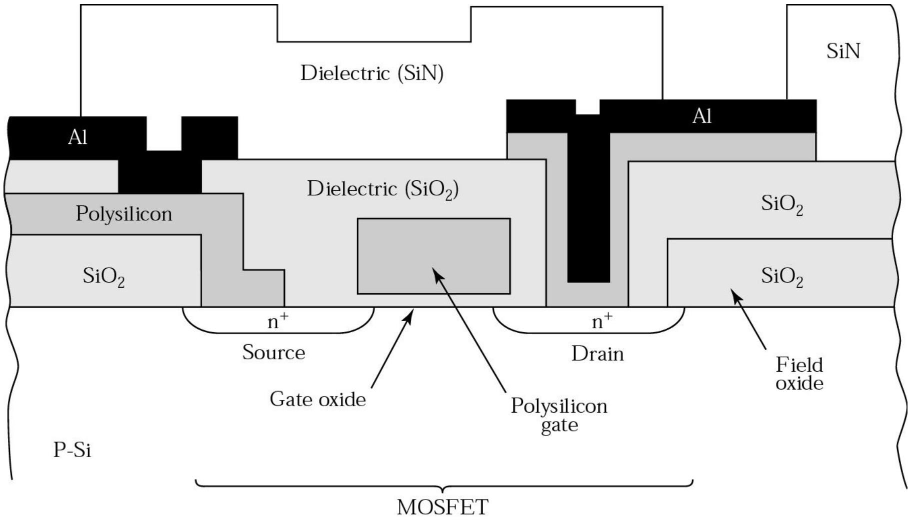
SILICON OXIDATION

Silicon Oxidation

- Many different kinds of thin films are used to fabricate discrete devices and integrated circuits. Including:
  - *Thermal oxides*
  - *Dielectric layers*
  - *Polycrystalline silicon*
  - *Metal films*



Schematic cross section of a metal-oxide-semiconductor field-effect transistor (MOSFET).

Silicon Oxidation (Cont.)

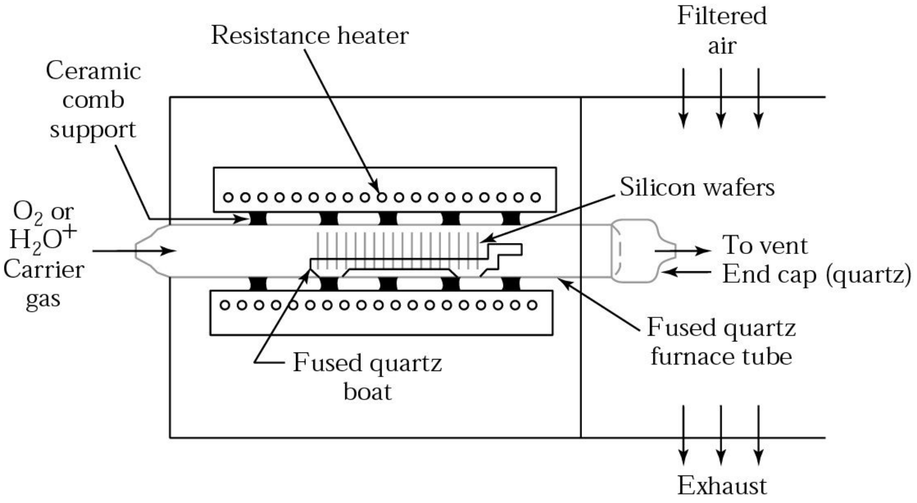
- The first important thin film from the thermal oxide group is the gate oxide layer. under which a conducting channel can be formed between the source and the drain.
- A related layer is the field oxide. which provides isolation from other devices.
- Both gate and field oxides generally are grown by a thermal oxidation process because only thermal oxidation can provide the *highest-quality oxides having the lowest interface trap densities*.

Silicon Oxidation (Cont.)

- Oxidation content
  - The thermal oxidation process used to form silicon dioxide (SiO_2).
  - Impurity redistribution during oxidation.
  - Material properties and thickness measurement techniques fir SiO_2 films.
- The silicon-silicon dioxide interface moves into the silicon during *the oxidation process*.
- This creates a fresh interface region with surface contamination on the original silicon ending up on the oxide surface.

THERMAL OXIDATION PROCESS

- Oxidation methods
  - Thermal oxidation → *most important for silicon*
  - Electrochemical anodization (electrolytic passivation process)
  - Plasma enhanced chemical vapor deposition (PECVD)
- Thermal oxidation rarely used for GaAs because of:
  - Poor electrical insulation
  - Poor semiconductor surface protection



Schematic cross section of a resistance-heated oxidation furnace.

THERMAL OXIDATION PROCESS

- Thermal Oxidation temperature is generally in the range of 900 ° C to 1200 ° C. and the typical gas now rate is about 1 L/min.
- The oxidation system uses microprocessors to regulate the gas flow sequence to control the automatic insertion and removal or silicon wafers. to ramp the temperature up (i.e . to increase the furnace temperature linearly) from a low temperature to the oxidation temperature so that the wafers will not warp duce to sudden temperature change. to maintain the oxidation temperature to within ±l °C and to ramp the temperature down when oxidation is completed.

Kinetics of Growth

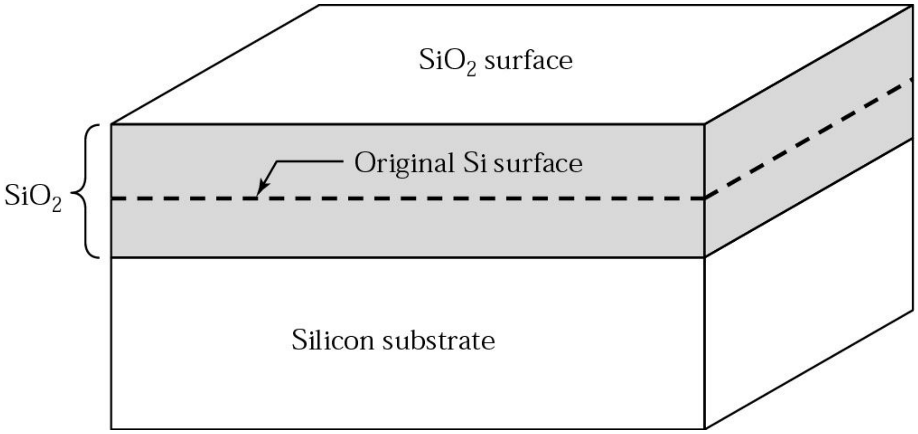
Dry oxidation:

Si (Solid) + O_2 (Gas) → SiO_2 (Solid)

Wet oxidation:

Si (Solid) + $2H_2O$ (Gas) → SiO_2 (Solid) + $2H_2$ (Gas)

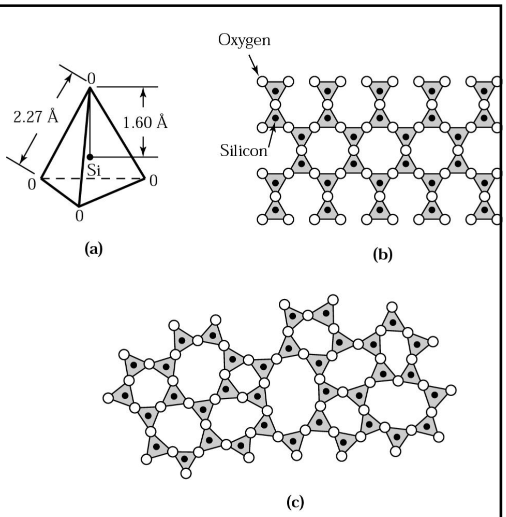
- The silicon-silicon dioxide interface moves into the silicon during *the oxidation process*.
- This creates a fresh interface region with surface contamination on the original silicon ending up on the oxide surface.



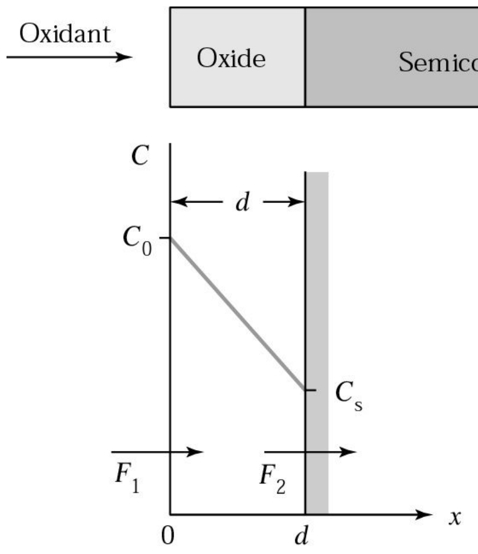
Growth of silicon dioxide by thermal oxidation.

Kinetics of Growth (Cont.)

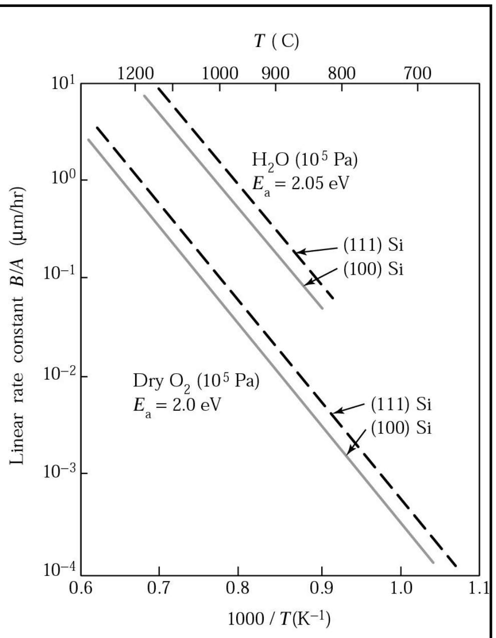
- The basic structural unit of thermally grown silicon dioxide is a silicon atom surrounded tetrahedrally by four oxygen. atoms. The silicon to oxygen internuclear distance is 1.6 A. and the oxygen to oxygen internuclear distance is 2.27A.
- Silica has several crystalline structures (e.g. quartz) and an amorphous structure. When silicon is thermally oxidized the silicon dioxide structure is *amorphous*. Typically. amorphous silica has a density of 2.21 gr/cm^3 compared with 2.65 gr/cm^3 for quartz.



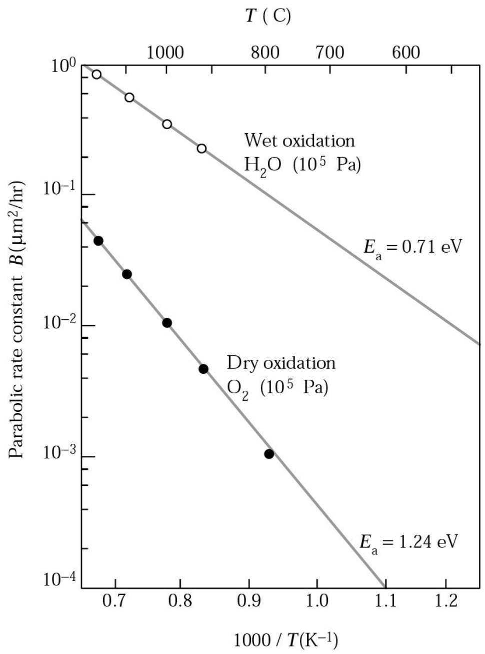
(a) Basic structural unit of silicon dioxide.
(b) Two-dimensional representation of a quartz crystal lattice.
(c) Two-dimensional representation of the amorphous structure of silicon dioxide.



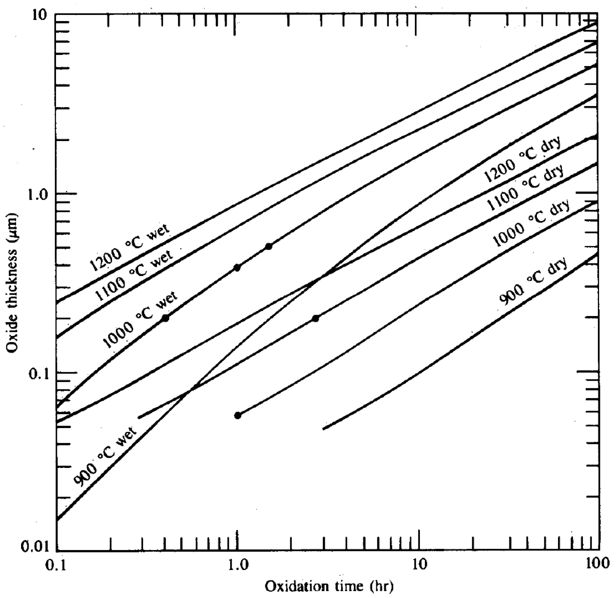
Basic model for the thermal oxidation of silicon



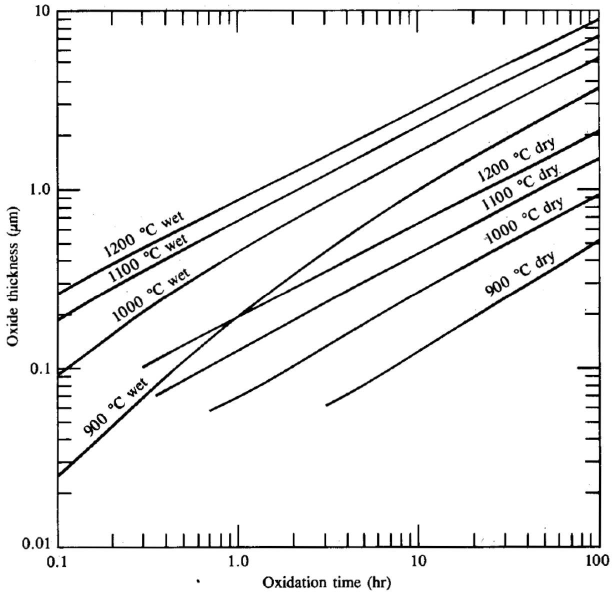
Linear rate constant versus temperature.



Parabolic rate constant versus temperature.



Wet and dry silicon dioxide growth for <100>silicon calculated using the data from Table 3.1.



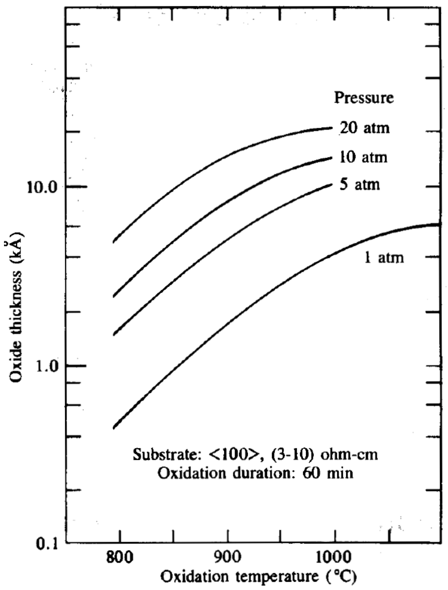
Wet and dry silicon dioxide growth for <111>silicon calculated using the data from Table 3.1.

Table 3.1 Values for Coefficient D_0 and Activation Energy E_A for Wet and Dry Oxygen.*

	Wet O_2 (X_i = 0 nm)		Dry O_2 (X_i = 25 nm)	
	D_0	E_A	D_0	E_A
⟨100⟩ Silicon				
Linear (B/A)....	9.70×10^7 μm/hr	2.05 eV	3.71×10^6 μm/hr	2.00 eV
Parabolic (B)....	386 μm^2/hr	0.78 eV	772 μm^2/hr	1.23 eV
⟨111⟩ Silicon				
Linear (B/A)....	1.63×10^8 μm/hr	2.05 eV	6.23×10^6 μm/hr	2.00 eV
Parabolic (B)....	386 μm^2/hr	0.78 eV	772 μm^2/hr	1.23 eV

*Data from ref. [7].

Wet oxide growth at increased pressures



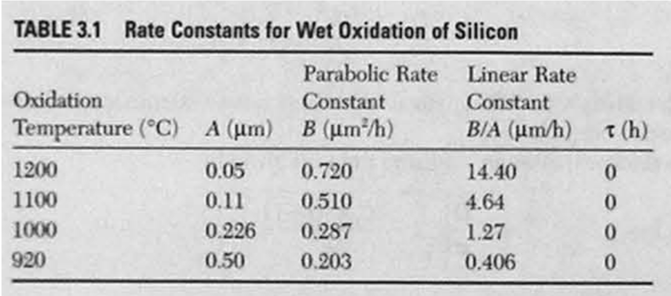


TABLE 3.1 Rate Constants for Wet Oxidation of Silicon

Oxidation Temperature (°C)	A (μm)	Parabolic Rate Constant B (μm^2/h)	Linear Rate Constant B/A (μm/h)	τ (h)
1200	0.05	0.720	14.40	0
1100	0.11	0.510	4.64	0
1000	0.226	0.287	1.27	0
920	0.50	0.203	0.406	0

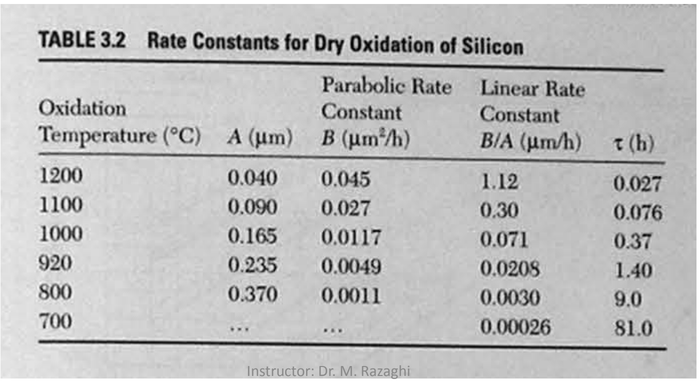
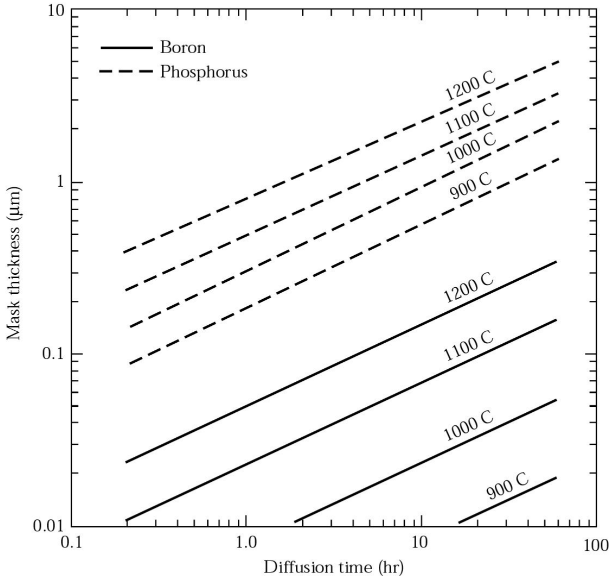


TABLE 3.2 Rate Constants for Dry Oxidation of Silicon

Oxidation Temperature (°C)	A (μm)	Parabolic Rate Constant B (μm^2/h)	Linear Rate Constant B/A (μm/h)	τ (h)
1200	0.040	0.045	1.12	0.027
1100	0.090	0.027	0.30	0.076
1000	0.165	0.0117	0.071	0.37
920	0.235	0.0049	0.0208	1.40
800	0.370	0.0011	0.0030	9.0
700	…	…	0.00026	81.0



Thickness of silicon dioxide needed to mask boron and phosphorus diffusions as a function of diffusion time and temperature