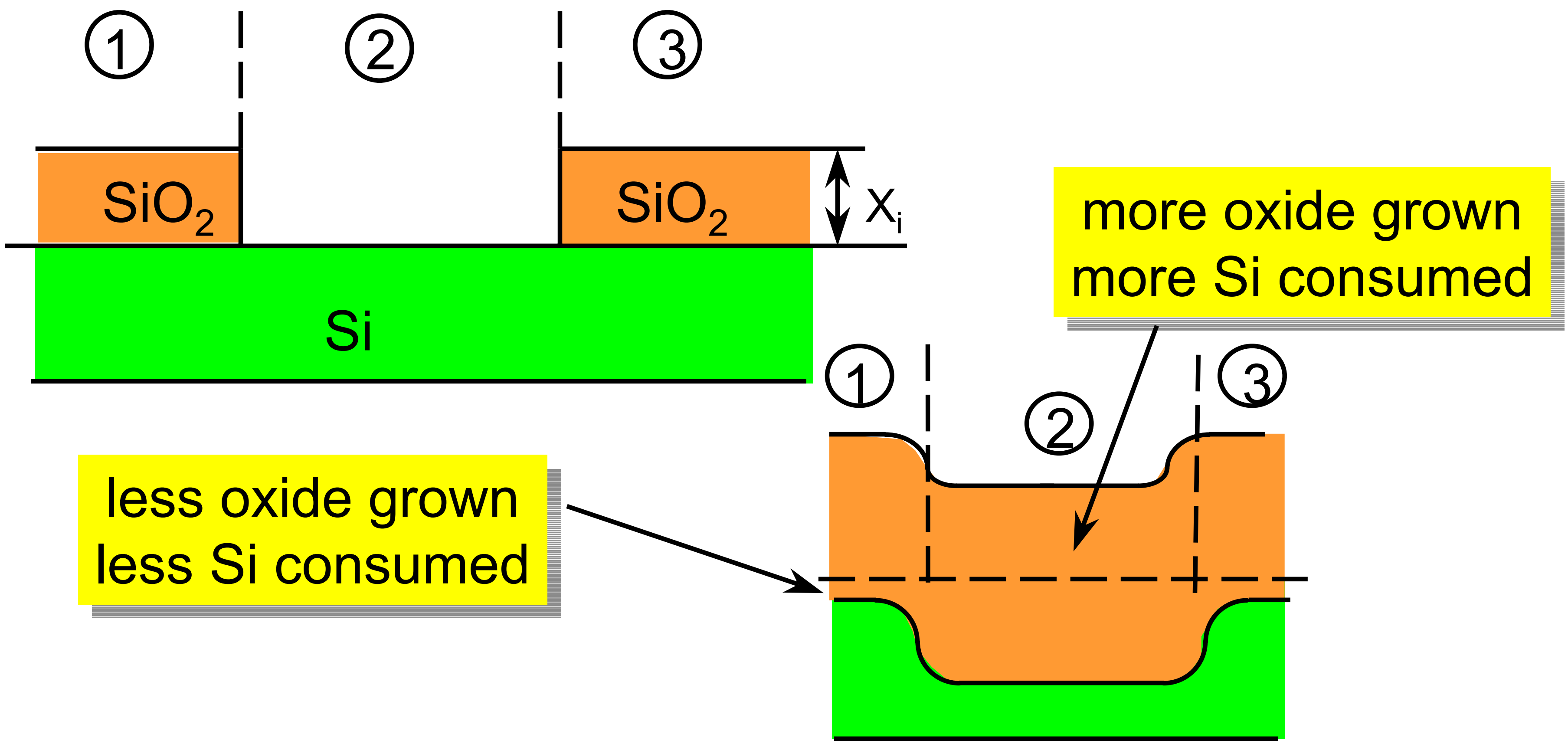
Effect of X_i on Wafer Topography



Factors Influencing Thermal Oxidation

– Temperature
– Ambient Type (Dry O_2, Steam, HCl)
– Ambient Pressure
– Substrate Crystallographic Orientation
– Substrate Doping

High Pressure Oxidation

$$B/A = C_A / [N_1(1/k_s+1/h)] \propto C_A \propto P_G$$

$$B = 2DC_A / N_1 \propto C_A \propto P_G$$

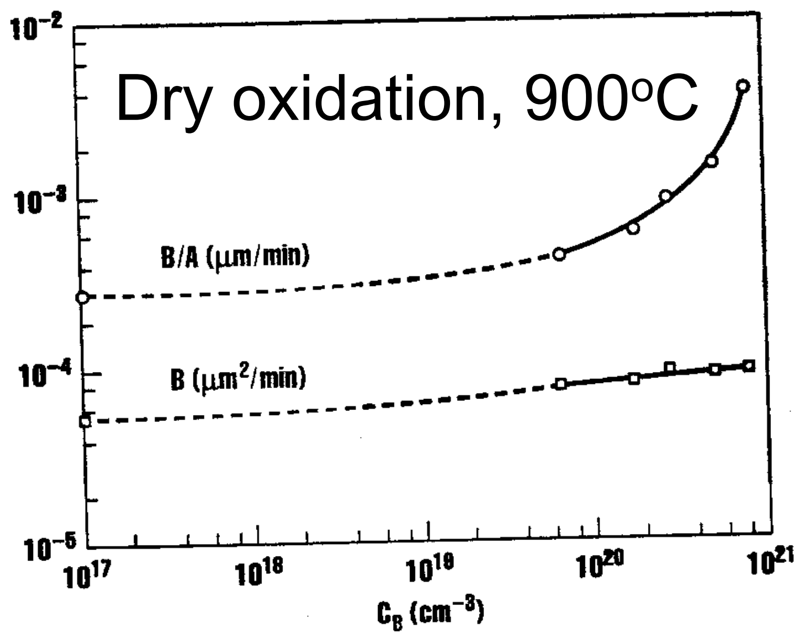
When P_G increases, both B and B/A will increase.
Therefore oxidation rate increases.

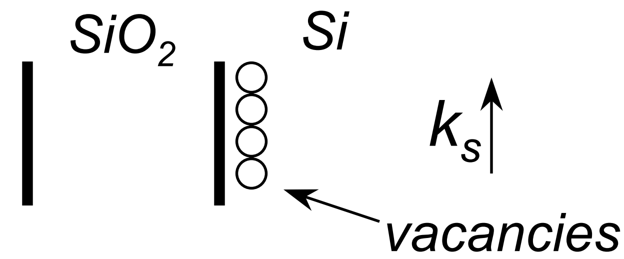
1) The oxidation temperature can be reduced if the pressure is increased, to achieve a given oxidation rate

2) To grow a given oxide thickness at same temperature, time can be reduced

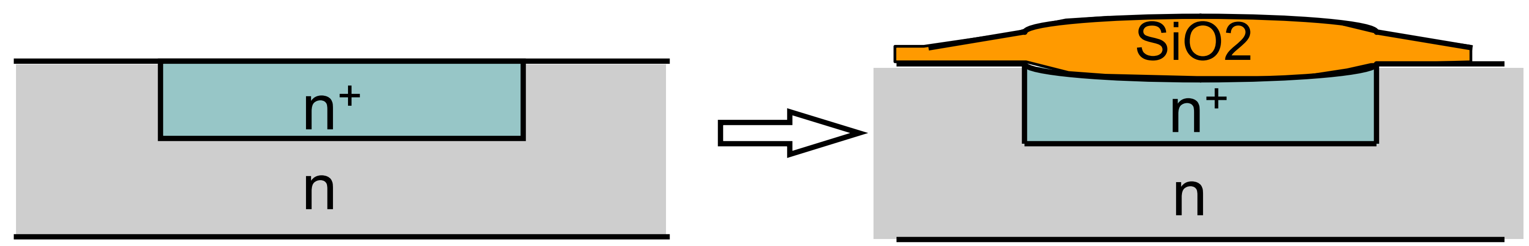
High Doping Concentration Effect

Coefficients for dry oxidation at 900°C
as function of surface Phosphorus concentration





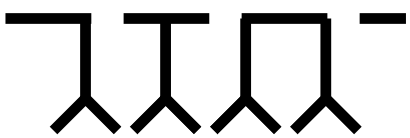
* highly doped Si has more vacancies



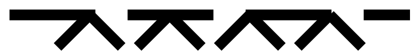
Origin of Substrate Orientation Effect

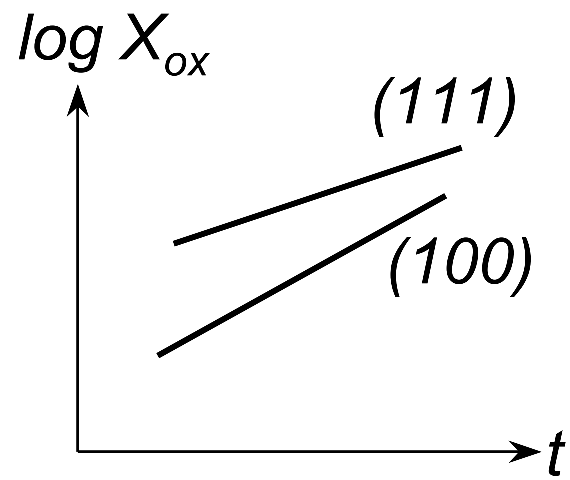
(111) Surface density of Si bonds >
(100) Surface density of Si bonds

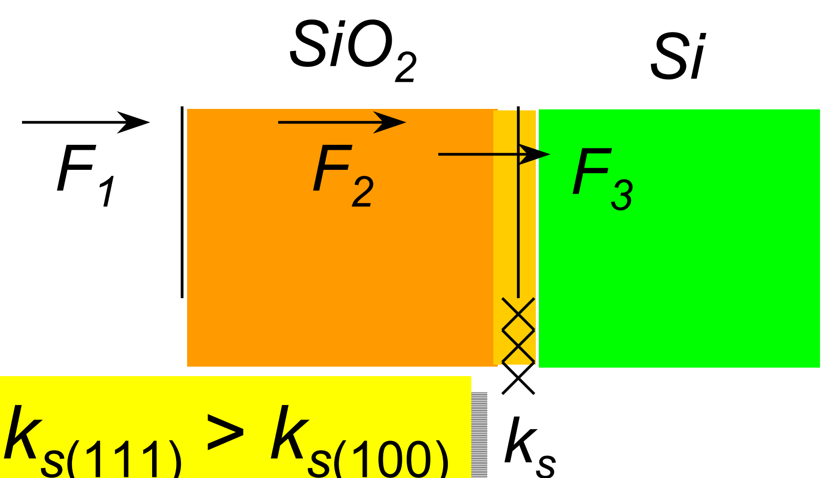
(100):



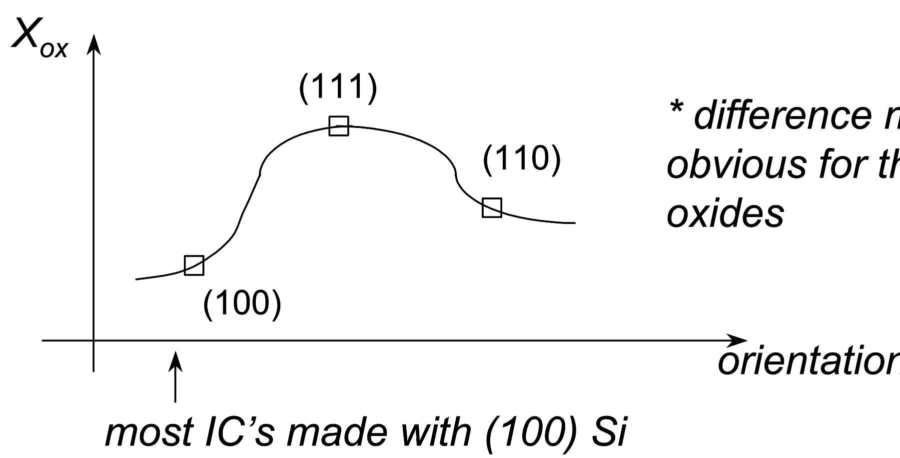
(111):





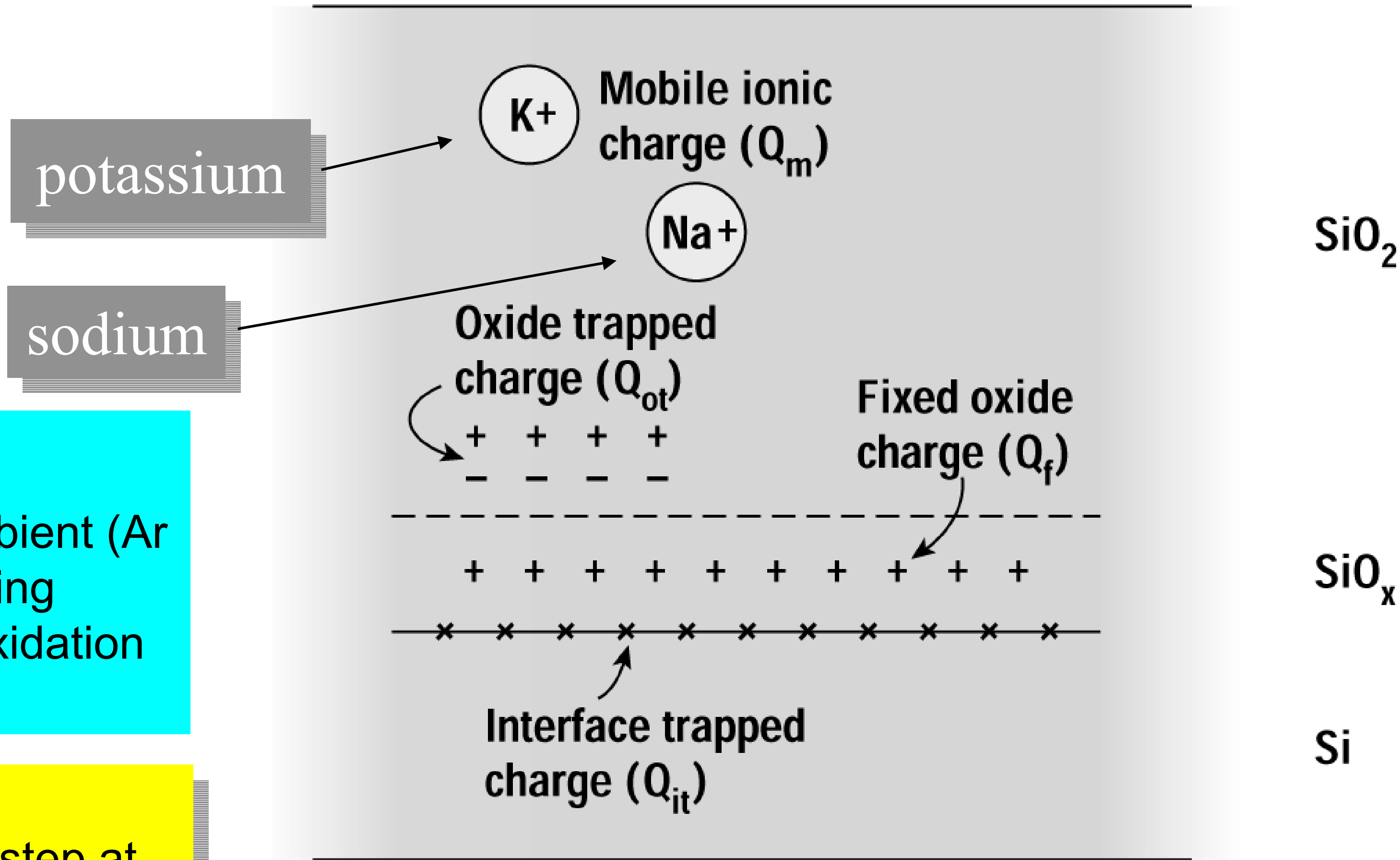


$k_{s(111)} > k_{s(100)}$



** difference more obvious for thin oxides*

Thermal Oxide Charges



To minimize Q_f

Use inert gas ambient (Ar or N2) when cooling down at end of oxidation step

To minimize Q_{it},
A final annealing step at 400-450°C is performed with 10%H_2+90%N_2 ambient ("forming gas") after the metallization step.

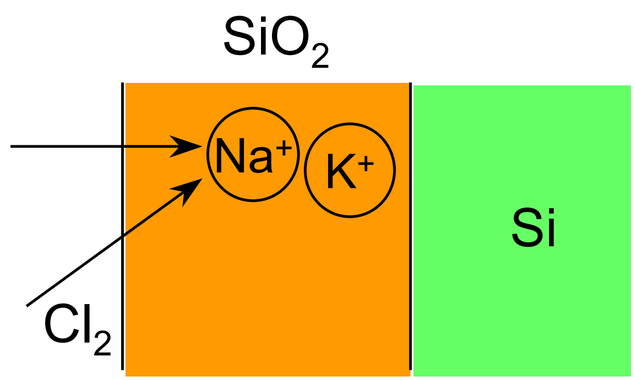
Figure 4.14 Silicon–silicon dioxide structure with mobile, fixed charge, and interface states *(© 1980, IEEE, after Deal).*

Oxidation with Cl-containing Gas

- Introduction of halogen species during oxidation
  e.g. add ~*1- 5%* HCl or TCE (trichloroethylene) to O_2

  → reduction in metallic contamination

  → improved SiO_2/Si interface properties

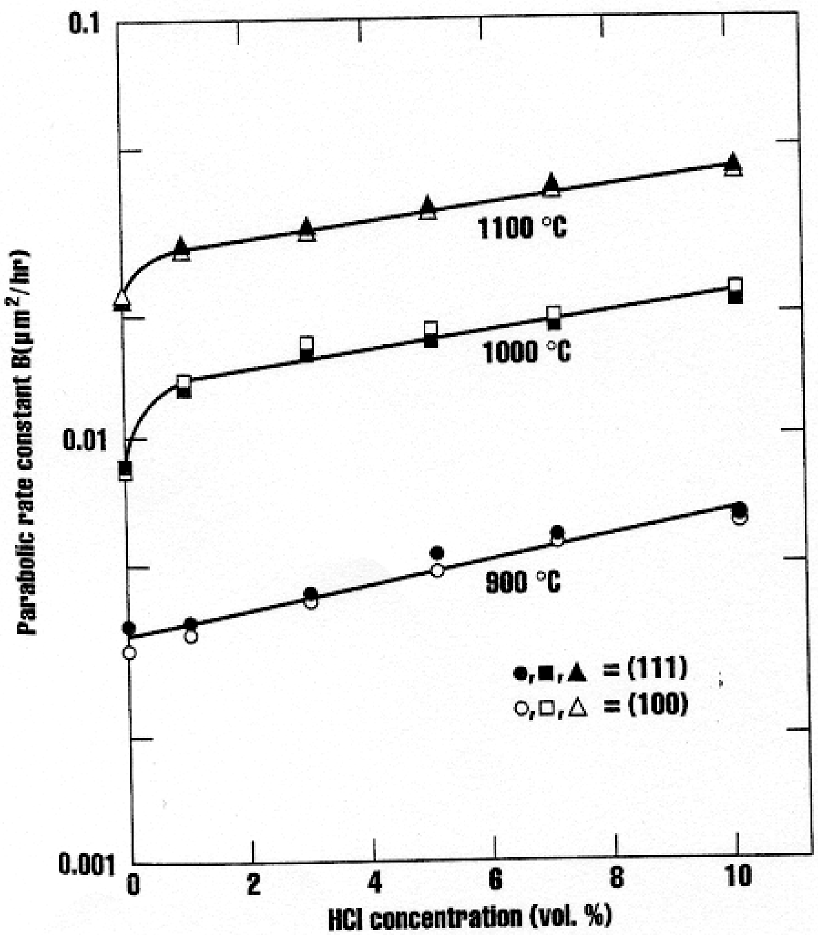


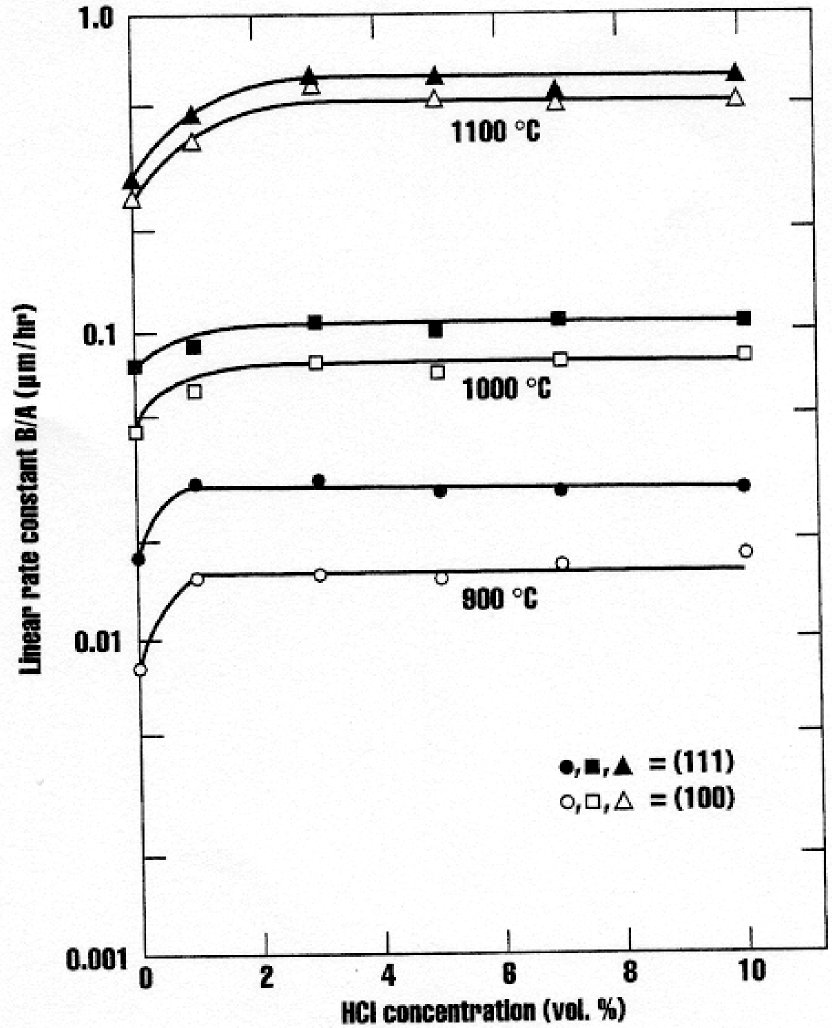
$$M + Cl \rightarrow MCl$$

Na^+ or K^+ in SiO_2 are mobile!

Effect of HCl on Oxidation Rate

$$HCl + O_2 \rightarrow H_2O + Cl_2$$





SUMMARY of Deal Grove Model

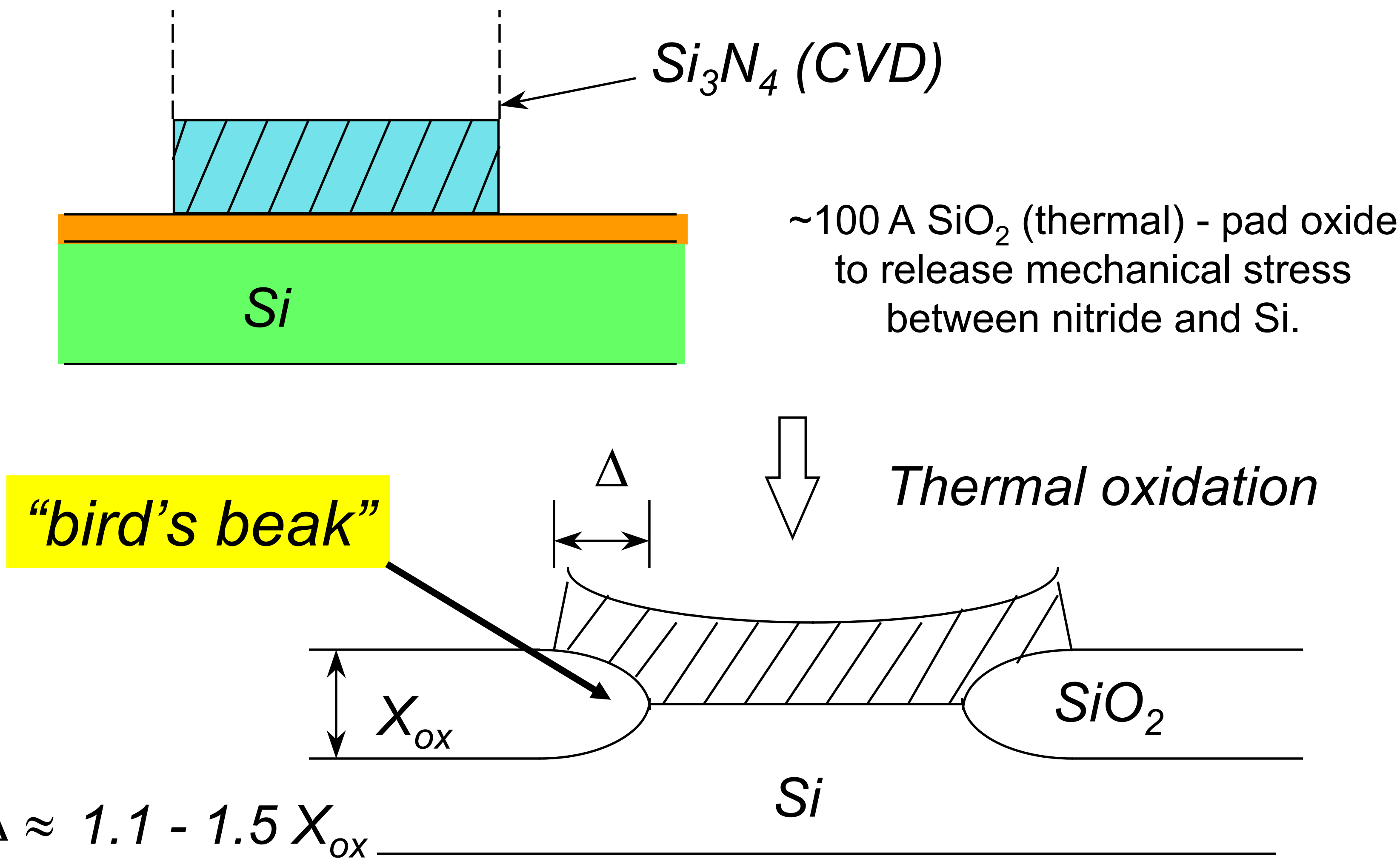
$$X_{ox}^2(t) + A\,X_{ox}(t) = B\,(t + \tau)$$

The growth rate $\frac{dX_{ox}}{dt} = \frac{B}{A+2X_{ox}}$ slows down as X_{ox} increases

Dependence of B/A and B on Processing Parameters

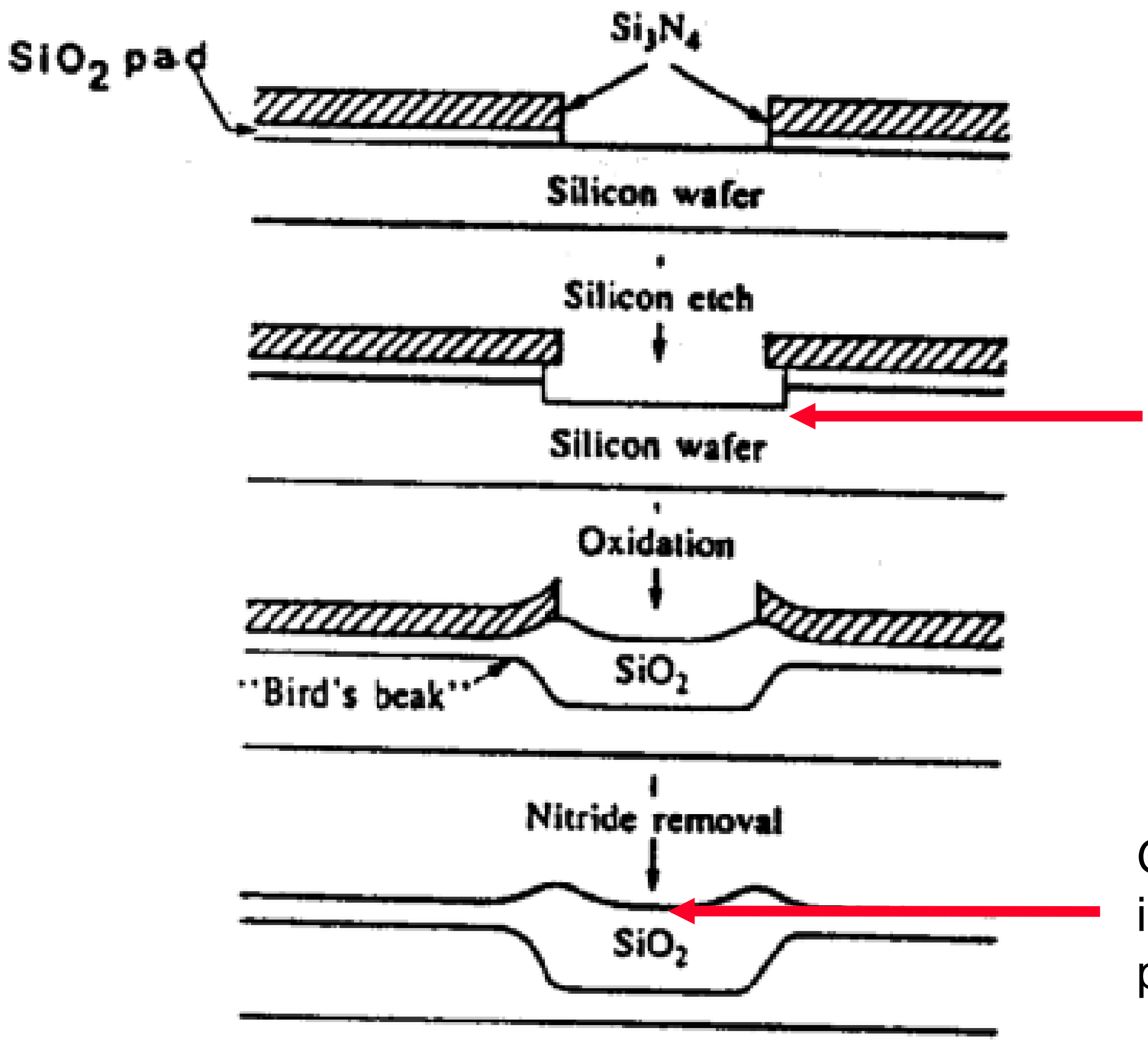
	Linear Constant B/A	Parabolic Constant B
Oxidation Pressure	linear with oxygen pressure (actually $\propto P^{0.8}$)	linear with oxygen pressure
Steam versus O_2	larger for steam oxidation	larger for steam oxidation
Si crystal orientation	B/A(111):B/A(100) = 1.68:1	independent of orientation
Dopant type and concentration in Si	increases with dopant concentration	insensitive
Addition of Cl-containing gas in oxidation ambient	insensitive	increases

Local Oxidation of Si [LOCOS]



$\Delta \approx 1.1 - 1.5\, X_{ox}$

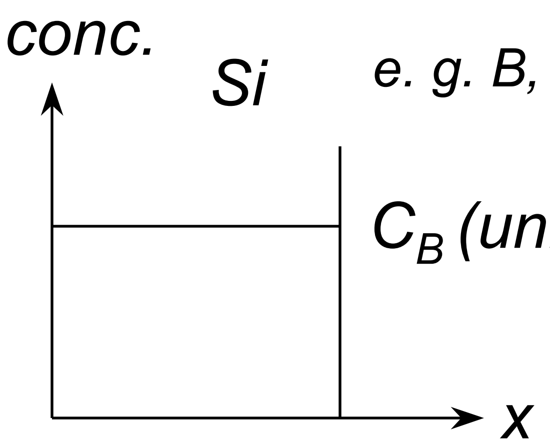
Fully Recessed LOCOS



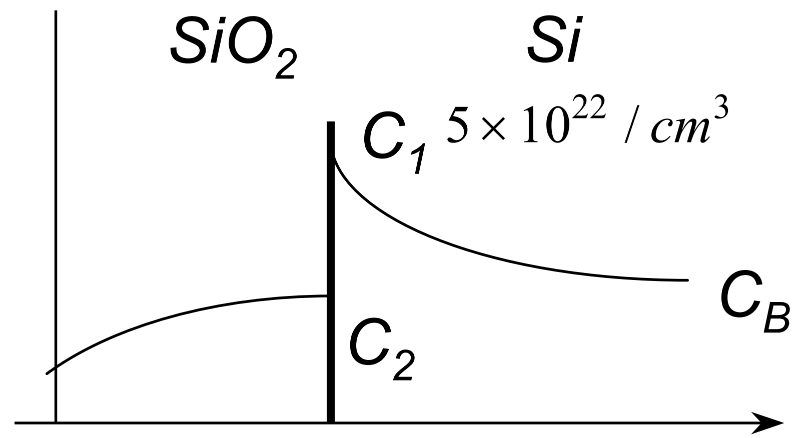
Si substrate is etched to a depth of ~1/2 the intended grown oxide thickness

Grown oxide surface is approximately planar with substrate surface

Dopant Redistribution during Thermal Oxidation



e. g. B, P, As, Sb.



Segregation Coefficient

$$m \equiv \frac{\text{equilibrium dopant conc. in Si}}{\text{equilibrium dopant conc. in } SiO_2}$$

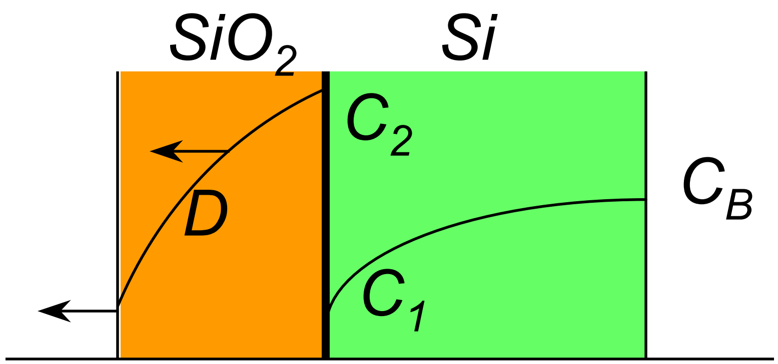
Fixed ratio

$$= \frac{C_1}{C_2}$$

(can be>1 or <1)

Four Cases of Interest

(A) m < 1 and dopant diffuses slowly in SiO_2

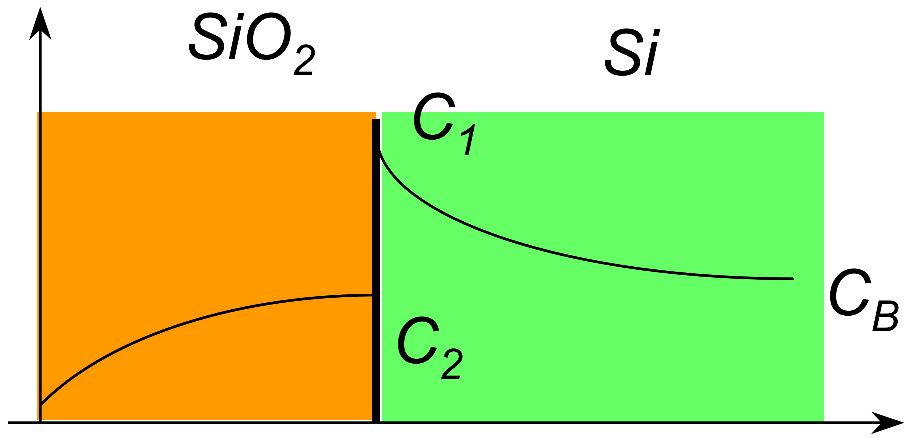


e. g. B (m = 0.3)

flux loss through SiO_2 surface not considered here.

$\Longrightarrow$ B will be depleted near Si interface.

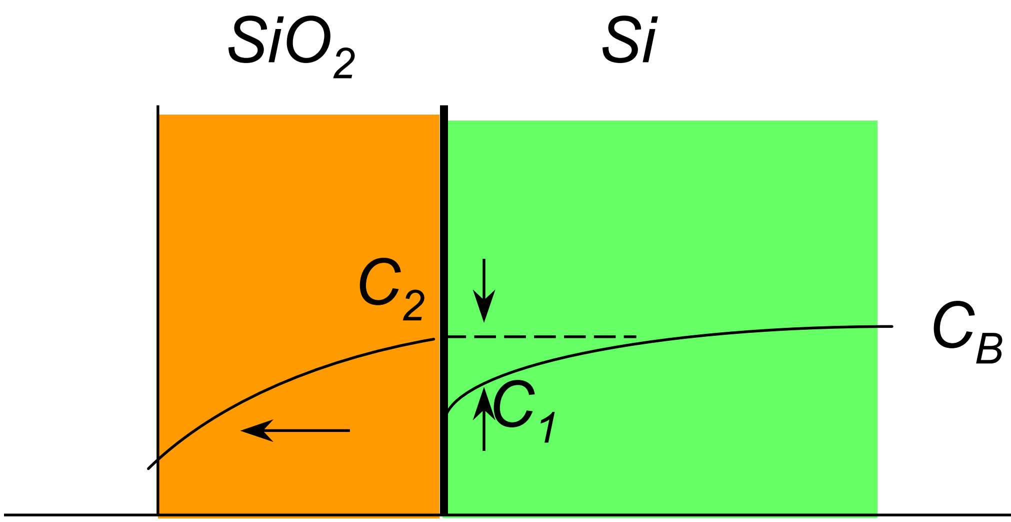
(B) m > 1, slow diffusion in SiO_2.



e.g. P, As, Sb

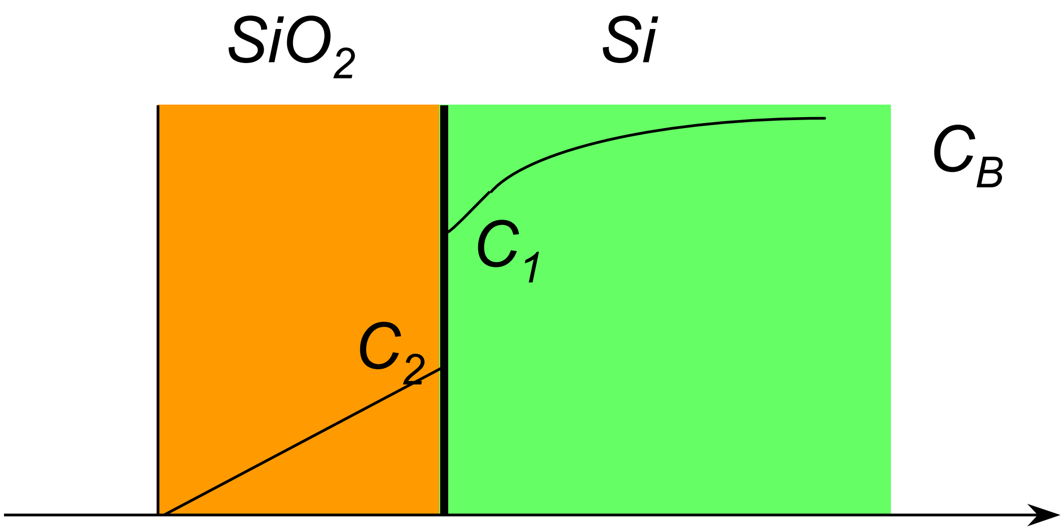
$\Rightarrow$ dopant piling up near Si interface for P, As & Sb

(C) m < 1, fast diffusion in SiO_2



e. g.
B,
oxidize with
presence of H_2

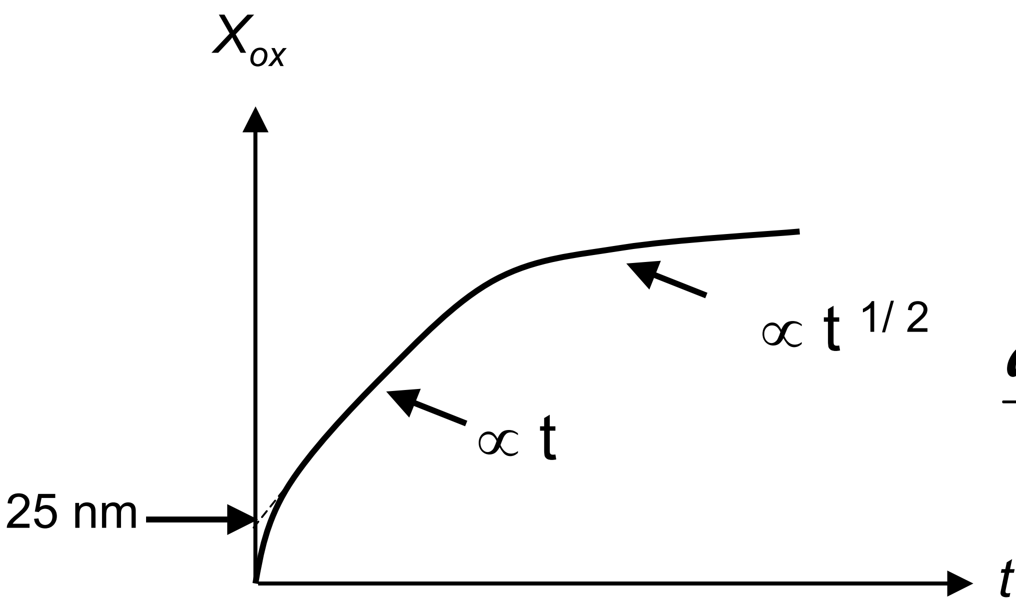
(D) m > 1, fast diffusion in SiO_2



e. g. Ga (m=20)

Thin Oxide Growth

The Deal-Grove model provides excellent agreement with experimental data except for thin (<20 nm) SiO_2 grown in O_2



When X_{ox} becomes large, additional term becomes zero

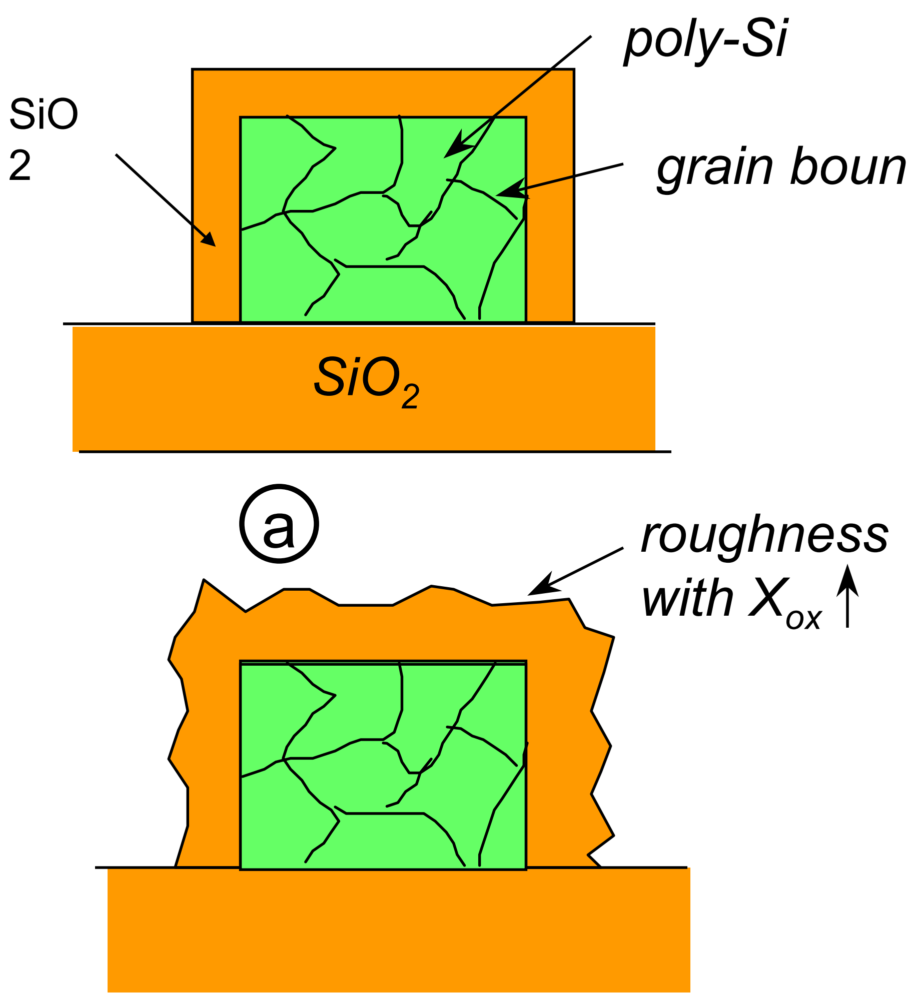
$$\frac{dX_{ox}}{dt} = \frac{B}{A + 2X_{ox}} + Ce^{-X_{ox}/L}$$

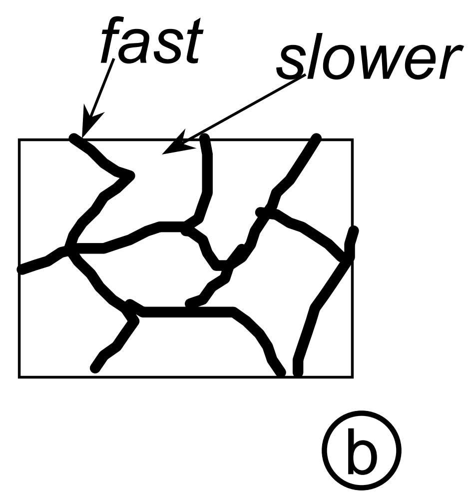
$L \sim 7nm$

=> For thick oxides grown in O_2 on bare Si,

assume X_i =25 nm when using the D-G equations

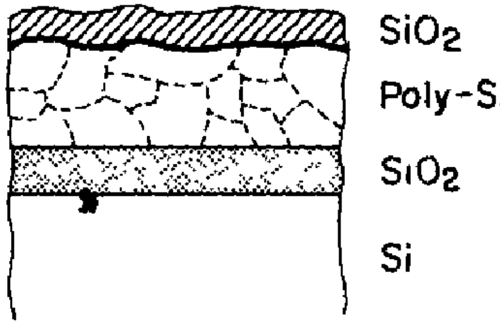
Polycrystalline Si Oxidation





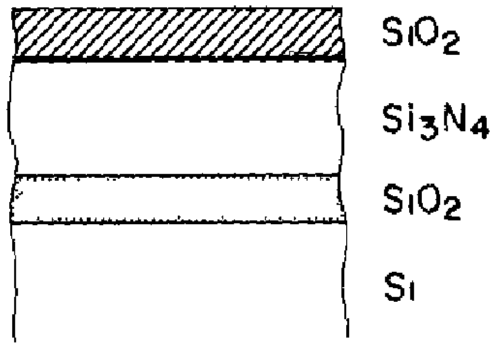
Overall growth rate is higher than single-crystal Si

Schematic Illustration of Thermal Oxidation of Si-containing materials in which SiO2 is the final reaction product



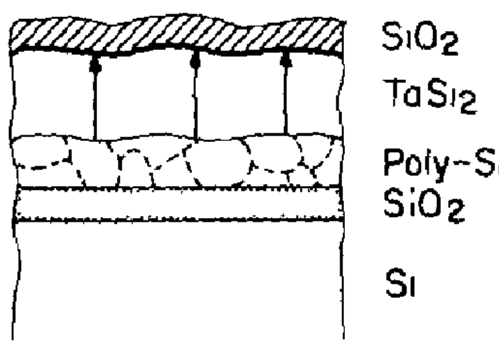
POLYCRYSTALLINE SILICON

$$Si + O_2 \rightarrow SiO_2$$



SILICON NITRIDE

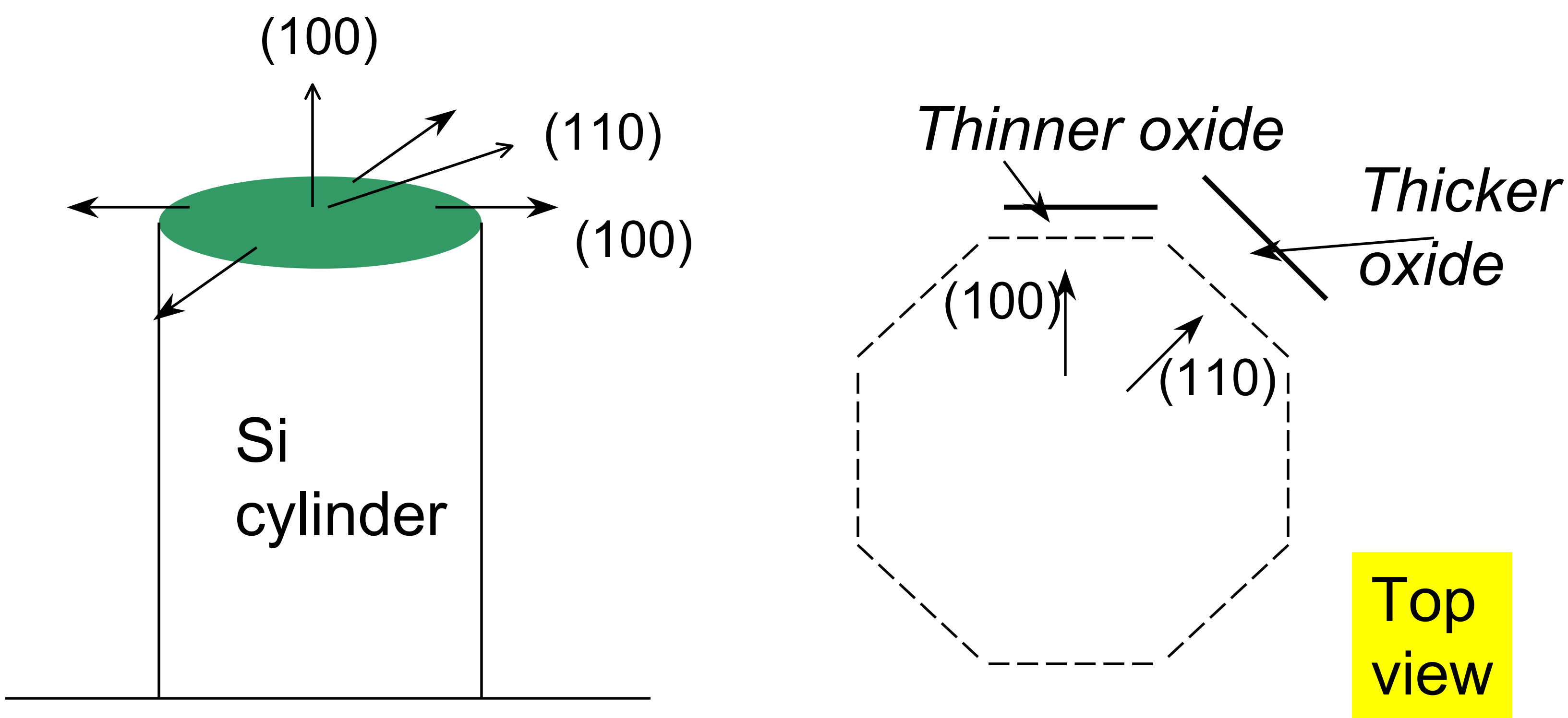
$$Si_3N_4 + 3\ O_2 \rightarrow 3\ SiO_2 + 2\ N_2$$



TANTALUM SILICIDE

$$TaSi_2 + Si + O_2 \rightarrow SiO_2 + TaSi_2$$

2-Dimensional oxidation effects



Mechanical stress created by SiO_2 volume expansion also affects oxide growth rate (if interested, see Kao et al, International Electron Devices Meeting Digest, 1985, p.388)