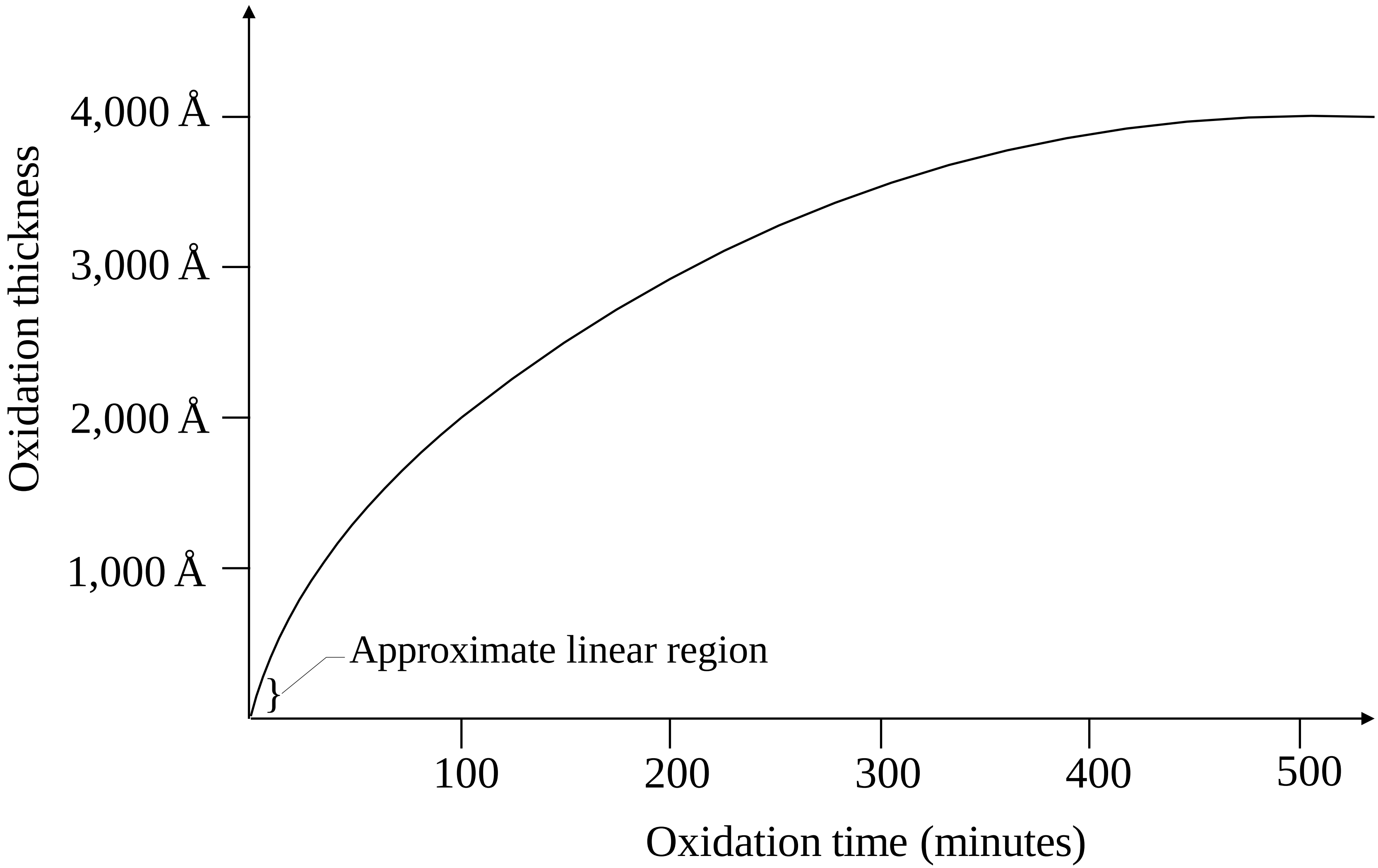
Liquid-State Diffusion



Diffusion of Oxygen Through Oxide Layer



Linear & Parabolic Stages for Dry Oxidation Growth at 1100ºC



Furnace Equipment

- Horizontal Furnace
- Vertical Furnace
- Rapid Thermal Processor (RTP)

Horizontal and Vertical Furnaces

Performance Factor	Performance Objective	Horizontal Furnace	Vertical Furnace
Typical wafer loading size	Small, for process flexibility	200 wafers/batch	100 wafers/batch
Clean room footprint	Small, to use less space	Larger, but has 4 process tubes	Smaller (single process tube)
Parallel processing	Ideal for process flexibility	Not capable	Capable of loading/unloading wafers during process, which increases throughput
Gas flow dynamics (GFD)	Optimize for uniformity	Worse due to paddle and boat hardware. Bouyancy and gravity effects cause non-uniform radial gas distribution.	Superior GFD and symmetric/uniform gas distribution
Boat rotation for improved film uniformity	Ideal condition	Impossible to design	Easy to include
Temperature gradient across wafer	Ideally small	Large, due to radiant shadow of paddle	Small
Particle control during loading/unloading	Minimum particles	Relatively poor	Improved particle control from top-down loading scheme
Quartz change	Easily done in short time	More involved and slow	Easier and quicker, leading to reduced downtime
Wafer loading technique	Ideally automated	Difficult to automate in a successful fashion	Easily automated with robotics
Pre-and post- process control of furnace ambient	Control is desirable	Relatively difficult to control	Excellent control, with options of either vacuum or neutral ambient

Table 10.3

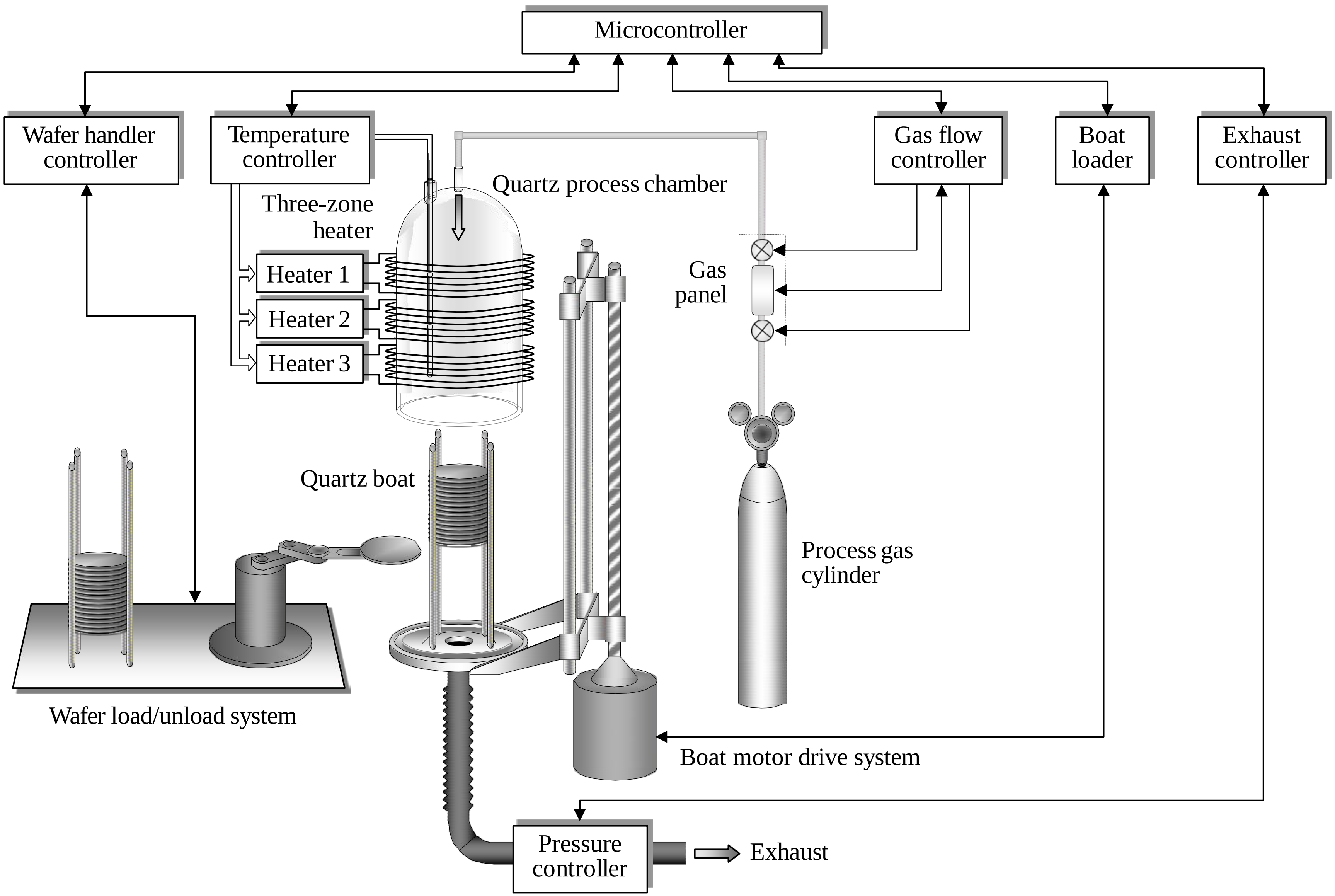
Horizontal Diffusion Furnace

Photograph courtesy of International SEMATECH

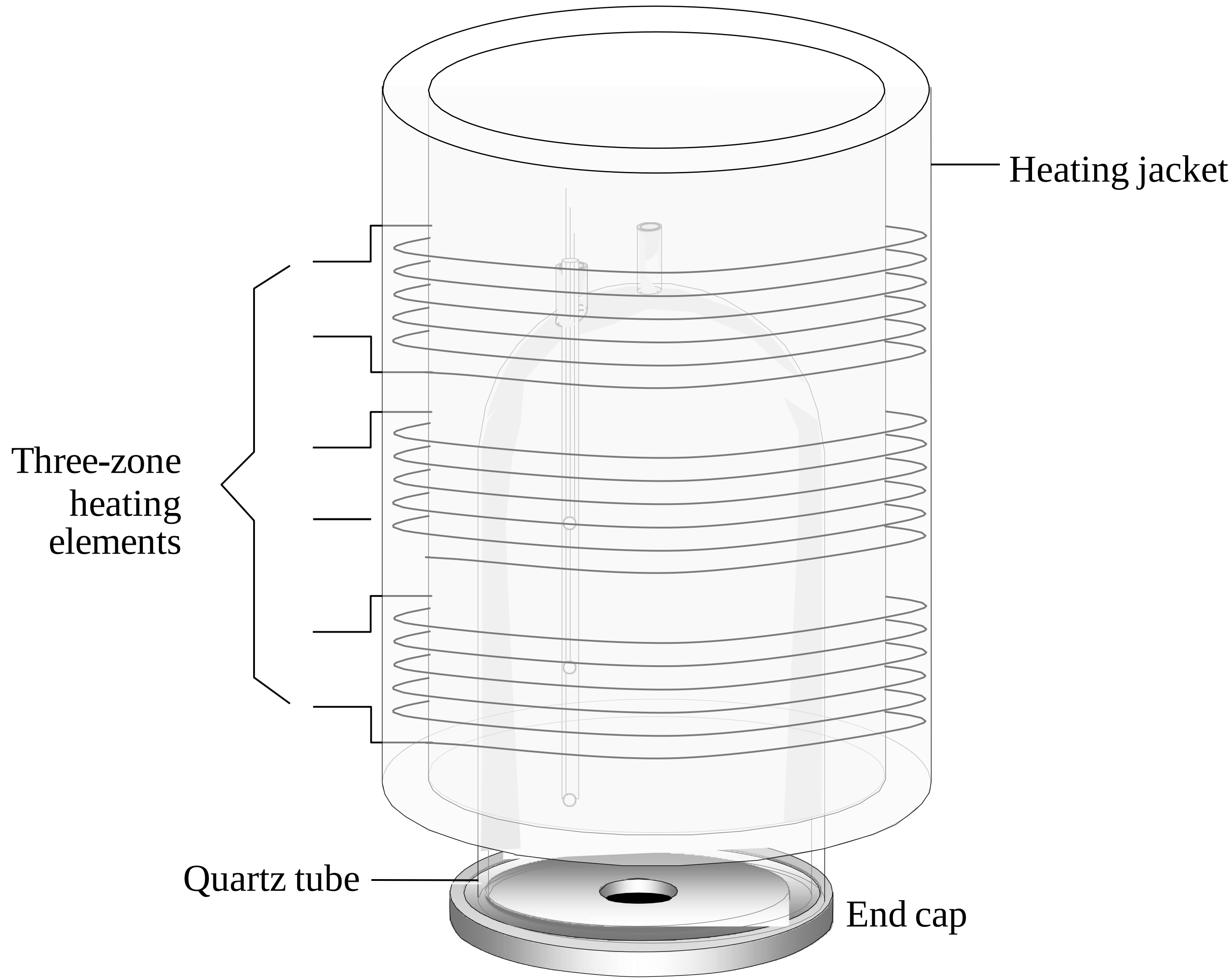
Vertical Diffusion Furnace

Photograph courtesy of International SEMATECH

Block Diagram of Vertical Furnace System



Vertical Furnace Process Tube



Common Gases used in Furnace Processes

Gases	Classifications	Examples
Bulk	Inert gas	Argon (Ar), Nitrogen (N_2)
	Reducing gas	Hydrogen (H_2)
	Oxidizing gas	Oxygen (O_2)
Specialty	Silicon-precursor gas	Silane (SiH_4), dichlorosilane (DCS) or (H_2SiCl_2)
	Dopant gas	Arsine (AsH_3), phosphine (PH_3) Diborane (B_2H_6)
	Reactant gas	Ammonia (NH_3), hydrogen chloride (HCl)
	Atmospheric/purge gas	Nitrogen (N_2), helium (He)
	Other specialty gases	Tungsten hexafluoride (WF_6)

The Main Advantages of a Rapid Thermal Processor

- Reduced thermal budget
- Minimized dopant movement in the silicon
- Ease of clustering multiple tools
- Reduced contamination due to cold wall heating
- Cleaner ambient because of the smaller chamber volume
- Shorter time to process a wafer (referred to as cycle time)

Comparison of Conventional Vertical Furnace and RTP

Vertical Furnace	**RTP**
Batch	Single-wafer
Hot wall	Cold wall
Long time to heat and cool batch	Short time to heat and cool wafer
Small thermal gradient across wafer	Large thermal gradient across wafer
Long cycle time	Short cycle time
Ambient temperature measurement	Wafer temperature measurement
Issues:	Issues:
Large thermal budget	Temperature uniformity
Particles	Minimize dopant movement
Ambient control	Repeatability from wafer to wafer
	Throughput
	Wafer stress due to rapid heating
	Absolute temperature measurement

Table 10.5

Rapid Thermal Processor

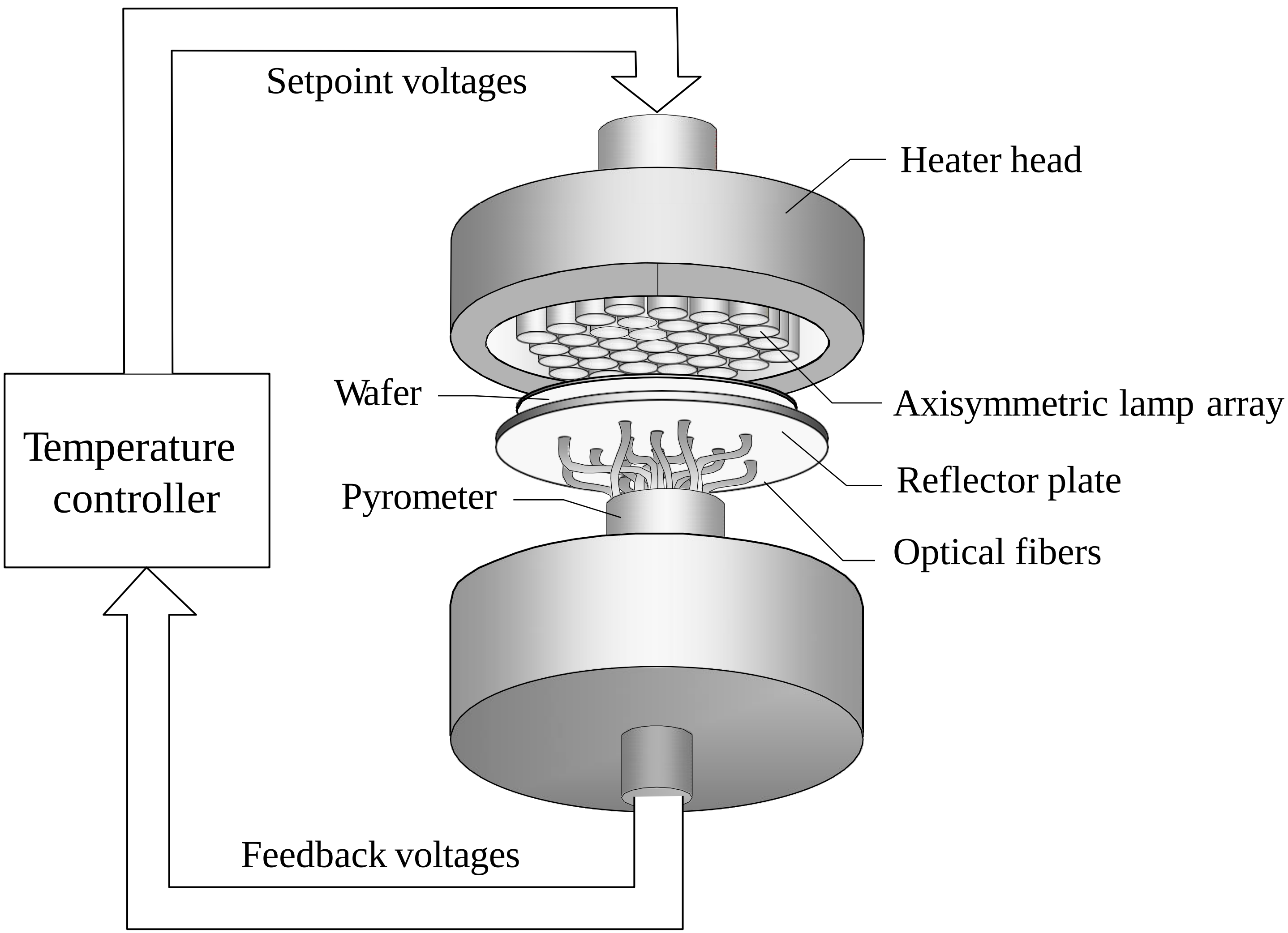
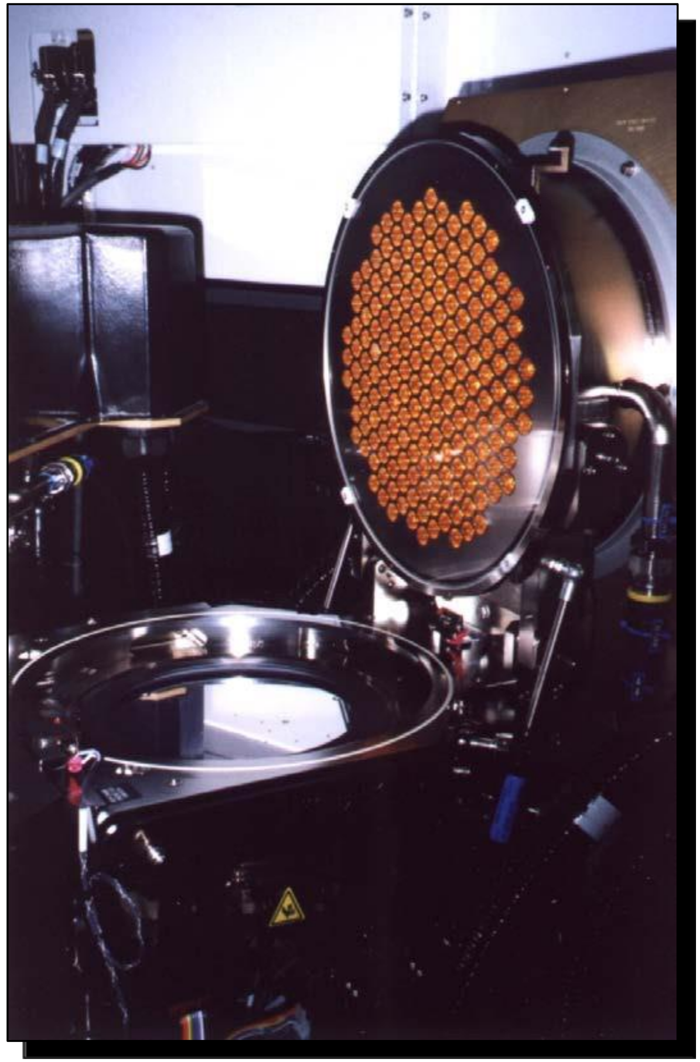


Figure 10.22

Rapid Thermal Processor



Photograph courtesy of Advanced Micro Devices, Applied Materials 5300 Centura RTP

RTP Applications

- Anneal of implants to remove defects and activate and diffuse dopants
- Densification of deposited films, such as deposited oxide layers
- Borophosphosilicate glass (BPSG) reflow
- Anneal of barrier layers, such as titanium nitride (TiN)
- Silicide formation, such as titanium silicide ($TiSi_2$)
- Contact alloying

Oxidation Process

- Pre Oxidation Cleaning
  - Oxidation process recipe
- Quality Measurements
- Oxidation Troubleshooting

Critical Issues for Minimizing Contamination

- Maintenance of the furnace and associated equipment (especially quartz components) for cleanliness
- Purity of processing chemicals
- Purity of oxidizing ambient (the source of oxygen in the furnace)
- Wafer cleaning and handling practices

Thermal Oxidation Process Flow Chart

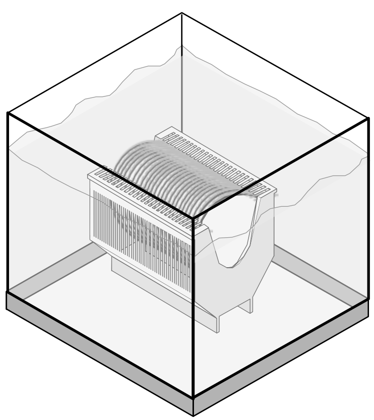
Wet Clean
- Chemicals
- % solution
- Temperature
- Time

→

Oxidation Furnace
- O_2, H_2 , N_2 , Cl
- Flow rate
- Exhaust
- Temperature
- Temperature profile
- Time

→

Inspection
- Film thickness
- Uniformity
- Particles
- Defects



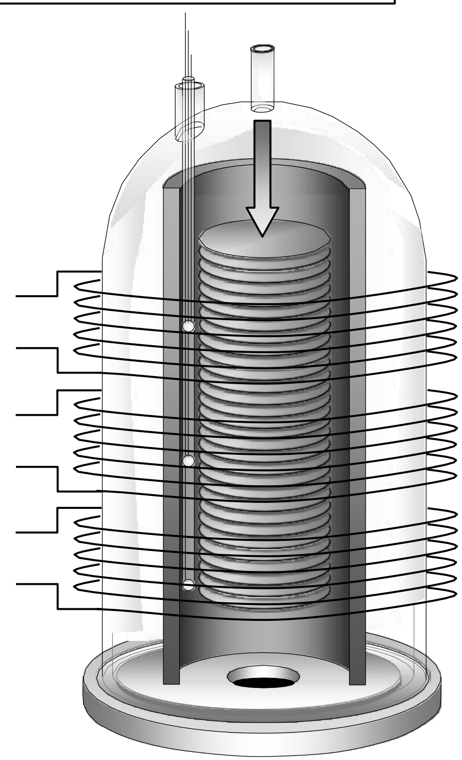
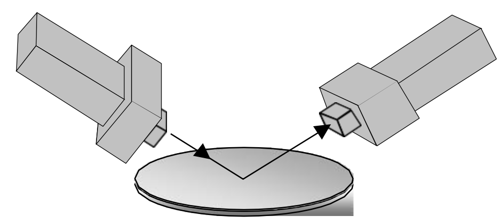


Figure 10.23



End of Slide