Oxidation

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Chapters 13

Previous lecture

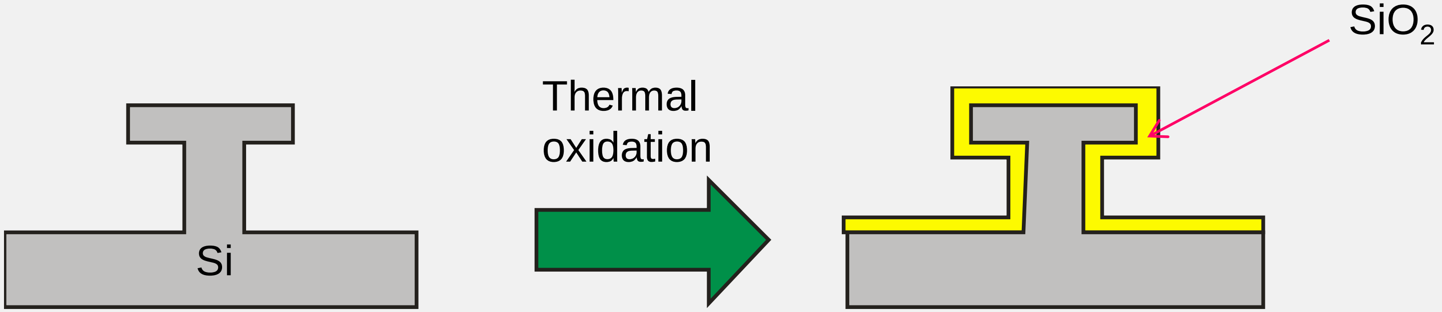
- Cleanroom
- Cleaning

Outline

- SiO_2 properties and applications
- Thermal oxidation of Si
- LOCOS
- Oxidation of structured surface

Thermal SiO_2 properties

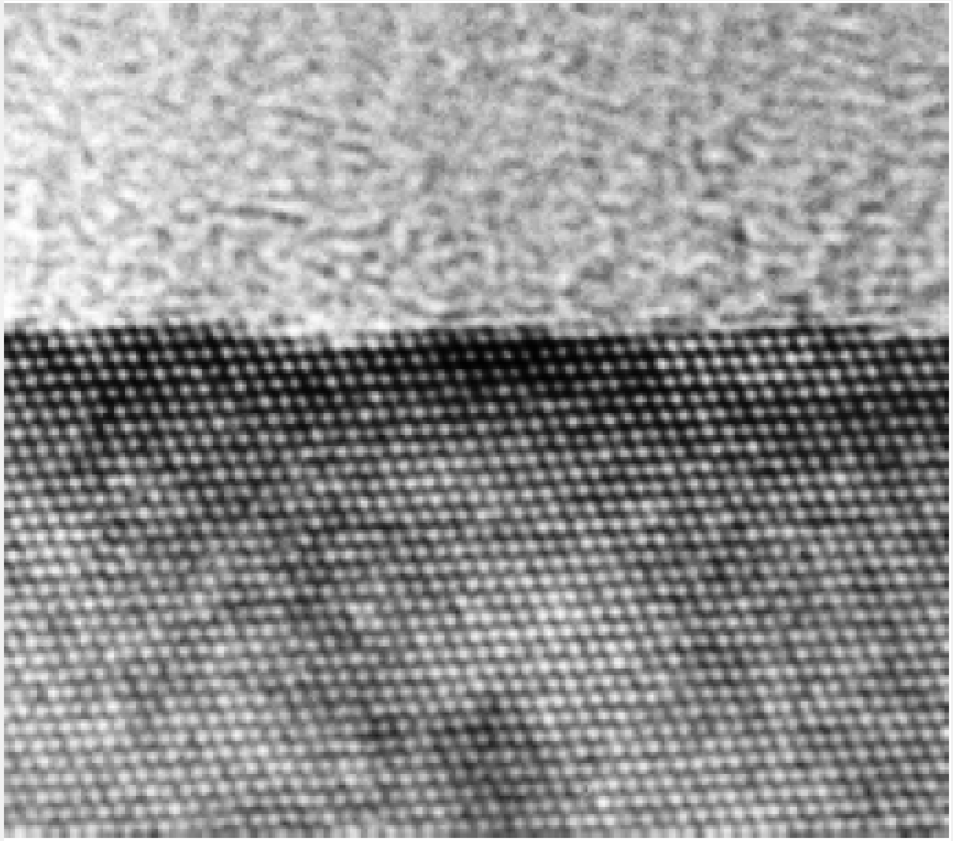
- Excellent electrical insulator - high breakdown electric field
- Stable and reproducible Si/SiO_2 interface
- Selective oxidation with corresponding mask, e.g. Si_3N_4
- Good diffusion mask for common dopants
- Very good etching selectivity between Si and SiO_2
- Conformal oxide growth on exposed Si surface



The Si/SiO_2 interface

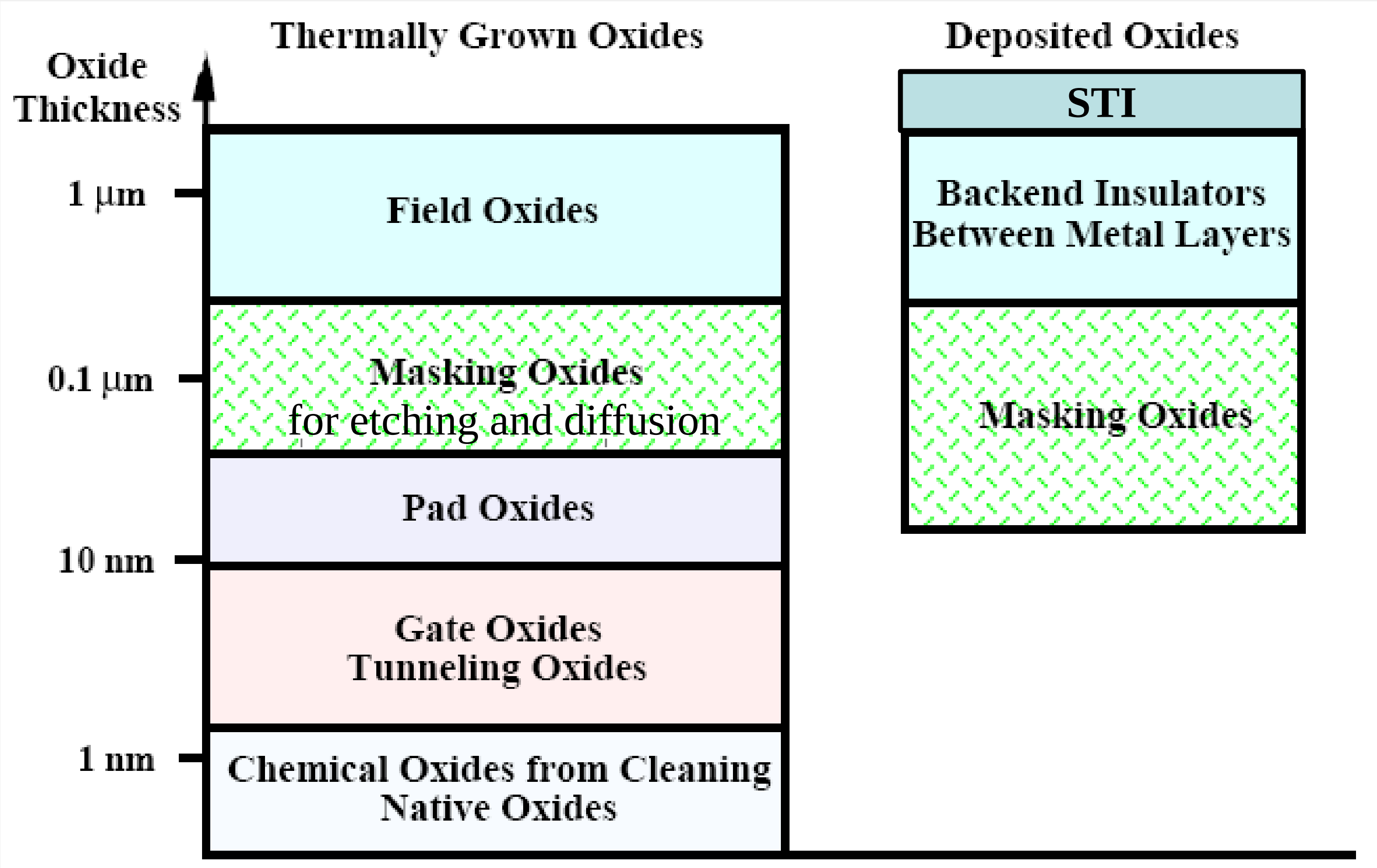
Thermal oxide (amorphous)

Si substrate (single crystal)



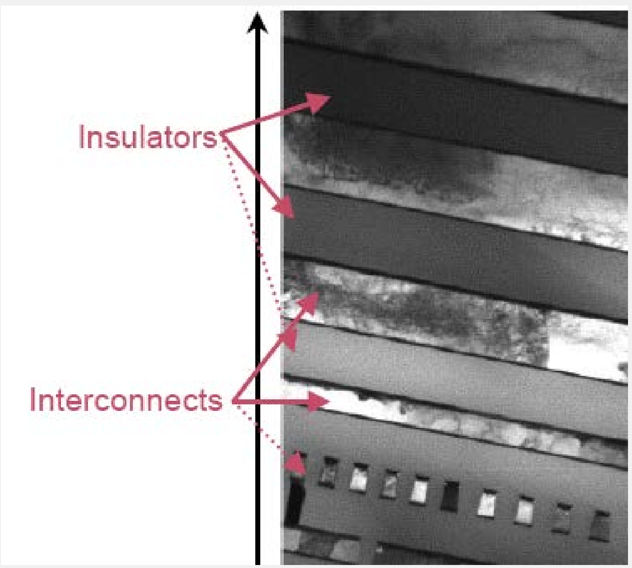
(Photo courtesy of J. Bravman.)

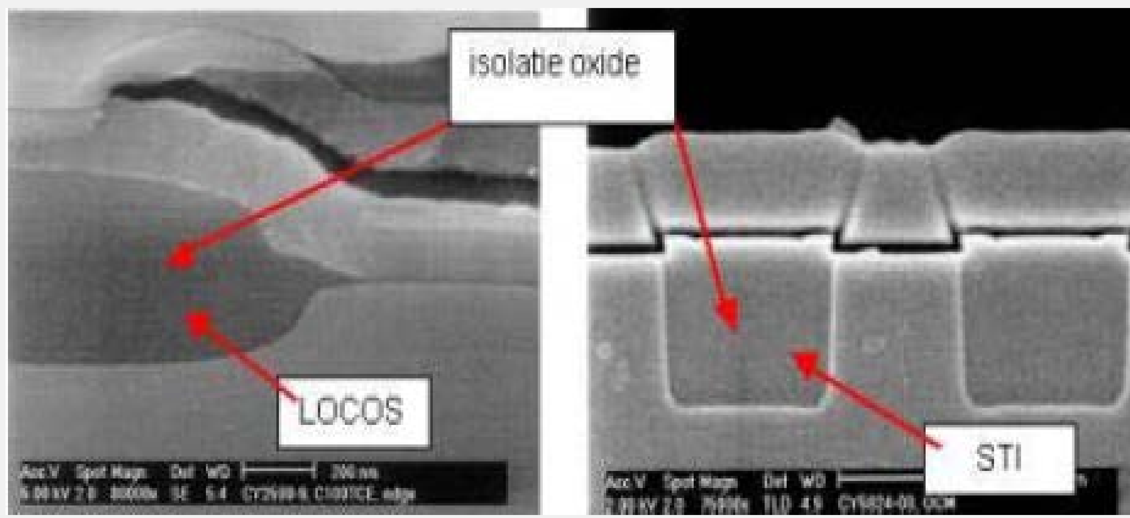
Applications of SiO_2



Applications of SiO_2 II

As insulation material between interconnection levels and adjacent devices





Basic schemes of oxidation

- Wet oxidation:

850 – 1150 ºC

- $Si (s) + 2 H_2O (g) ==> SiO_2 (s) + 2 H_2 (g)$ fast
- thick <2.5 μm, good insulator, for field oxides or masking

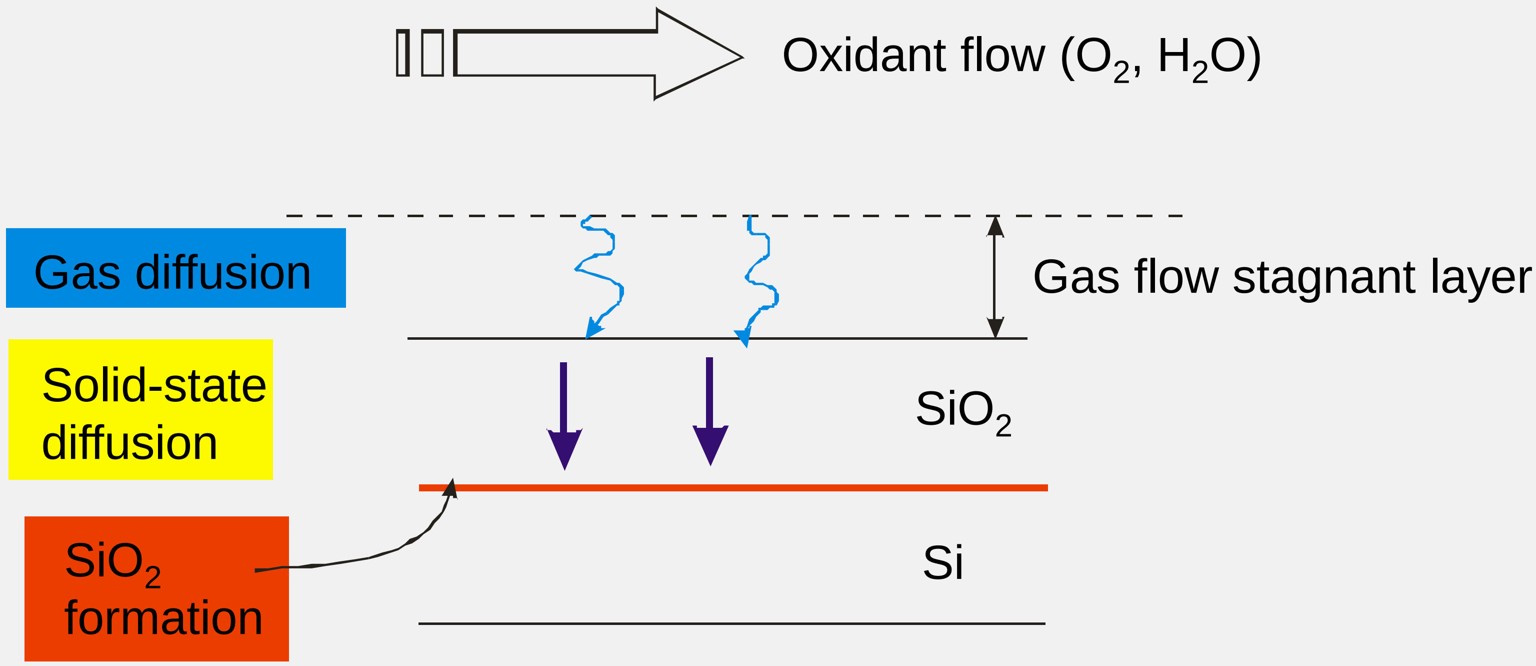
HCl, 3%

- Dry oxidation:

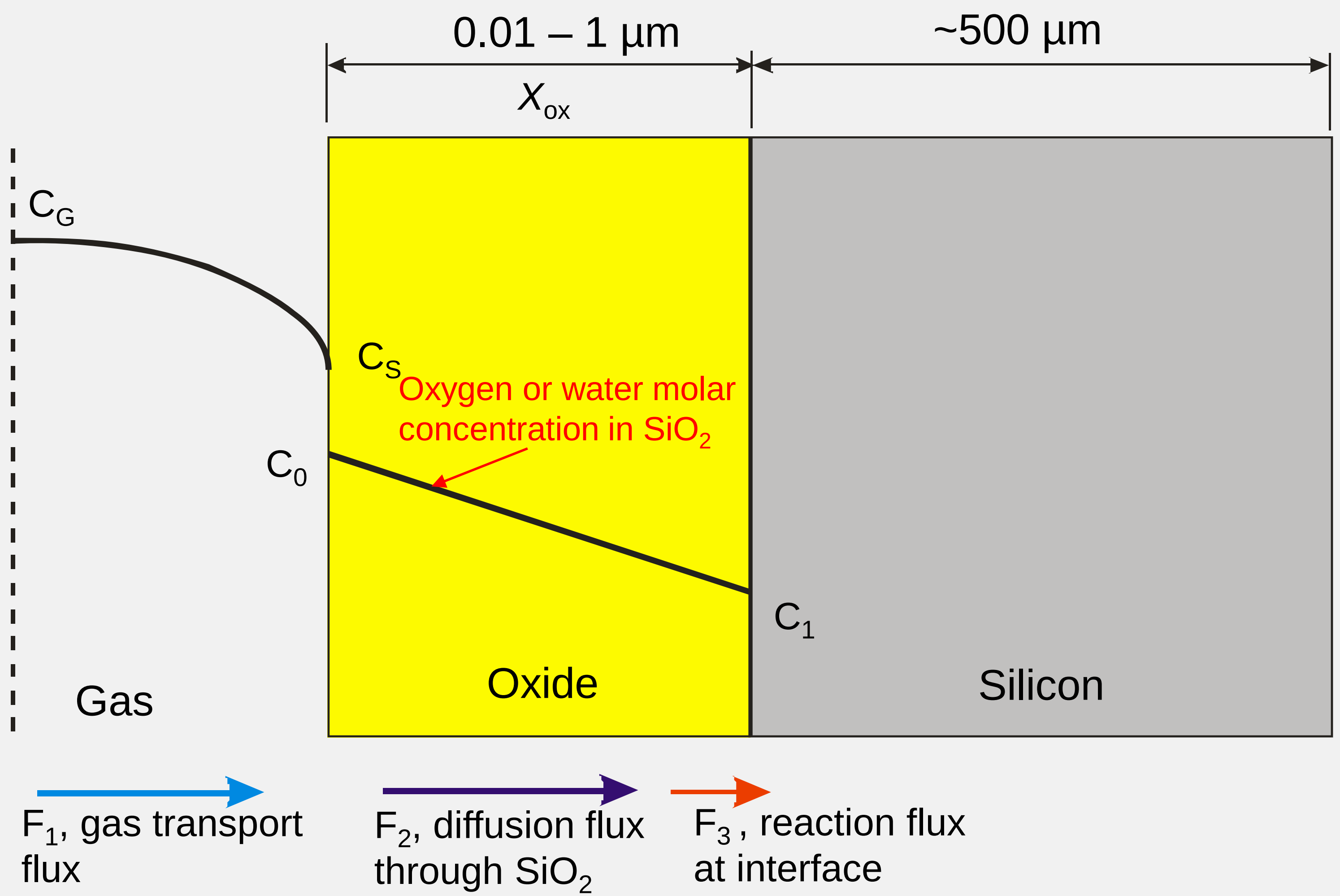
850 – 1050 ºC

- $Si (s) + O_2 (g) ==> SiO_2 (s)$ slow
- thin 0.05-0.2μm, excellent insulator, for gate oxides
- HCl reacts with metals to clean and improve quality

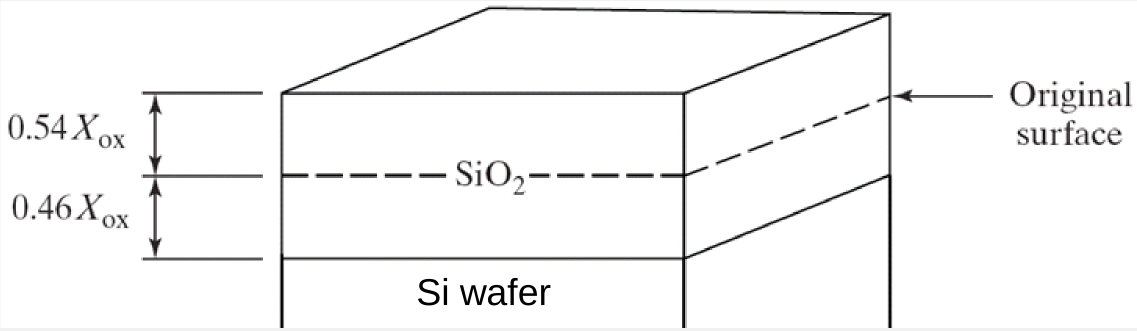
Kinetics of SiO_2 growth



Deal-Grove oxidation model I



Deal-Grove oxidation model II



X_{ox} is final oxide thickness

$$t = \frac{x}{kC_s v} + \frac{x^2}{2DC_s v},$$

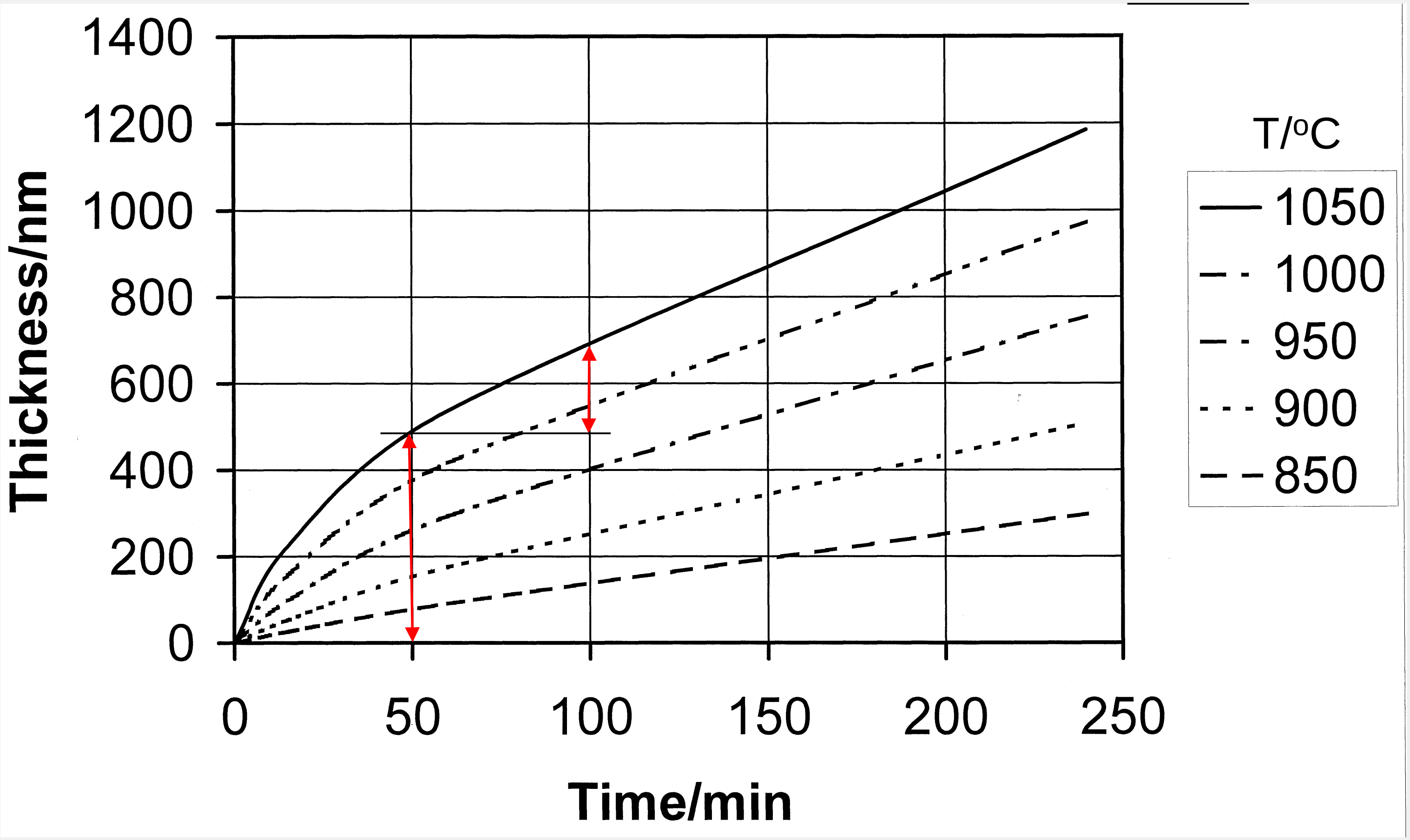
$$x = kC_s vt \qquad x < 100nm,$$

$$x = \sqrt{2DC_s t} \qquad x > 100nm.$$

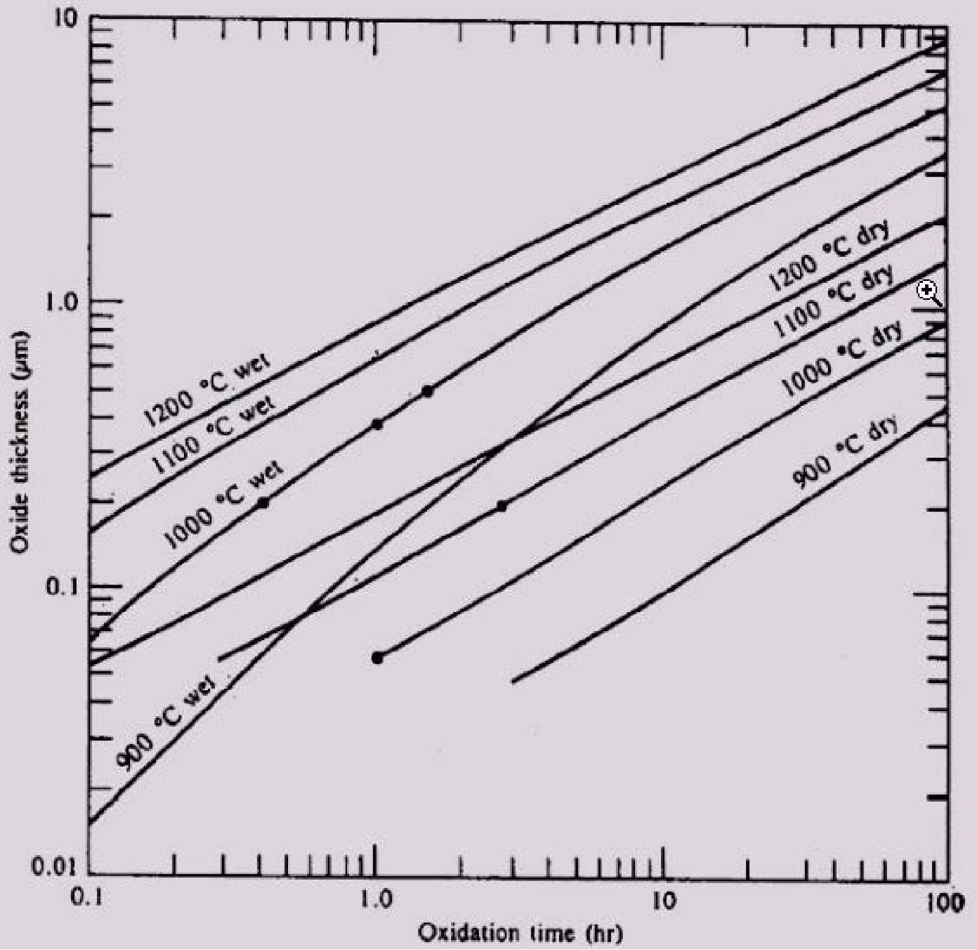
- *D* – diffusion coefficient, *v* – SiO_2 molar volume, *k* – rate constant , C_s – dopant concentration on the surface

Oxidation is slow: 1000 nm is thick

Parabolic rate law: thickness = constant * √time



Oxidation charts

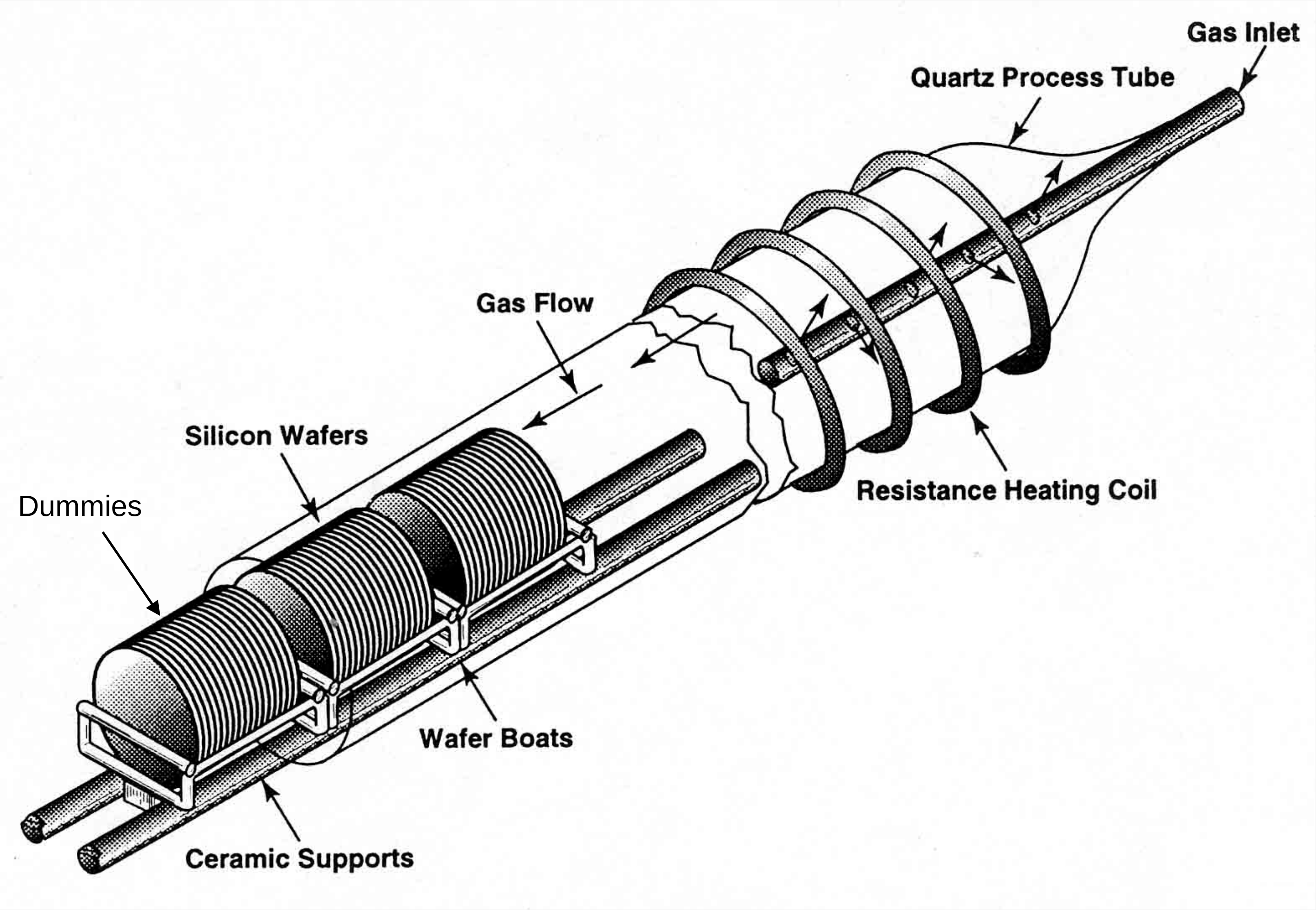


Wet and dry SiO_2 growth on (100) Si

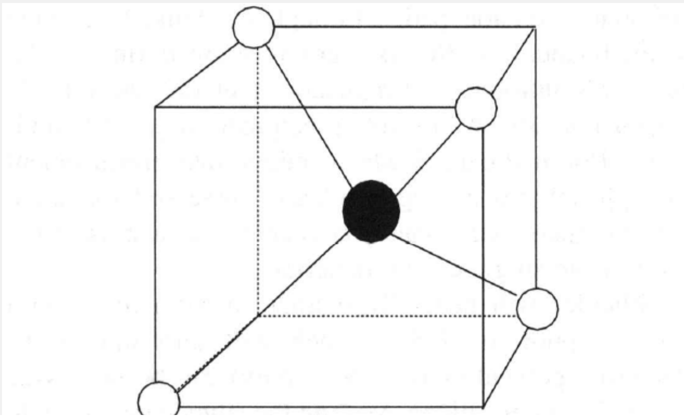
(111) oxidation rate is higher than (100) one

n-Si is oxidized faster than *p*-Si

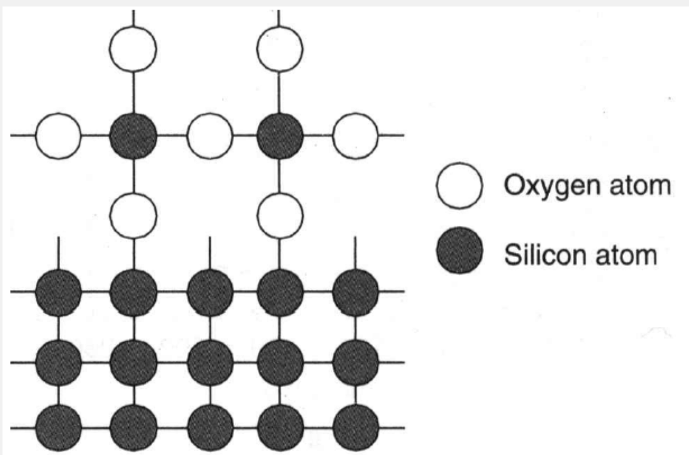
Oxidation furnace



Oxide structure

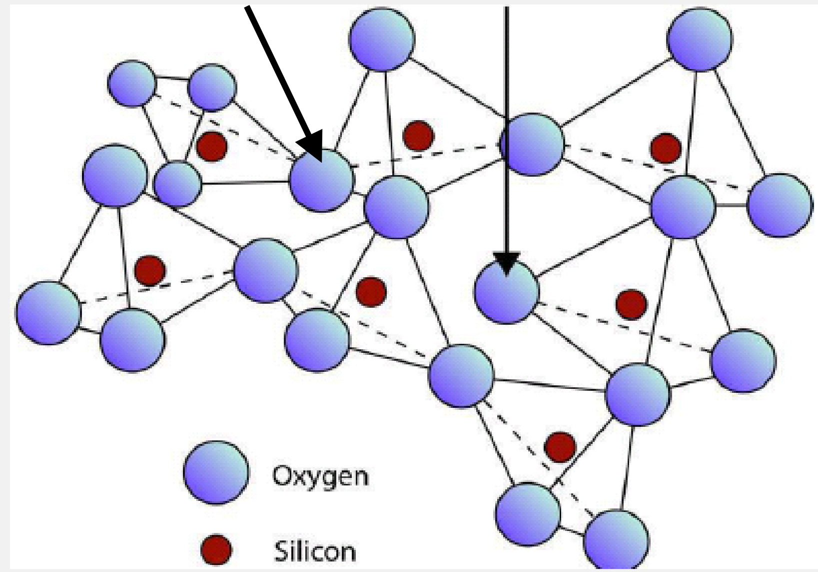


Basic structure of silica: a silicon atom tetrahedrally bonds to four oxygen atoms

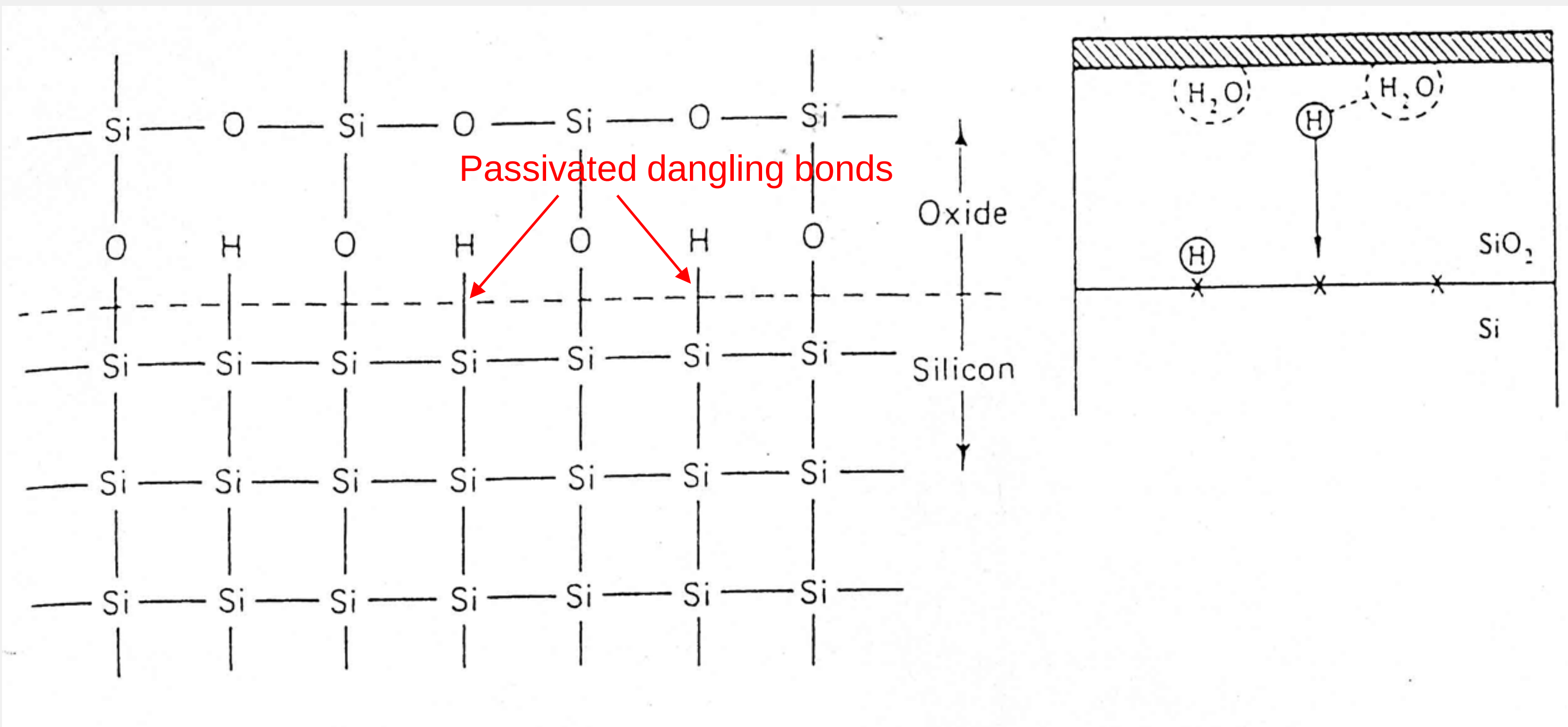


The structure of silicon-silicon dioxide interface: some silicon atoms have dangling bonds.

Bridging oxygen   Non-bridging

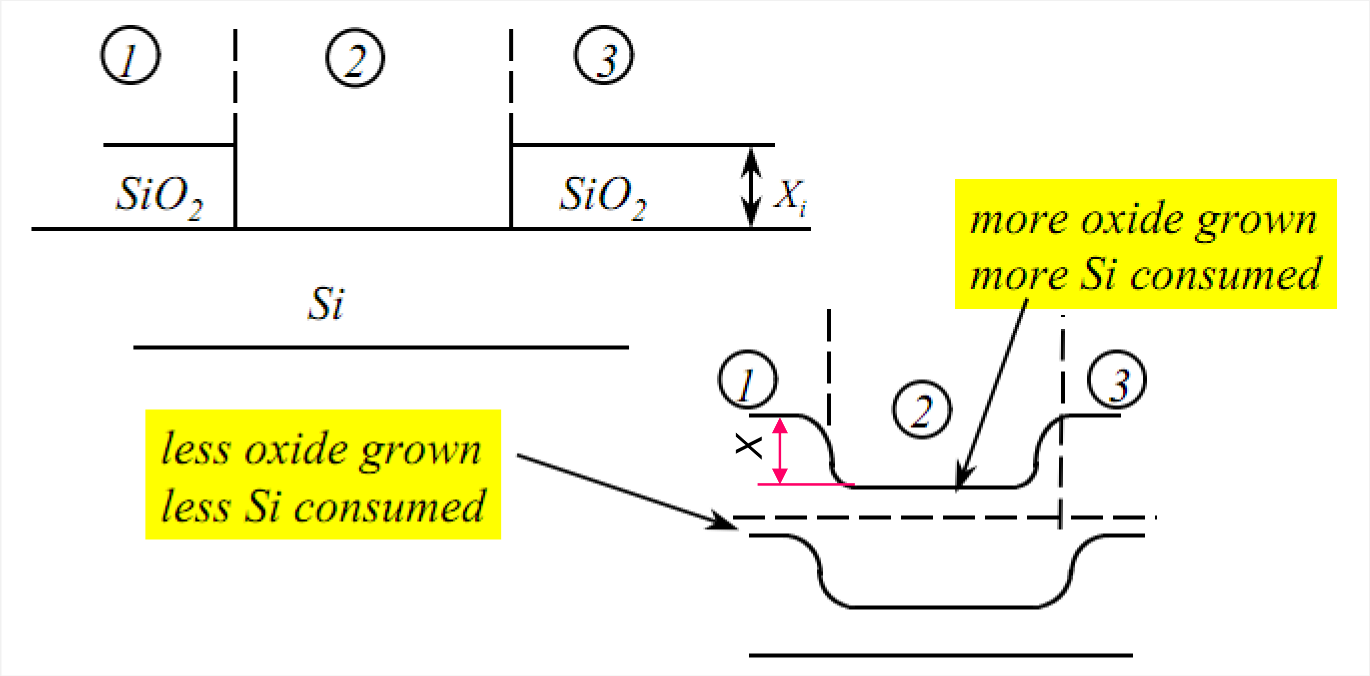


Hydrogen passivation



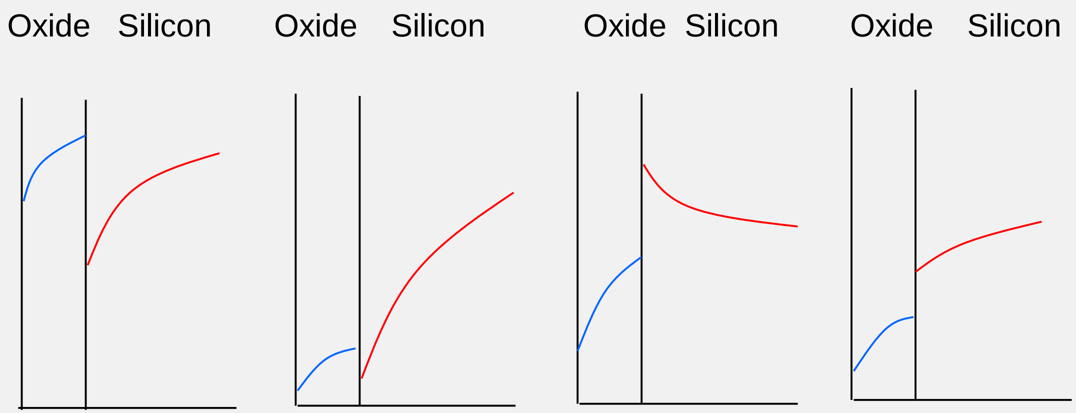
Effect of initial oxide on wafer topography

$X<X_i$



Segregation

Impurity segregation at the Si/SiO_2 interface during thermal oxidation



$m \equiv C(Si)/C(SiO_2)$

diffusion in oxide slow, m<1 (boron)

diffusion in oxide fast, m<1 (boron in H_2 ambient)

diffusion in oxide slow, m>1 (phosphorous)

diffusion in oxide fast, m>1 (gallium)

What happens to materials in oxygen at 1000°C ?

-silicon
-epitaxial silicon
-polysilicon
-amorphous silicon

} oxidized into SiO_2

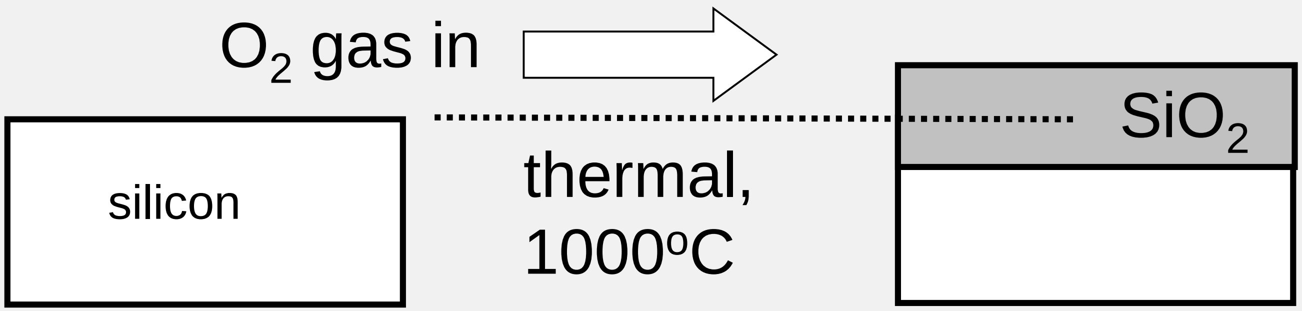
-silicon nitride: not affected
-metals: melted (Al m.p. 653°C)
-metals: oxidized (e.g. CuO)
(==> not conductive any more)
-metals: reacted with silicon (e.g. $TiSi_2$, conductor)
-polymers (e.g. resist): burned (CO_2; H_2O)

Poly and Silicide oxidation

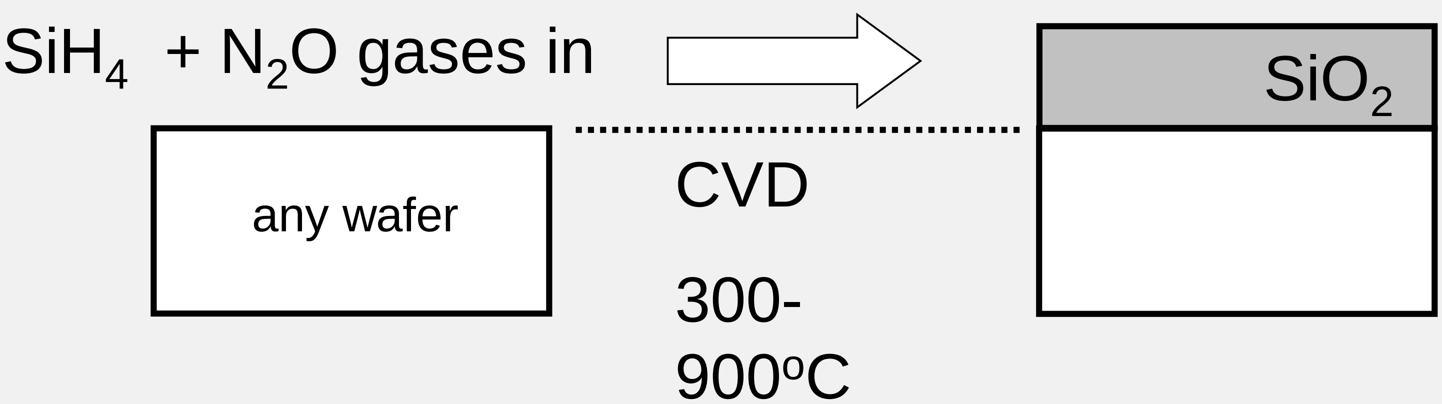
- Polyoxide – oxidized poly-Si
  - rough surface vs. smooth of *c*-Si
  - grain structure vs. amorphous of *c*-Si

Silicide ($MeSi_x$) oxidation results in SiO_2, exclude $TiSi_2$

Thermal oxide vs. CVD oxide



Compressive stress always, silicon consumed



Stress can be tailored tensile or compressive, deposition also on metals

LOCOS I

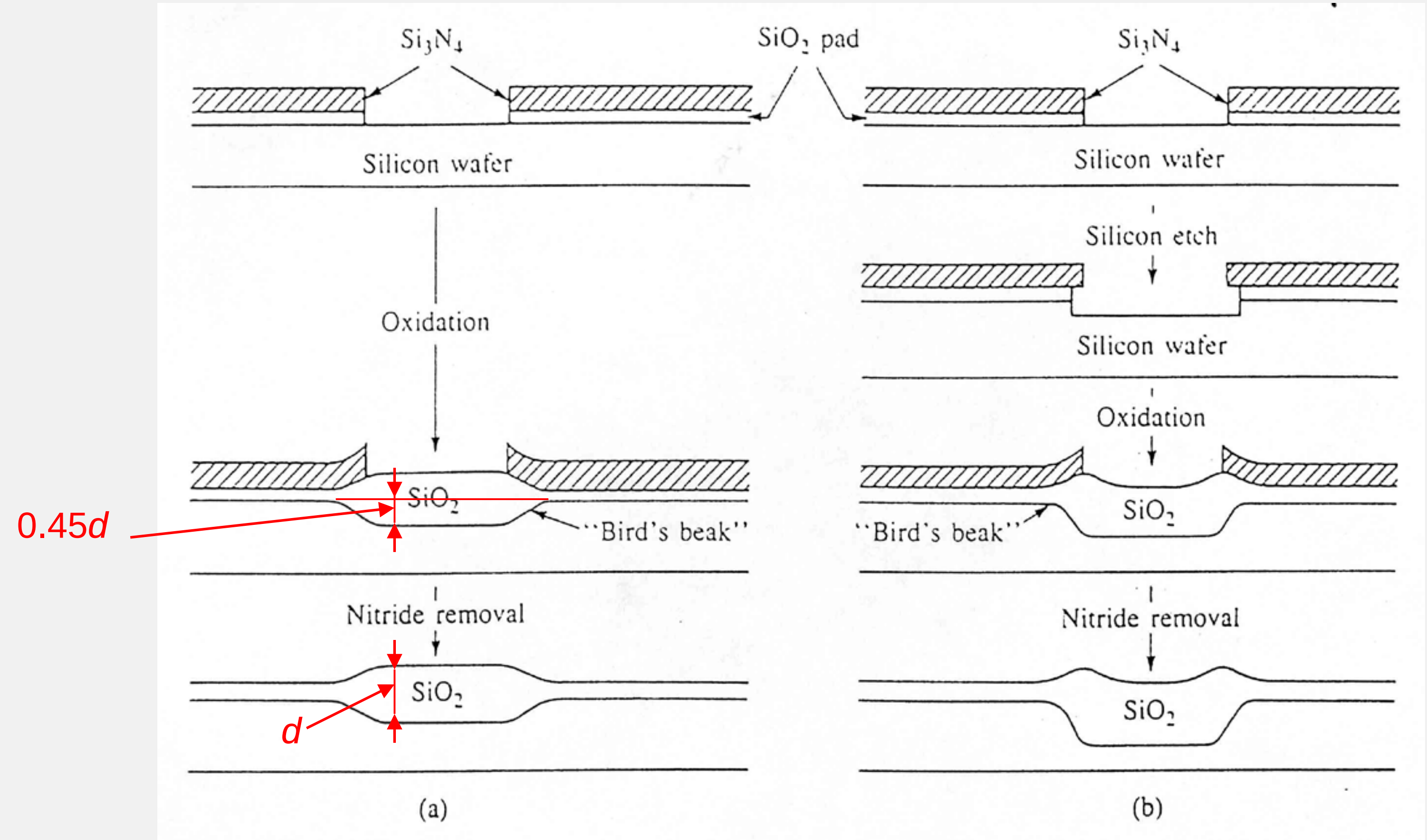
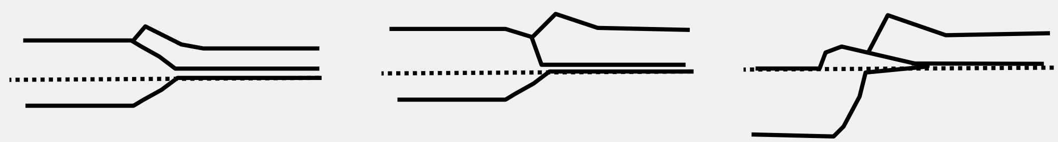
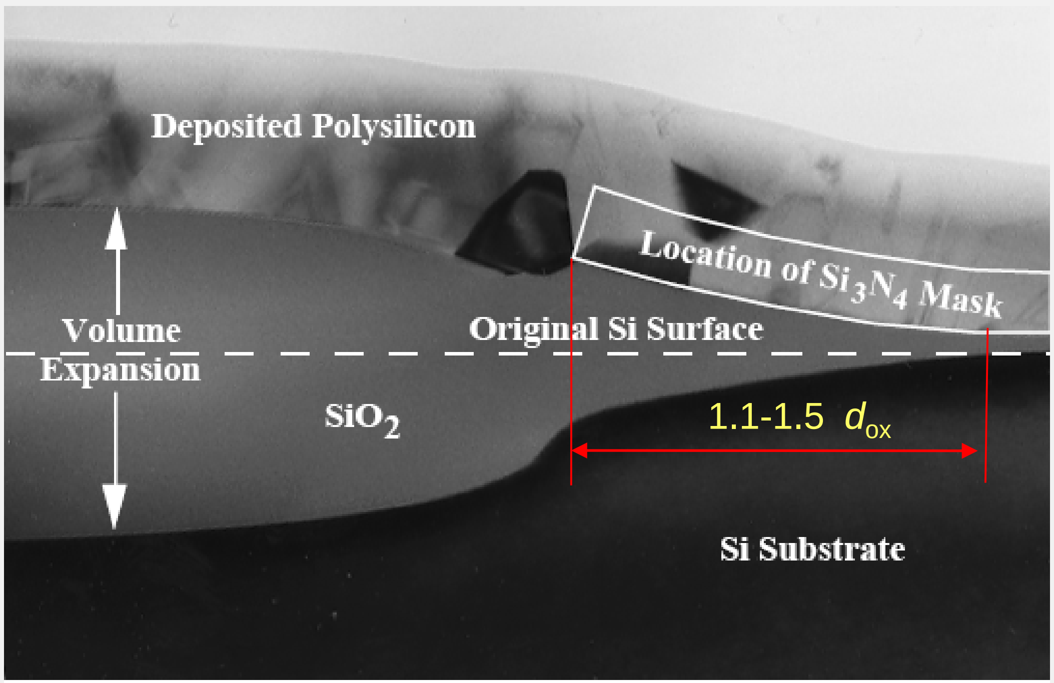


Fig. 3.12 Cross section depicting process sequence for (a) semirecessed and (b) fully recessed oxidations of silicon.

LOCOS II

thin nitride | thick nitride | recessed



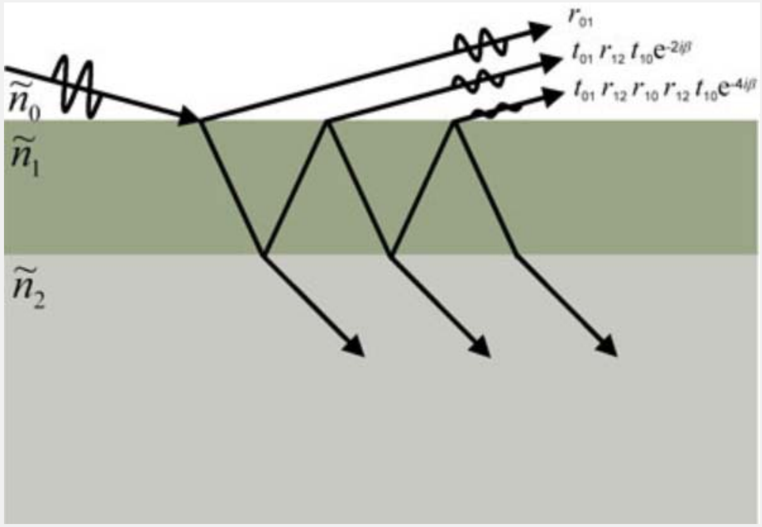


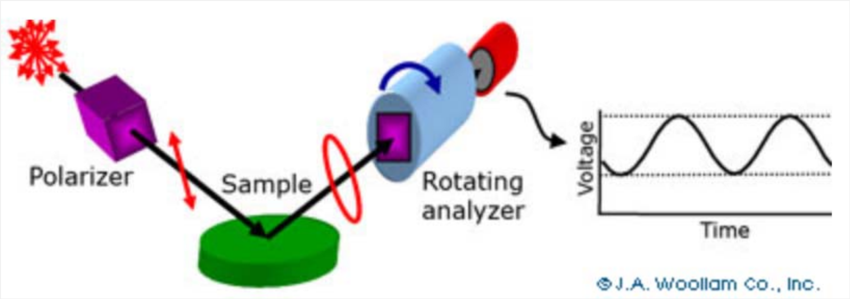
(Photo courtesy of J. Bravman.)

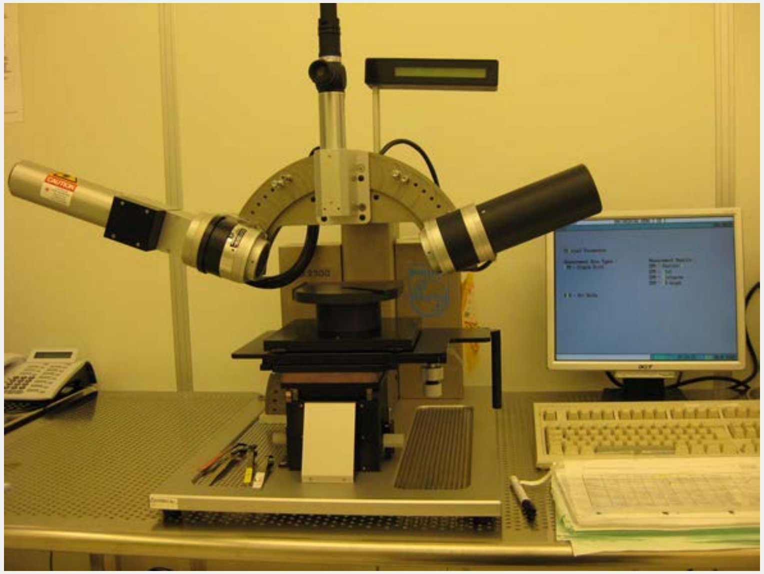
SiO_2 measurements

- Ellipsometry – thickness, refractive index
- Profilometry - thickness
- Looking wafer color - thickness
- *C-V* – thickness, for known dielectric constant

Ellipsometry

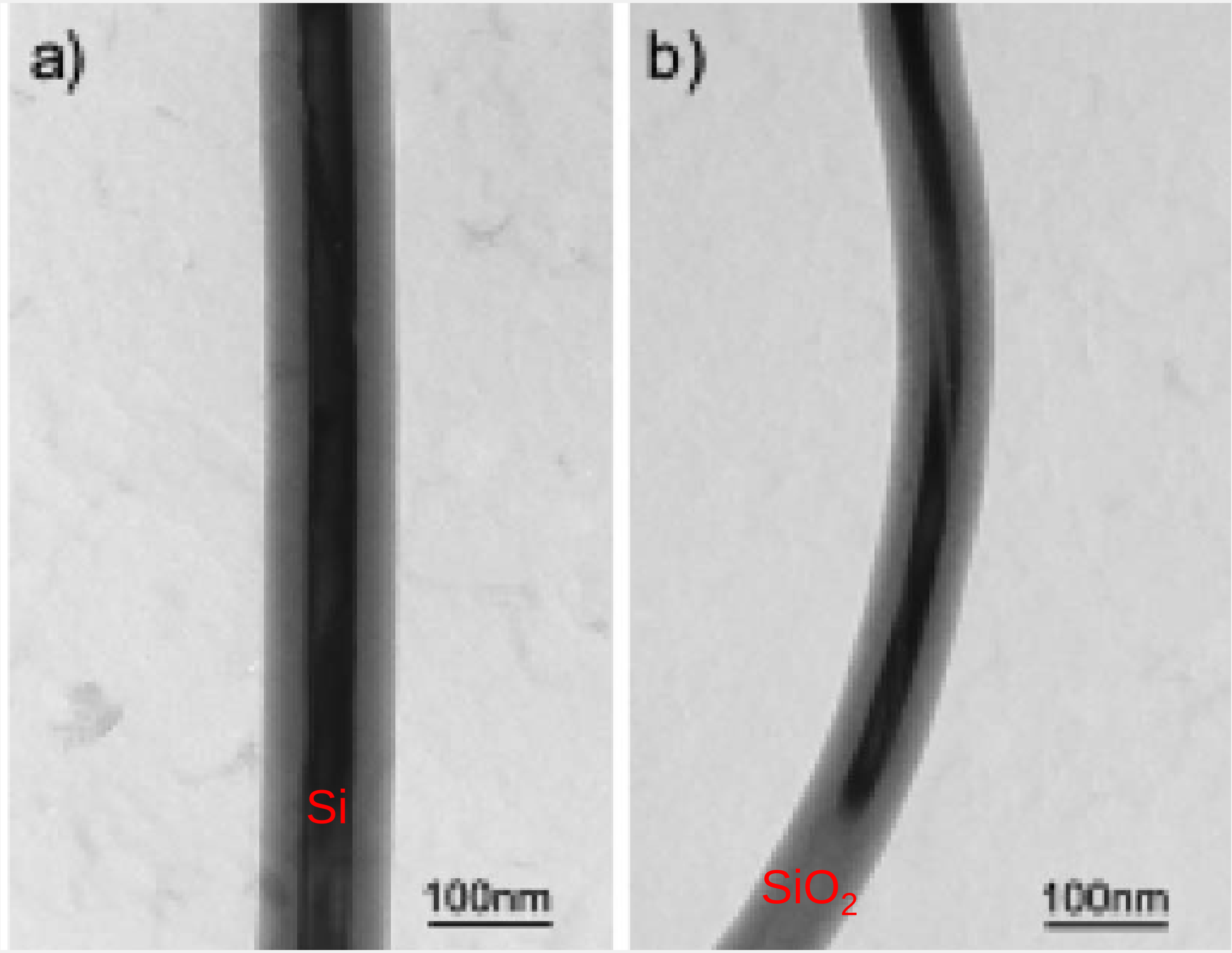




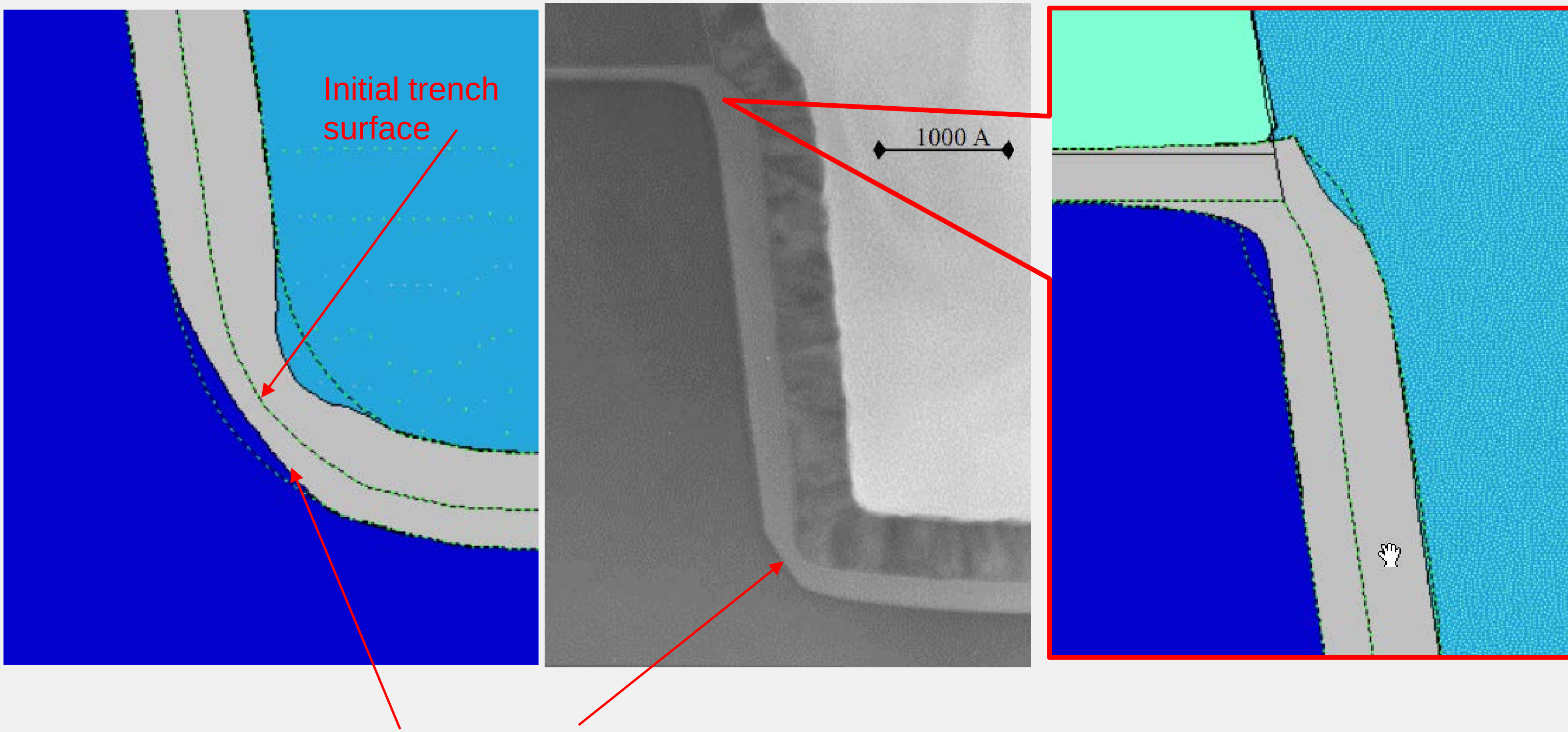


Best accuracy 0.1nm
Transparent films 10 – 1000 nm

Self-limiting oxidation of Si nanowires



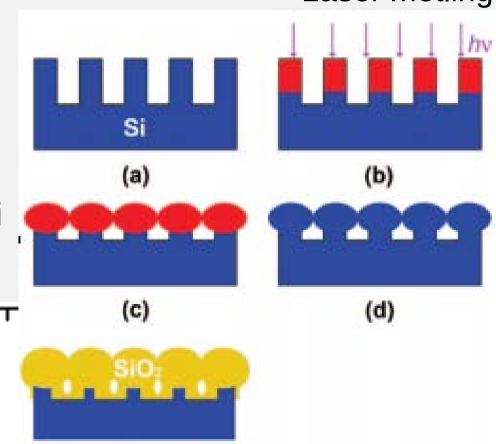
Corner oxidation



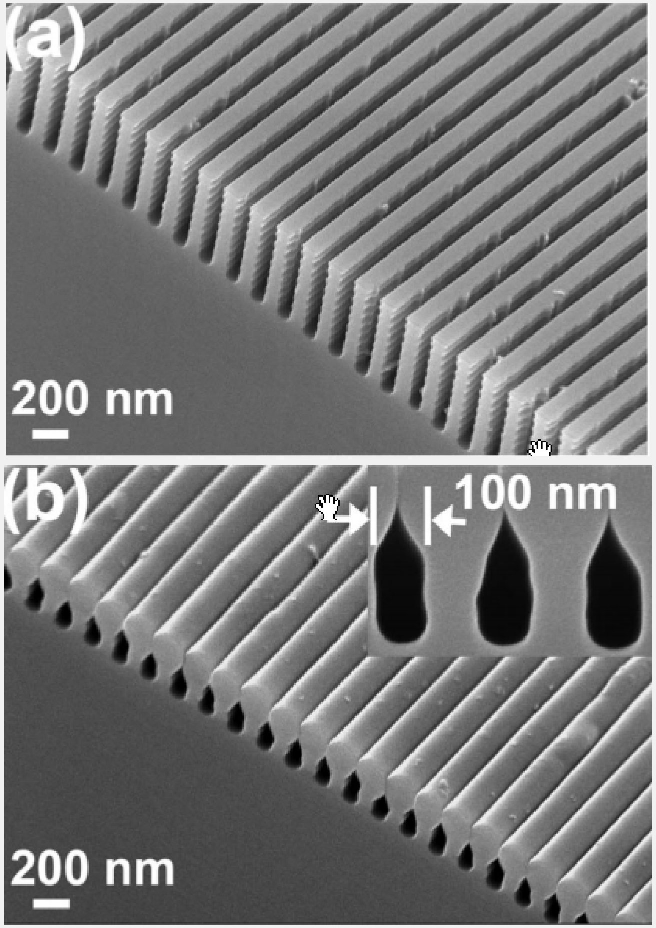
Anisotropic oxidation facet

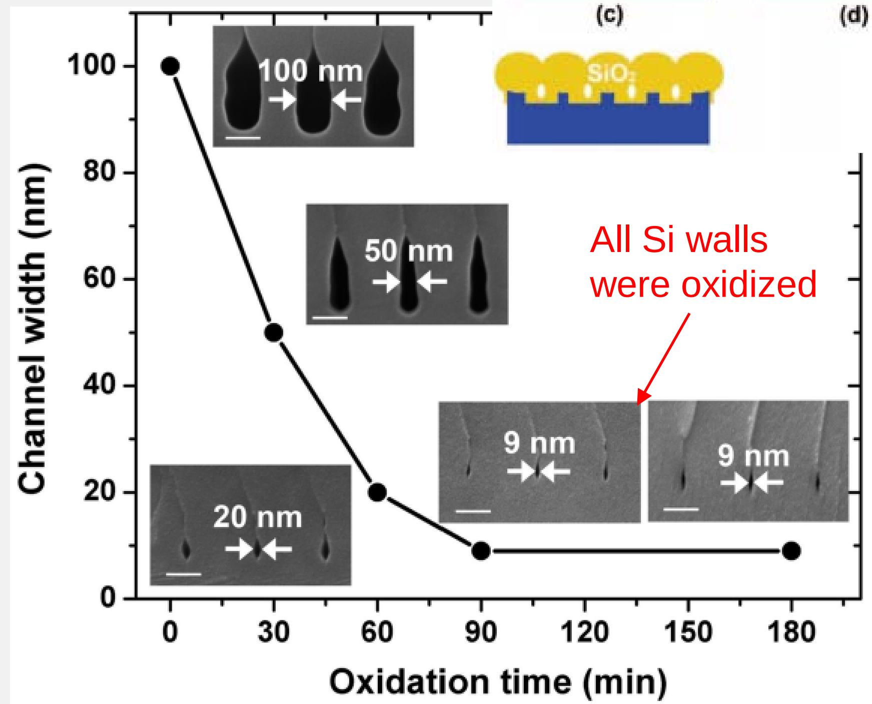
Nanostructure oxidation

Laser metling



Molten and reflowed Si

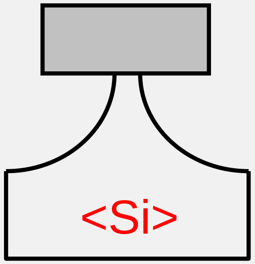




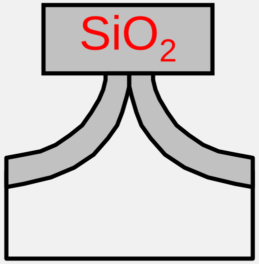
Qiangfei Xia et al., Nano Lett., v.8, No. 11, 2008, pp. 3830 - 3833

Si sharpening

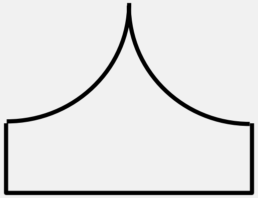
Isotropic Si etching

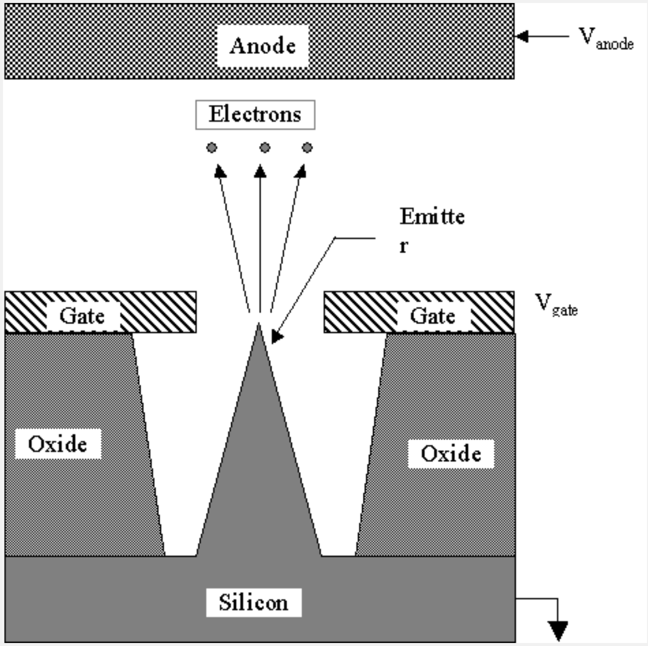


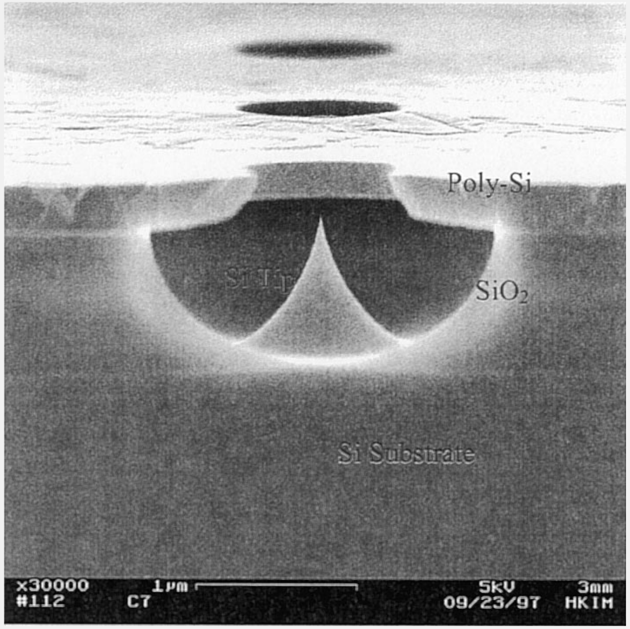
Thermal oxidation



SiO_2 etching



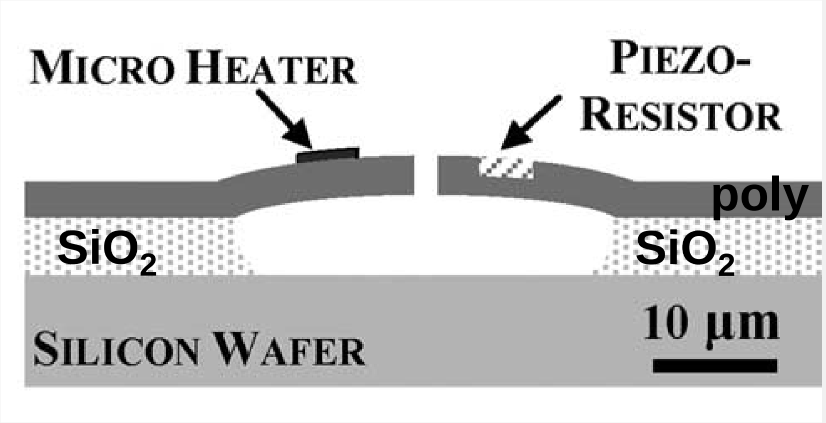


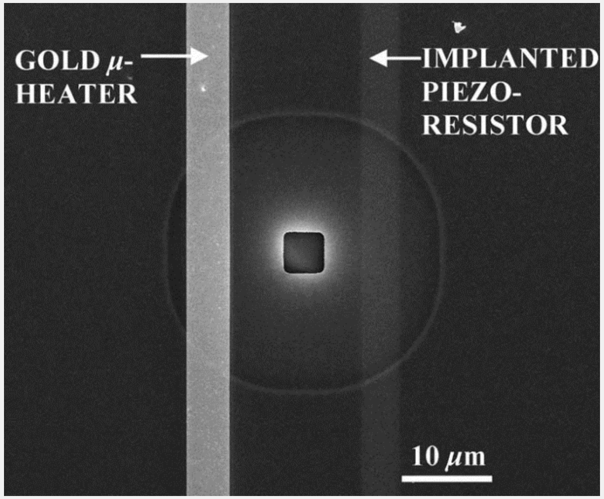


Field emission display (FED)

Ding, "Silicon Field Emission Arrays With Atomically Sharp Tips: Turn-On Voltage and the Effect of Tip Radius Distribution", 2002.

Oxide as sacrificial material





H. G. Craighead

Isotropic HF wet etching of oxide under polysilicon
➔ Membrane is released and can move (=vibrate according to cyclic thermal expansion induced by cyclic heating the gold wire)

Summary

- Theramal oxidation happens at 800 ºC-1200 ºC
- It is a batch process
- It provides high quality SiO_2
- Growth rate is non-constant, parabolic law.
- Surface oxidation and Si doping affect on growth rate