Thermal Oxidation of Silicon

(i) SiO_2 Structure & Properties

(ii) Kinetics of Thermal Growth of Silicon

(iii) Si-SiO_2 interface

(iv) Characterisation of Quality of SiO_2

(v) Growth Technology

MOS Technology is used in creation of Silicon ICs, owe most of it's credit to $Si-SiO_2$ system.

In fact more than calling ICs as Silicon ICs, we should really call ICs as SiO_2 ICs.

SiO_2 is used in VLSI Technology as

(i) Field Oxide (4000 Å to 1.4 μm)

(ii) Masking Oxide (600 Å to 4000 Å)

(iii) Gate Oxide (Gate Dielectric) [1 nm to 1000 Å]

(iv) Pad Oxide (100 to 400 Å)

(v) Chemical oxide ; During RCA Cleaning

Technologies used for creation of SiO_2

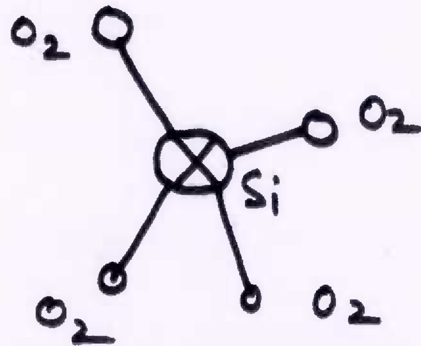
1. Thermal Oxidation
   (a) Dry Oxidation
   (b) Wet Oxidation

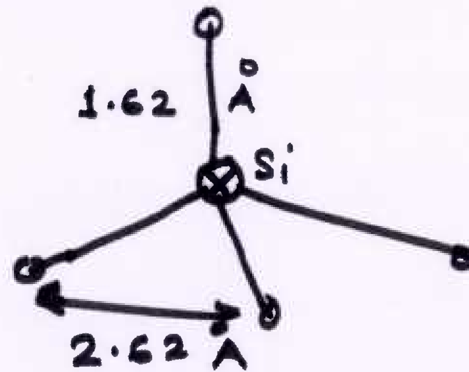
2. Deposition techniques
   (a) Chemical Vapour Deposition
   (b) Physical Vapour Deposition
   (c) Rapid Thermal Oxidation
   (d) Sol.-gel Process
   (e) Plasma Oxidation

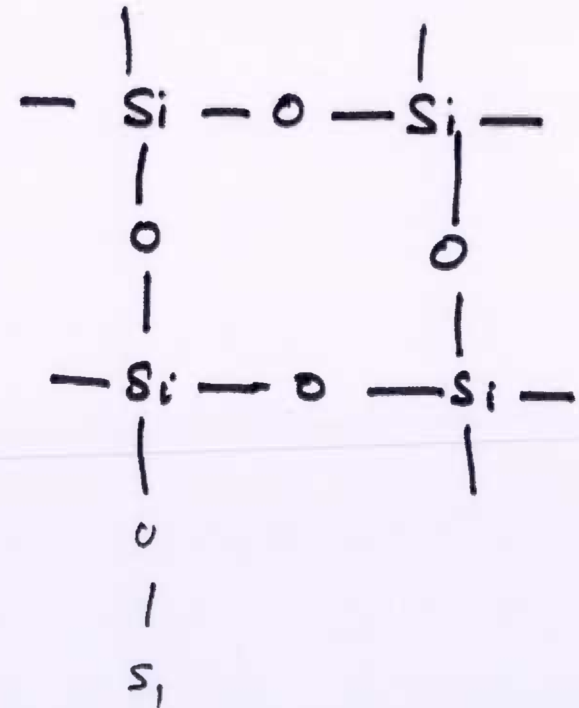
Thermal Oxidation is most basic oxidation technique and is most important step in creation of Gate - Oxide in a MOS Transistor.

Properties of Silicon Dioxide

(i) Bonding : Si – O – Si is a natural bond in SiO_2.







O – O Bond length → 2.62 Å

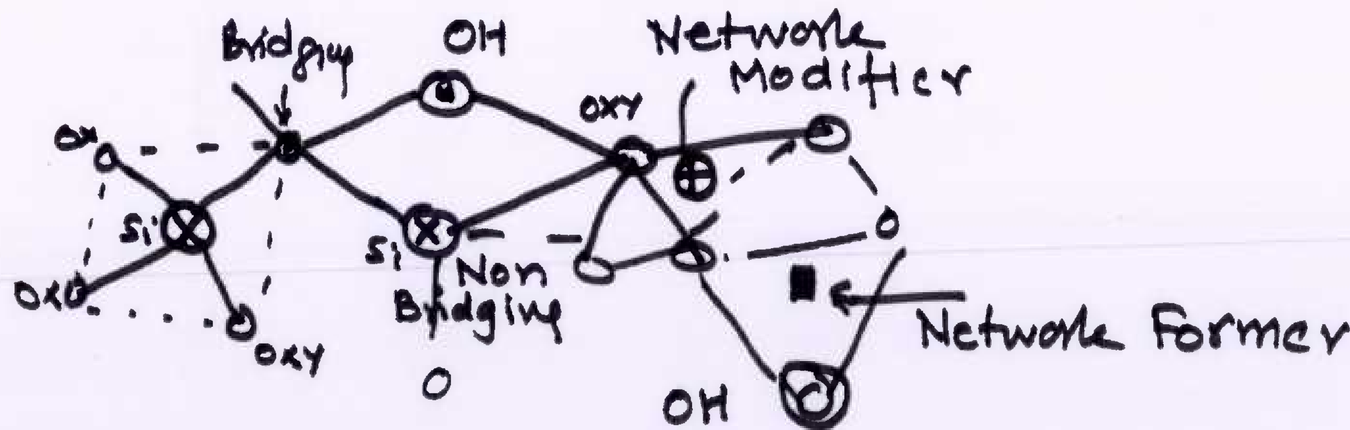
Si – O Bond Length → 1.62 Å

Si – Si Bond Length → 3 Å

SiO_2 is a Dielectric Material and is available in (i) Amorphous Phase

(ii) Crystalline Phase → Quartz

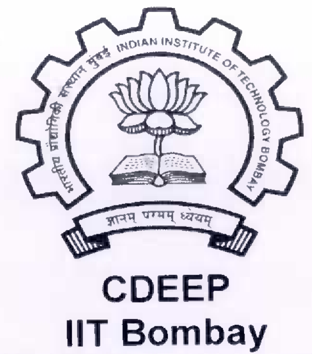
Thermally grown oxides are Amorphous in nature. Typical atomic structure of SiO_2 with some impurities or ions is as below:



Some observations :

(i) From the lattice structures of SiO_2, we observe that if Si has to leave SiO_2 lattice, it must break 4 Si-O bonds. While if Oxygen atom has to leave SiO_2 lattice, it needs to break only One bond.

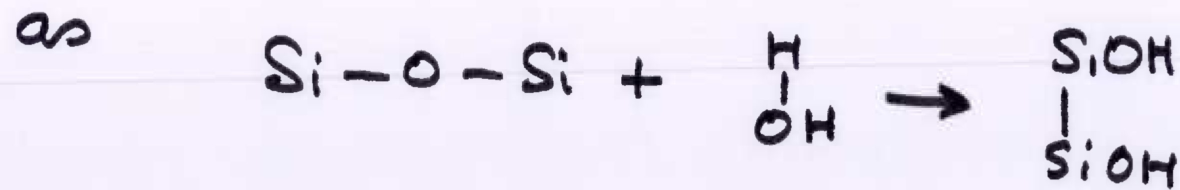
(ii) SiO_2 with no Impurities like Diffusing Impurities, or Sodium, Lead, Borium etc, is called Intrinsic Silica.
While SiO_2 with Impurities is called Extrinsic Silica.



(iii) Boron, Phosphorous & Arsenic (etc.) replace Silicon and hence create bond between Oxygen & them. Such Impurities are called Network former.

However if Impurities sit in Interstitial Sites, then they modify the Network of SiO_2, and hence called Network Modifier. Na_2O, Pb_2O_3, Ba_2O_3 are such Modifier.

(iv) If SiO_2 is put into water, we can have reaction as



It is also to be noted that SiO_2 is strong Hydrophilic in nature.

(v) Physical Properties of SiO_2

1. $\sigma \leq 10^{-16}$ mhos/cm
2. Bandgap $E_g \geq 9\,eV$
3. Refractory Index $\eta = 1.45$
4. Density = 2.22
5. No. of atoms/cc = 2.3×10^{22}/cc
6. Dielectric Constant $K_{SiO_2} = 3.9$
7. Dielectric Strength = 10^{7} V/cm.

(vi) SiO_2 has strong Utility in IC processing as

(a) Easy to Etch

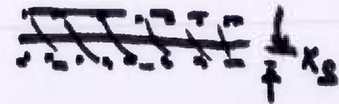
(b) Excellent Insulator with High Dielectric Strength

(c) Most Impurities (in Silicon) have poor Diffusion Constant in SiO_2.

(d) It is extremely Stable.

(e) Interface is quite Stable ($Si - SiO_2$) and very much reproducible as is desired in IC fabrication.

(vii) When Si is Oxidised, there is volume expansion. If x_s is Silicon Thickness and after oxidation it creates oxide Thickness X_{ox}. Then we use Law of Mass-action to say



$N_s \cdot x_s = N_{ox} x_{ox}$ where N_s is Si Conc $= 5\times10^{22}/cc$ and N_{ox} is SiO_2 Conc. $= 2.3\times10^{22}/cc$

$$\therefore X_s = \frac{N_{ox}}{N_s} \cdot X_{ox} = 0.46\, X_{ox}$$

Local Oxidation Silicon.

LOCOS

"Kinetics of Thermal Oxidation of Silicon"

Silicon dioxide (SiO_2) is generally grown by Oxidation of Silicon at high temperatures (800°c to 1200°c) in Oxygen rich ambient. It could be pure O_2 or H_2O. Oxygen reacts with Silicon to form SiO_2.

SiO_2 formation by oxidation of Silicon in Water Vapour may have a bit complicated reaction. Overall however it may be like: