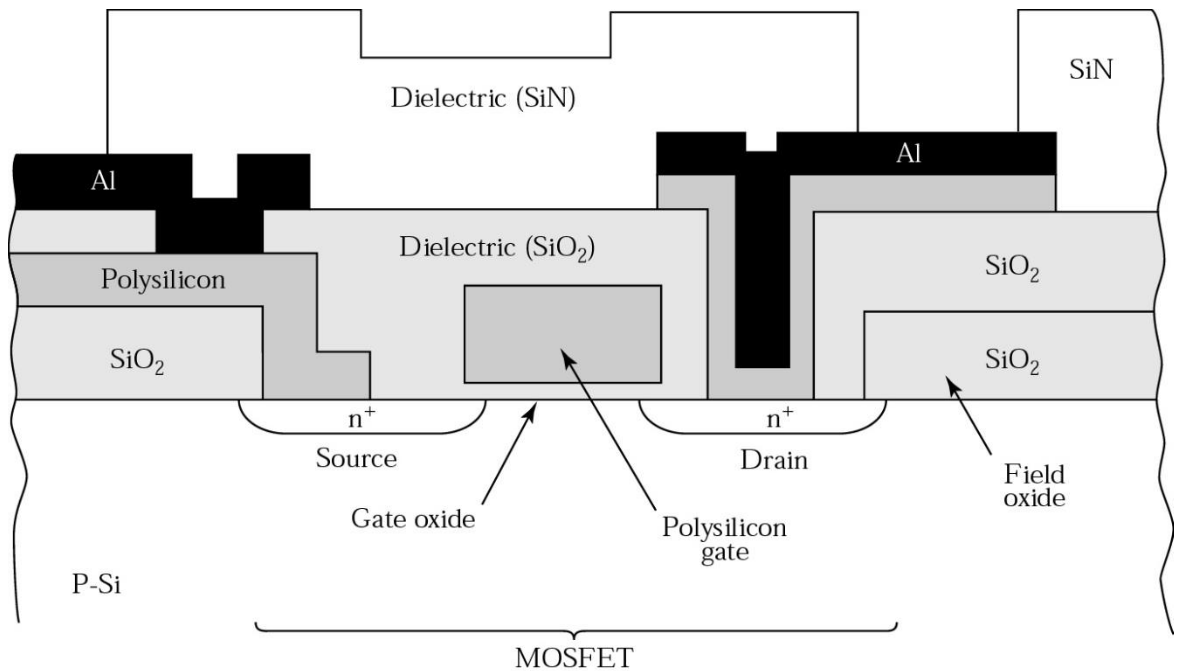
Lecture#5:

Oxidation

Oxidation

- **Thin films**
  - If some film has below 1um (~10um) thickness, we call it thin film
    ex) Metal, semiconductor, insulator thin film



Silicon Oxidation

Oxidation

- **Principal uses**

  - **Insulating layer** in device and between metal lines (t_{ox} = 50~200Å)
  - **Passivation layer** to seal silicon surface (i.e. diffusion barrier) (t_{ox} = 0.5~1 um)
  - **Blocking layer** to stop or mask impurity atoms (t_{ox} = ~ 1 um)

- **Silicon Oxide (SiO_2)**

  i) Easy and simple fabrication process; upon exposure to oxygen, the surface of a silicon wafer oxidizes to form silicon dioxide.

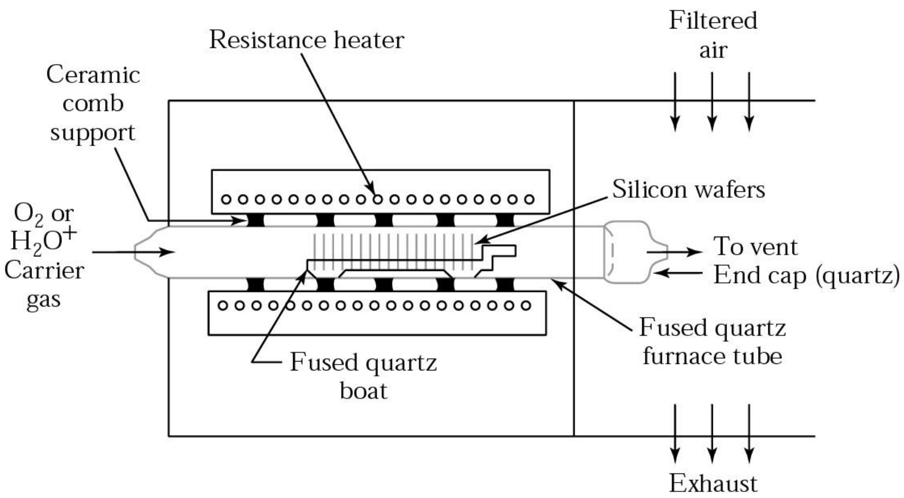
  ii) Good insulating property: >10^7V/cm (Thermal oxide), 10^6V/cm (CVD oxide)

  iii) Etching selectivity with Si material ex) ZnO

Oxidation

- **Thermal oxidation process**

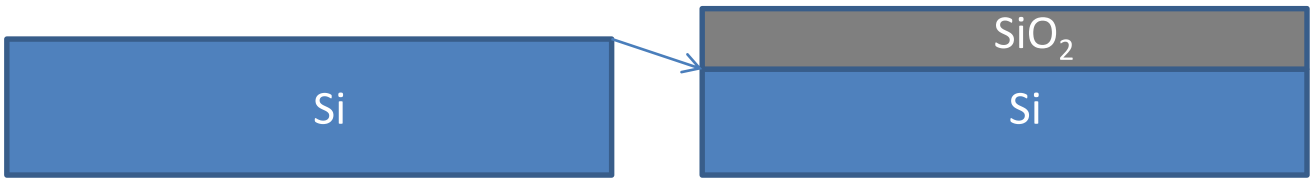
  - Thermal oxidation of silicon is easily achieved by heating the wafer to a high temperature, typically 900 to 1200 C, in an atmosphere containing either pure oxygen or water vapor.



Oxidation

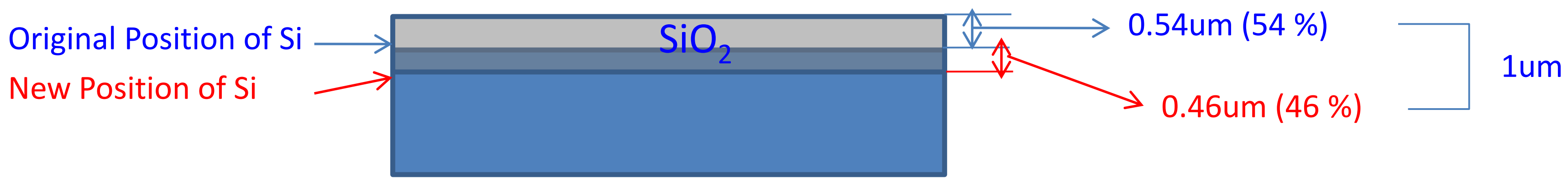
- **Dry oxidation (O_2 gas)**
  Si (solid/wafer) + $O_2 \rightarrow SiO_2$ (Solid)

- **Wet oxidation (water vapor)**
  Si (solid/wafer) + $2H_2O \rightarrow SiO_2$ (Solid) + $2H_2$



Si surface is changed

Question) To growth 1um SiO_2, what is the thickness of Si being consumed?



- In order for oxidation to occur, oxygen must reach the silicon surface. As the oxide grows, oxygen must pass through more and more oxide, and the growth rate decrease as time goes on.

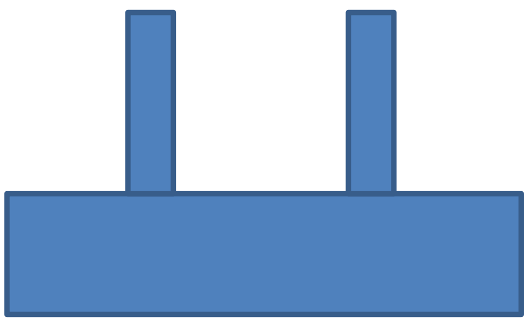
[Note] 0.46 t_{ox} is important

Oxidation

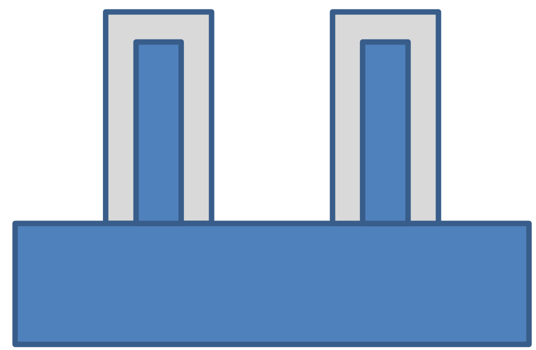
- **n wells are removed**

Oxidation

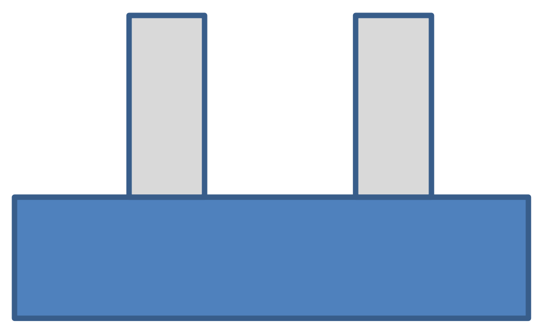
- **All parts of Si structures are oxidized**



Target



Final Result

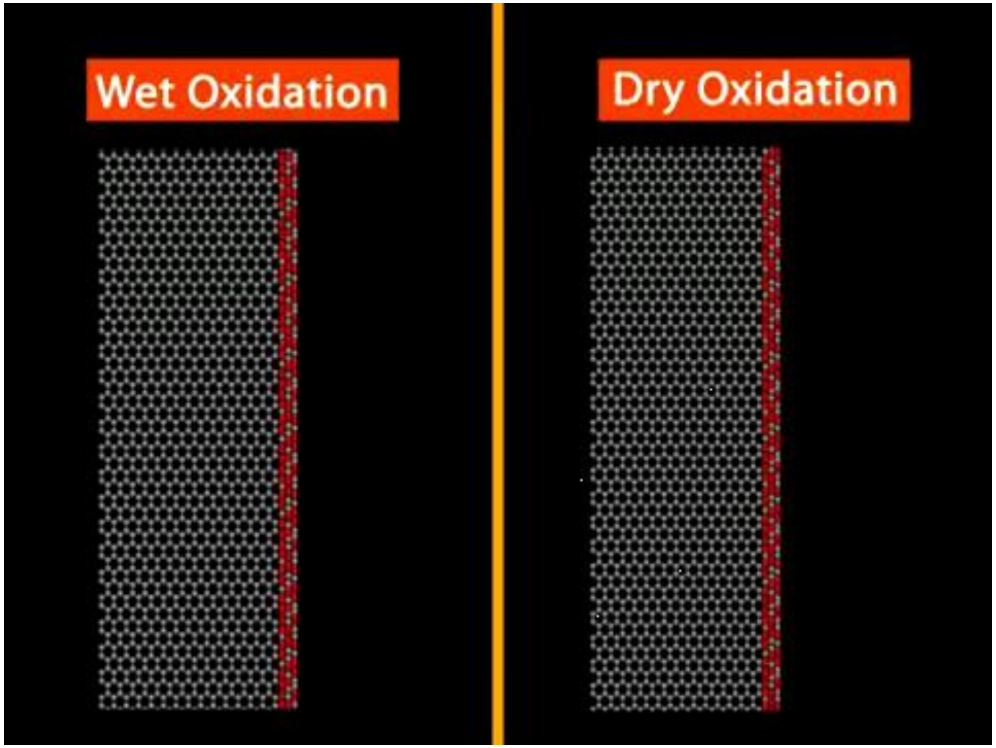


You should keep in mind this equation !

Comparison (Dry & Wet)

Oxidation

	Dry oxidation	Wet oxidation
process	$Si + O_2 \rightarrow SiO_2$	$Si + 2H_2O \rightarrow SiO_2 + 2H_2$
grow rate	low	high
quality	high (dense)	low
application	MOS gate oxide	Etch mask



Modeling (1)

Oxidation

- **Fick's first law of diffusion**

  - the particle flow per unit area, J (particle flux), is directly proportional to the concentration gradient of the particle:

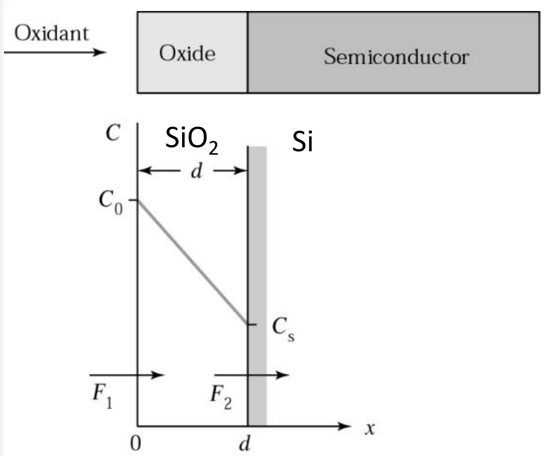
$$J = -D\frac{\partial N(x,t)}{\partial x}$$

where D is the diffusion coefficient and N is the particle concentration.

- **For the case of silicon oxidation**

- it is assumed that the oxygen flux (F) through the oxide is constant; oxygen does not accumulate in the oxide.

$$F_1 = \frac{D(C_0 - C_s)}{X}$$



where X is the thickness of the oxide, and C_o and C_s are the concentrations of the oxidizing species in the oxide at the oxide surface and silicon dioxide-silicon interface, respectively.

- (at the SiO_2 and Si interface) the oxidation rate is proportional to the concentration of the oxidizing species:

$$F_2 = kC_s$$

where k is called the rate constant for the reaction at the Si-SiO_2 interface

Modeling (2)

Oxidation

- In steady state

$$F = \frac{D(C_0 - C_s)}{x} = kC_s$$

$$F = \frac{DC_0}{x + (\frac{D}{k})}$$

- The rate of change of thickness of the oxide layer

$$\frac{dx}{dt} = \frac{\text{Flux}}{\text{Concentration of the oxidizing species}} = \frac{F}{C_1} = \frac{DC_0/C_1}{x + (\frac{D}{k})}$$

Let solve differential equation (1st order),

$$t = \frac{x^2}{B} + x/(\frac{B}{A}) - \tau \qquad A = 2D/k$$

$$B = 2DC_0/C_1$$

$$x = 0.5A\left[\sqrt{1 + \frac{4B}{A^2}(\tau + t)} - 1\right]$$

* τ represents the time which would have been required to grow the initial oxide.

Modeling (3)

Oxidation

$$x = 0.5A\left[\sqrt{1+\frac{4B}{A^2}(\tau+t)} - 1\right]$$

$$A = 2D/k$$

$$B = 2DC_0/C_1$$

$$x = \frac{D}{\kappa}\left[\sqrt{1+\frac{2C_0\kappa^2(t+\tau)}{DC_1}} - 1\right]$$

For small values of t,

$$x \cong \frac{C_0\kappa}{C_1}(t+\tau)$$

For large values of t,

$$x \cong \sqrt{\frac{2DC_0}{C_1}(t+\tau)}$$

i) Short time $(t+\tau) \ll A^2/4B$

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

Key) 1.B/A *is* ***linear rate constant***
2.Growth rate just depends on time
; Linear dependence
3. Limit is the reaction of Si surface

ii) Long time $(t+\tau) \gg A^2/4B$ $t \gg \tau$

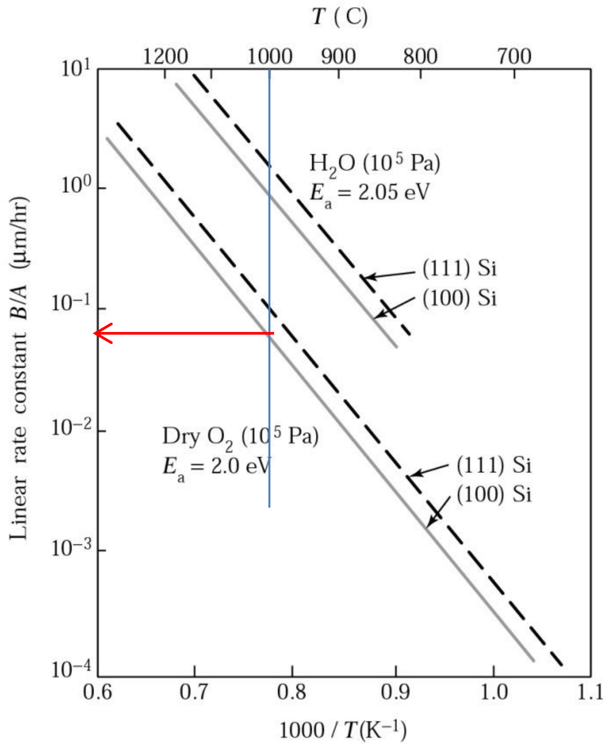
$$x = \sqrt{B(t+\tau)}$$

Key) 1.B *is* ***Parabolic rate constant***
2.Growth rate is limited by diffusion
; parabolic dependence
3. Limit is the diffusion of oxygen

Rate Constant

Oxidation

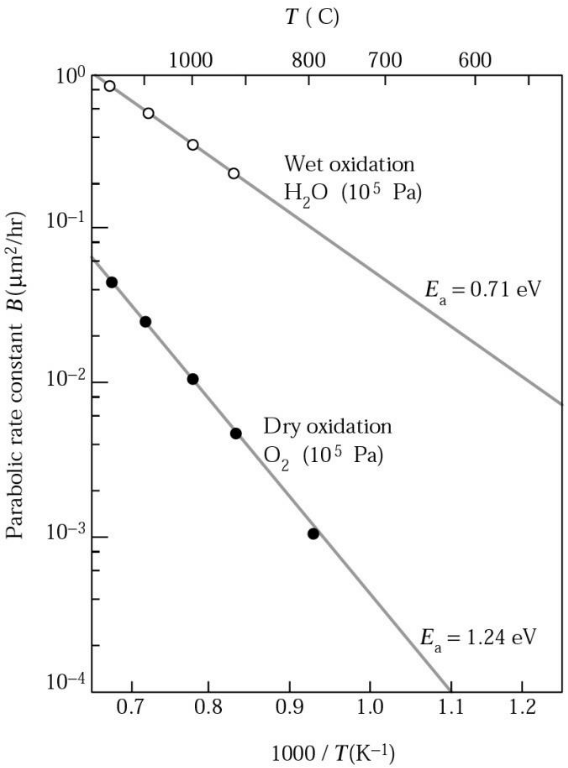
Linear rate constant



Why (111) substrate has higher growth rate?

Available bonding density is higher than that of (100)

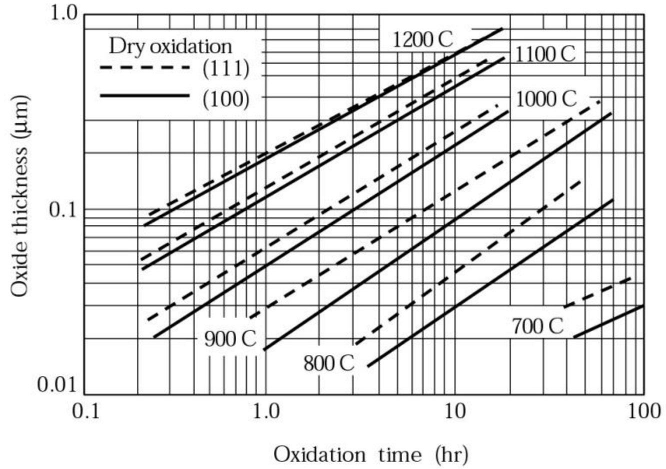
Parabolic rate constant



Wet oxidation (H_2O) rate is faster than dry oxidation (O_2)
Generally, 5~10 times faster

Oxidation

Oxide thickness



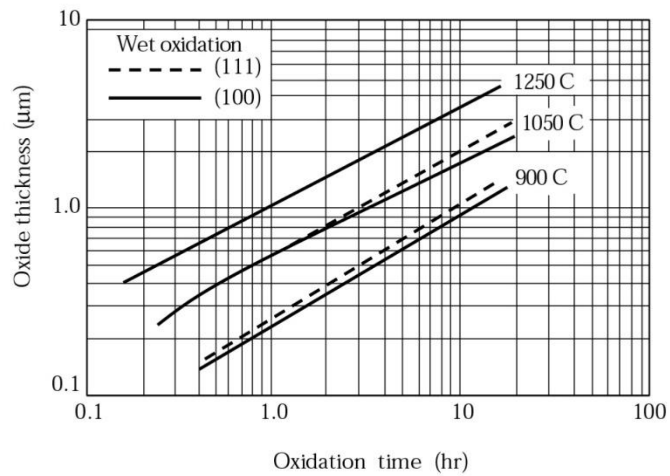
(a)

Dry oxidation : Low growth rate

Film quality is good

showing best electrical properties

<20nm , gate oxide



(b)

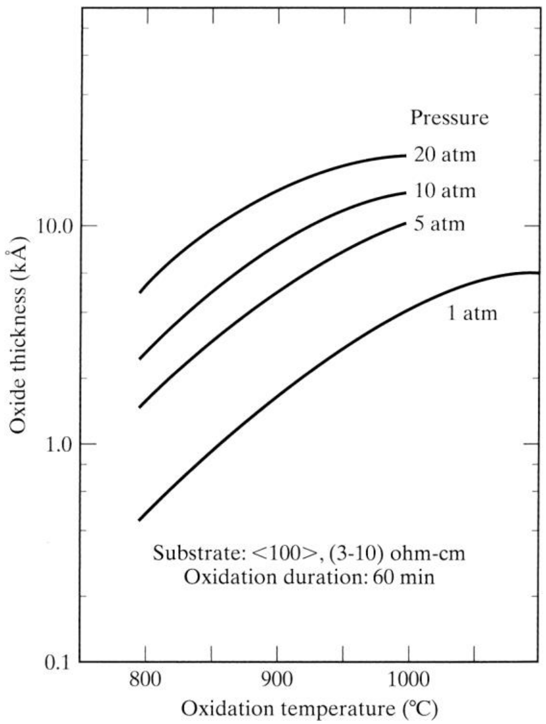
Wet oxidation : High growth rate

Film quality is not good

Electrically not bad

>20nm , Mask or passivation

- Oxide thickness with various partial pressure



Thin Oxide Growth

-Slow growth : Good quality and reproducibility

1. Dry oxidation
2. Low temperature (800C ~900C)
3. Low partial pressure of oxygen

Process Parameters (1)

Oxidation

- **1) Temperature, Time, Initial oxide thickness (major parameter)**

Conditions	Oxidation rate	Oxidation thickness
Lower Temp. Thin oxide	Reaction-limited (linear rate)	$t_{ox} \propto \text{Time}$
Higher Temp. Thick oxide	Diffusion-limited (parabolic rate)	$t_{ox} \propto \text{Time}^{1/2}$

- **2) Pressure**

  - at low temperature (reaction limited)
  - pressure ↑, grow rate ↑

Process Parameters (2)

Oxidation

- **3) Crystal orientation**

  - R(111) > R(100)

    # of silicon bonds to be broken at surface

- **4) Impurity / Dopant type**

  - n type (linear rate)
  - p type (parabolic rate)

  → dopant redistribution during oxidation process

    (segregation coefficient & diffusion coefficient)

- **5) Impurity / Dopant / Defect Concentration**

  - High dopant concentration

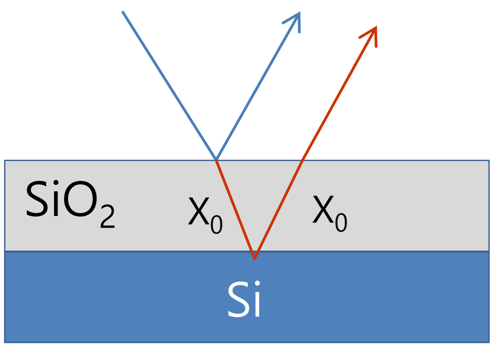
  → point defects exist (voids, interstitial atoms)

  → increase surface reaction rate

Characterization for Oxide Thickness

Oxidation

Constructive interference



Wavelength

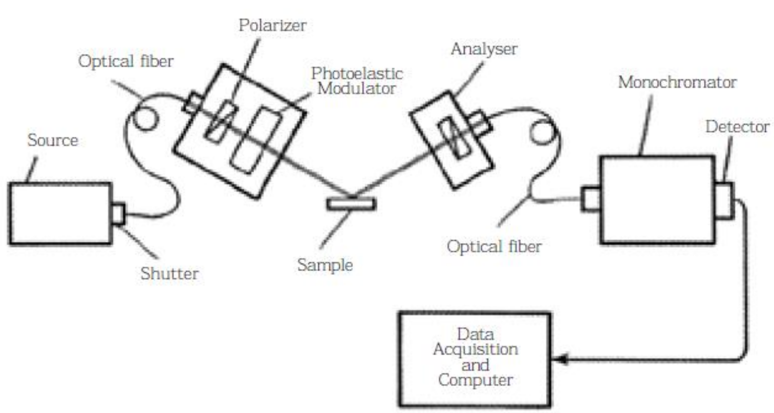
$$2X_0 = k\lambda/n$$

Pass length Integer Refractive index

SiO$_2$ Thickness Color Chart

Film Thickness (Å)	Color of Film (those shown are only indicative)
500	tan
700	brown
1000	dark violet to red violet
1200	royal blue
1500	light blue to metallic blue
1700	metallic to very light yellow-green
2000	light gold or yellow - slightly metallic
2200	gold with slight yellow-orange
2500	orange to melon
2700	red-violet
3000	blue to violet-blue
3100	blue
3200	blue to blue-green
3400	light green
3500	green to yellow-green
3600	yellow-green
3700	green-yellow
3900	yellow
4100	light orange
4200	carnation pink
4400	violet-red
4600	red-violet
4700	violet
4800	blue-violet
4900	blue
5000	blue-green

Ellipsometry : detect the polarization change



Profilometry (α-step) : mechanical movement