Lecture 3 Silicon Oxidation

In this lecture we'll cover the processes of oxidation.

References:

R.C. Jaeger, Introduction to Microelectronic Fabrication, Addison-Wesley, New York, 1988 - Chapter 3

S.K. Ghandi, VLSI Fabrication Principles, John Wiley and Sons, New York, 1983 - Chapter 4

S.M. Sze, ed., VLSI Technology, McGraw-Hill, New York, 1988 - Chapter 7

A.S. Grove, Physics and Technology of Semiconductor Devices, John Wiley and Sons, New York, 1967

Chemical Process

Heat silicon wafer to 900° to 1200°C in atmosphere containing oxygen or water vapor.

1. O_2 or H_2O (oxidant) diffuses to silicon surface
2. Oxidation reaction occurs

   $Si + O_2 \text{ -----> } SiO_2$

   $Si + 2 H_2O \text{ -----> } SiO_2 + 2 H_2$

Physical Process

Oxidant fluxes

$$J = \frac{- D (N_0 - N_i)}{X_0} \qquad \text{Fick's law}$$

$$J = k_s N_i \qquad \text{reaction rate}$$

where,

D = diffusivity of oxidant $\quad$ k_s = rate constant

Eliminate N_i from above

$$J = \frac{DN_0}{X_0 + D/k_s}$$

Oxide growth rate proportional to flux

$$\frac{dX_0}{dt} = \frac{J}{M} = \left(\frac{D N_0}{M}\right)\left(X_0 + D/k_s\right)$$

where,

M = number of atoms of oxidant incorporated per unit thickness of film

Solve for $X_0(t)$

$$X_0(t) = \frac{A}{2}\left(\left(1+\frac{4B}{A^2}(t + \tau)\right)^{1/2} - 1\right)$$

where,

$$A = 2D/k_s \quad B = 2DN_0/M$$

$$\tau = X_i^2/B + AX_i/B \qquad X_i = \text{initial oxide thickness}$$

At short times, growth is "linear"

$$X_0(t) = \frac{B}{A}(t + \tau)$$

B/A is the linear rate constant, depends on reaction rate constant, concentration (or partial pressure) of oxidant

At long times, growth is "parabolic"

$$X_0(t) = (Bt)^{1/2}$$

B is the parabolic rate constant, depends on diffusivity, concentration (or partial pressure) of oxidant

Linear and parabolic rate constants are strong functions of temperature, through reaction rate constant, k_s, and diffusivity, D

Oxidation - Growth Charts

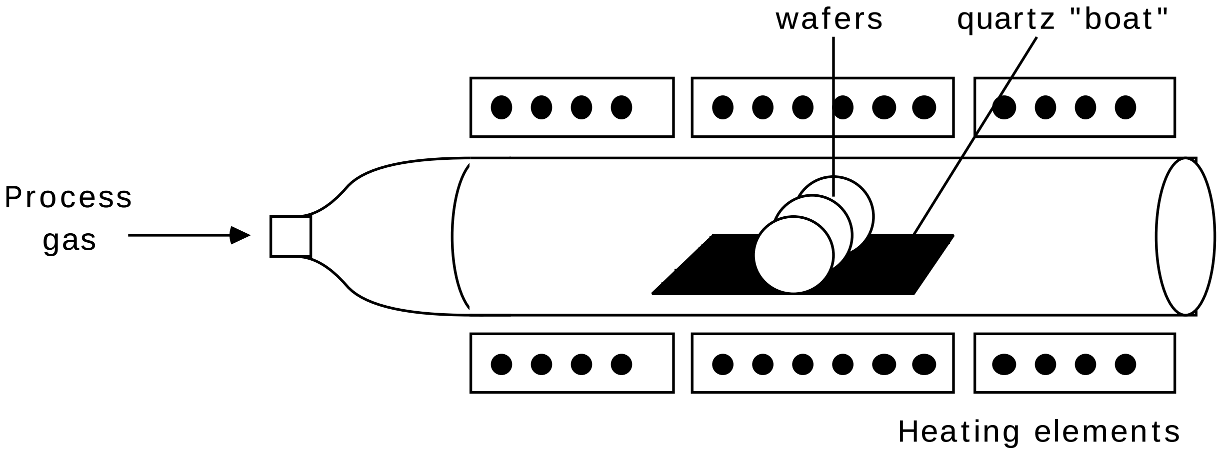
"Dry" (O_2) versus "Wet" (H_2O)   oxidation

Dry oxide more dense, used for gate oxides (< 100 nm)

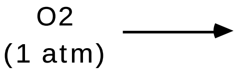
Wet oxide used for thicker field oxides, masking. Actual process usually involves dry/wet/dry sequence

How do we do it?

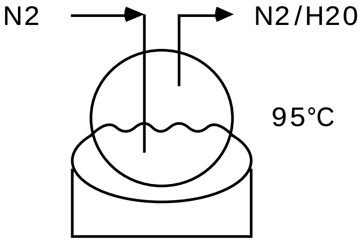
Furnace



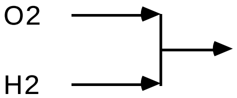
Process gas options



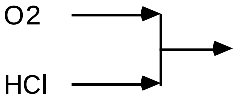
"Dry" oxidation



"Wet" oxidation



"Wet" oxidation
(Hydrox)



"Chlorine"
oxidation

Oxide Thickness Determination

Ellipsometry

Polarized laser light is incident on the oxide covered wafer. The polarization of the reflected light, which depends on the thickness and index of refraction (known) of the oxide layer, is determined and used to calculate the oxide thickness.

Profilometry

Oxide etched away over part of the wafer and a mechanical stylus is dragged over the resulting step.

Color

Light reflected from the surface of an oxidized silicon wafer will experience constructive interference when the path length in the oxide is equal to an integer multiple of the wavelength of the light.

$$2 X_0 = k \lambda / n$$

where x_0 = oxide thickness, k=1,2,3,..., λ= wavelength of incident light, n= refractive index of SiO_2 1.46