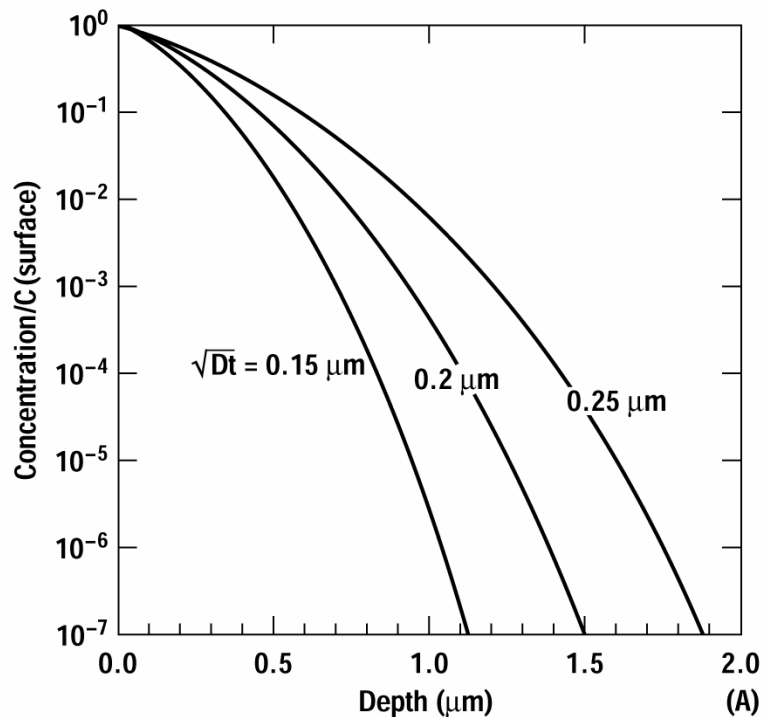


# Pre-deposition and Drive-in Diffusion Profiles: Solutions to Fick's 2<sup>nd</sup> Law

Erfc (complementary error function)  
'infinite' source



Gaussian: finite source

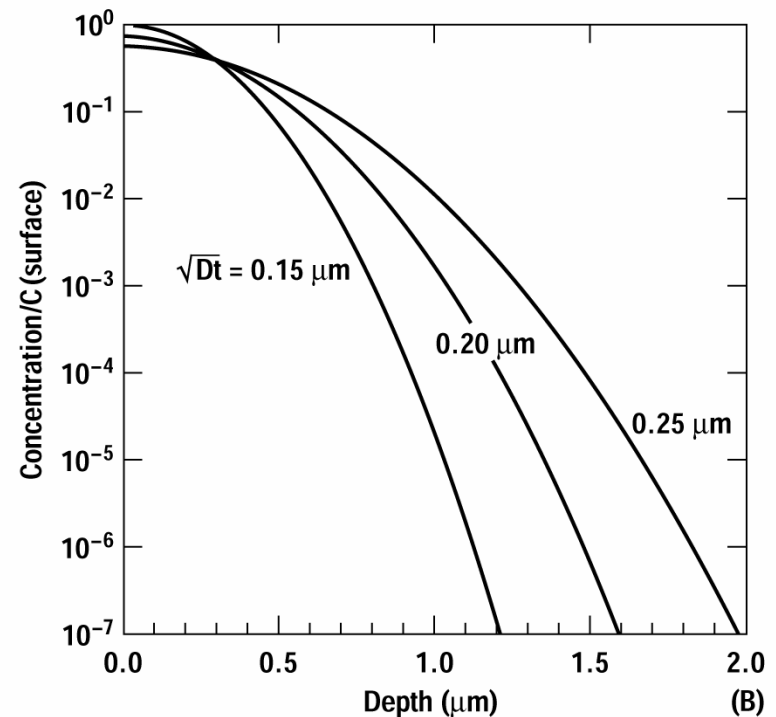


Figure 3.7 Concentration as a function of depth for (A) predeposition and (B) drive in diffusions for several values of the characteristic diffusion length.

# Forming an electronic junction in a semiconductor

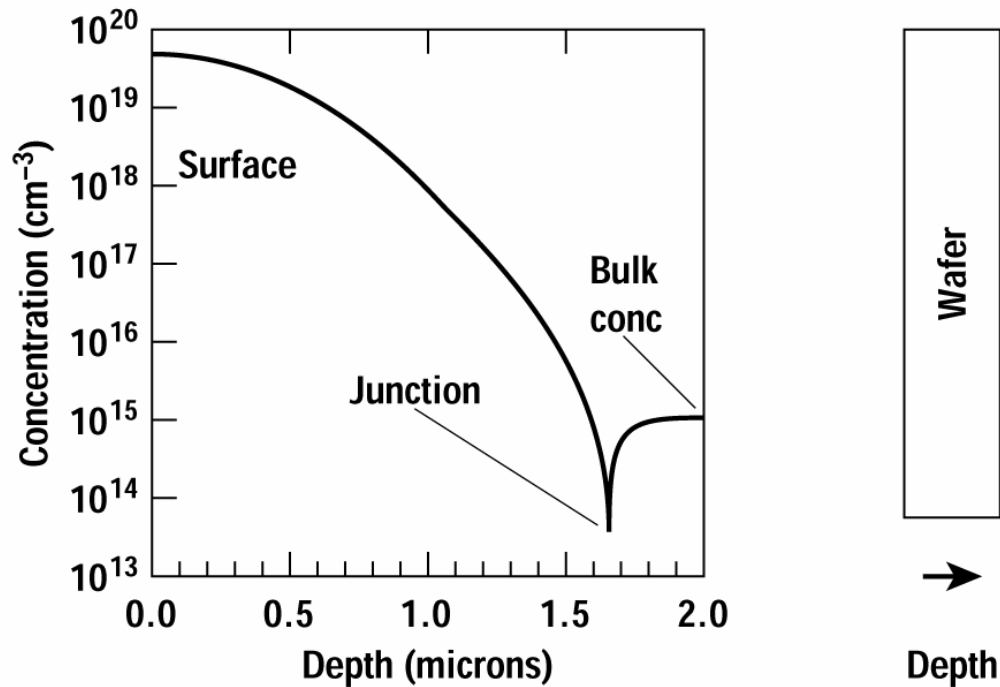
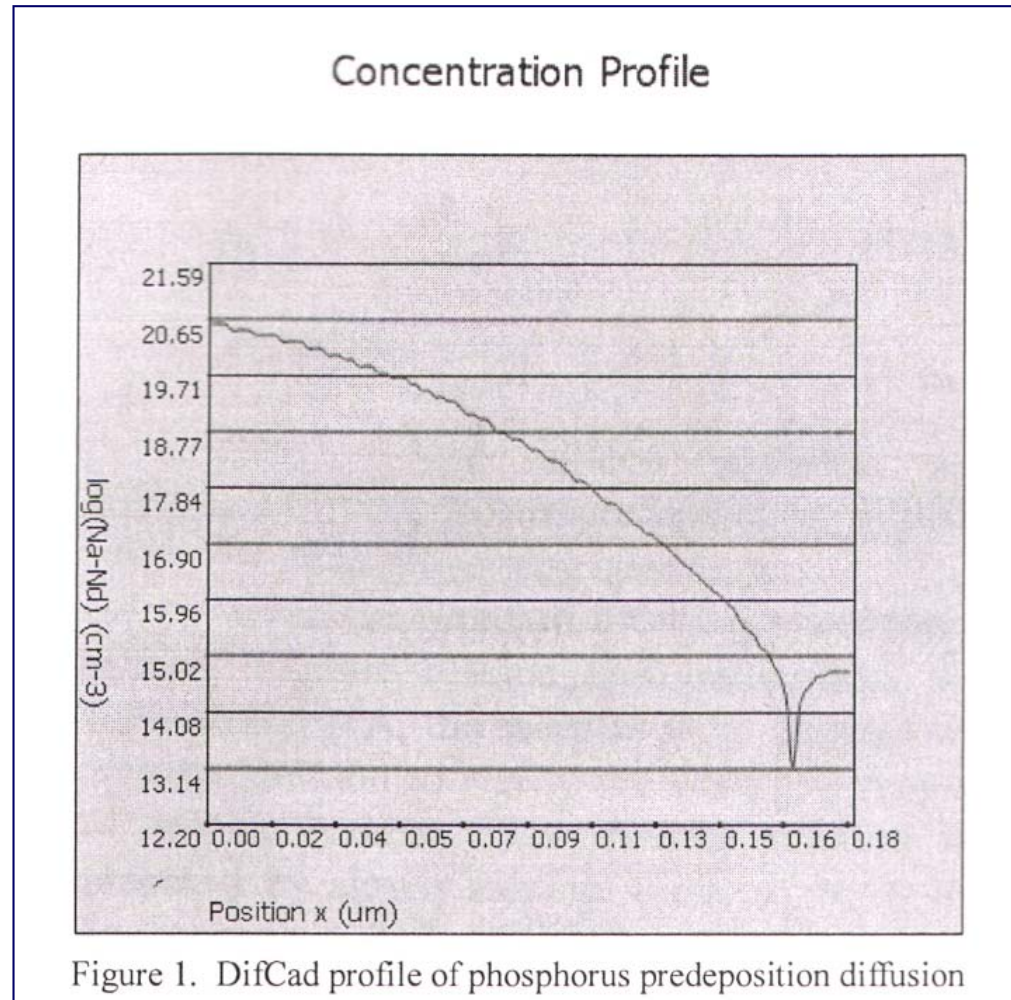


Figure 3.1 Typical concentration plot of impurities or carriers as a function of depth into the wafer. Note that these profiles are typically much less than 1% of the total wafer thickness.

# Diffusion

- 'Pre-deposition' does NOT mean that the dopant is only at the surface
- Starting with p-Si, doping with Phosphorus (n-dopant) to form p-n junction

Assumes p-Si  
starting material  
Finite junction  
depth~ 0.165  
microns  
Concentration of P  
varies as a  
function of  
distance



## Variabilities?

- Temperature gradients in furnace
- Errors in time of introduction of wafers
- Size of the sample wafers relative to size of the source wafers
- Breaking through phosphorous glass?
- Sheet resistance or bulk? What is the depth of the doped layer?
  - Simulation of diffusion profile
  - **Estimate of diffusion depth:**  $D_0 = 3.9 \exp \{-3.66/kT\}$ ; 10 times the diffusion length  $\sim 1.18 \times 10^{-5}$  cm (0.118 microns)

# Diffusion Constants in Silicon vs. Temperature

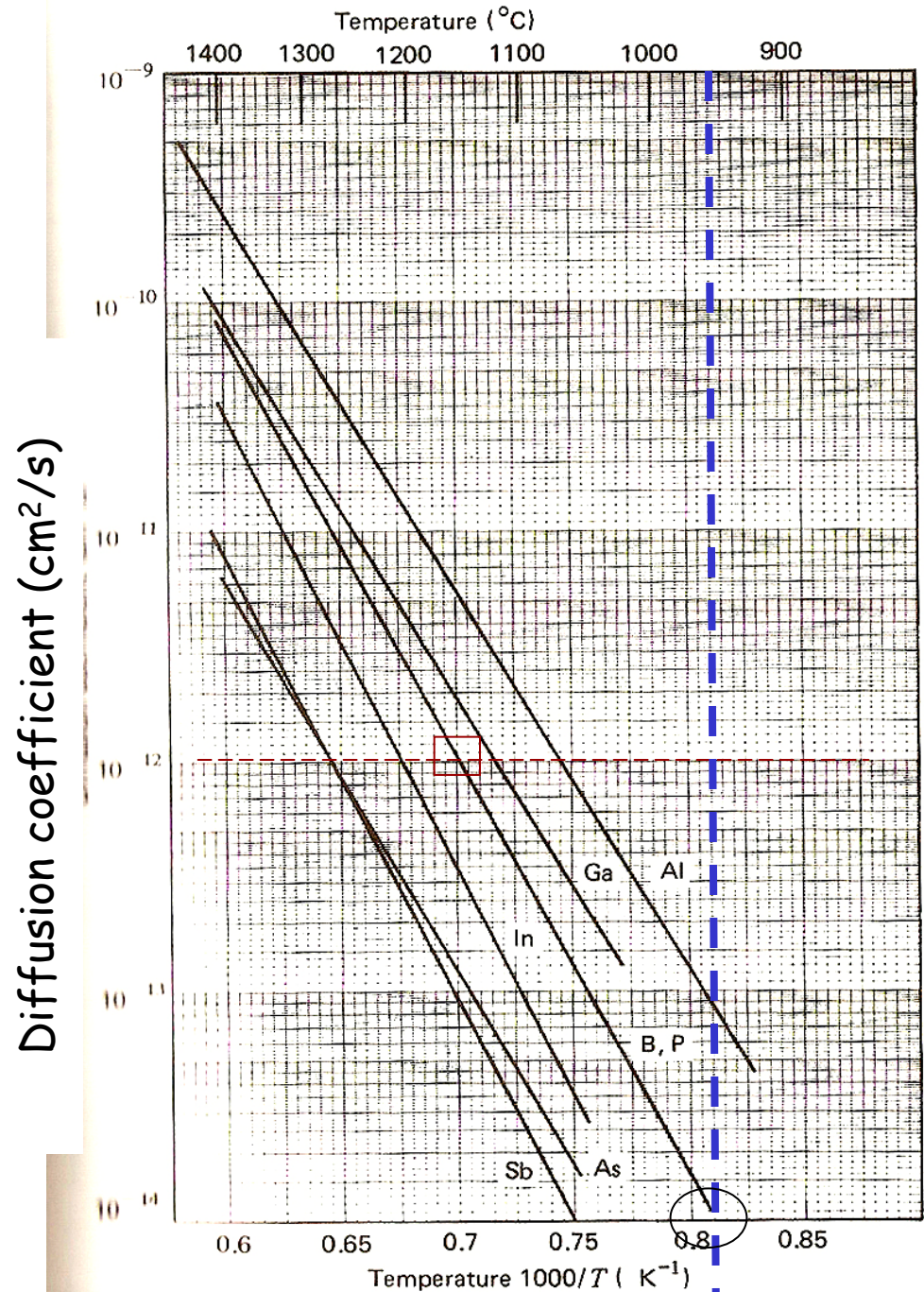
$$L_d = [Dt]^{1/2}$$

At 950C, diffusion constant of P in Si  $\sim 10^{-14}$  cm<sup>2</sup>/sec

5 minutes = 300 sec

$$[10^{-14} \times 300]^{1/2} =$$

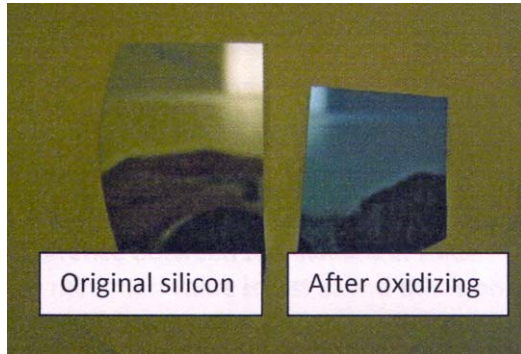
$$1.7 \times 10^{-6} \text{ cm} = 17 \text{ nm}$$



From Ghandhi  
VLSI Fabrication Principles



# Oxidation



- Experimental procedures straight-forward
- Good understanding of the differences between wet and dry oxidation
- Many of you tried and compared different ways of measuring the oxide

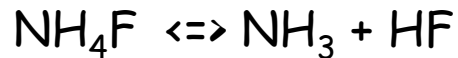
## Wet Etching, buffered HF and what does it mean to be buffered?



HF will etch the OXIDE, but not Si  
(we need something to first OXIDIZE the Si to form SiO<sub>2</sub>)

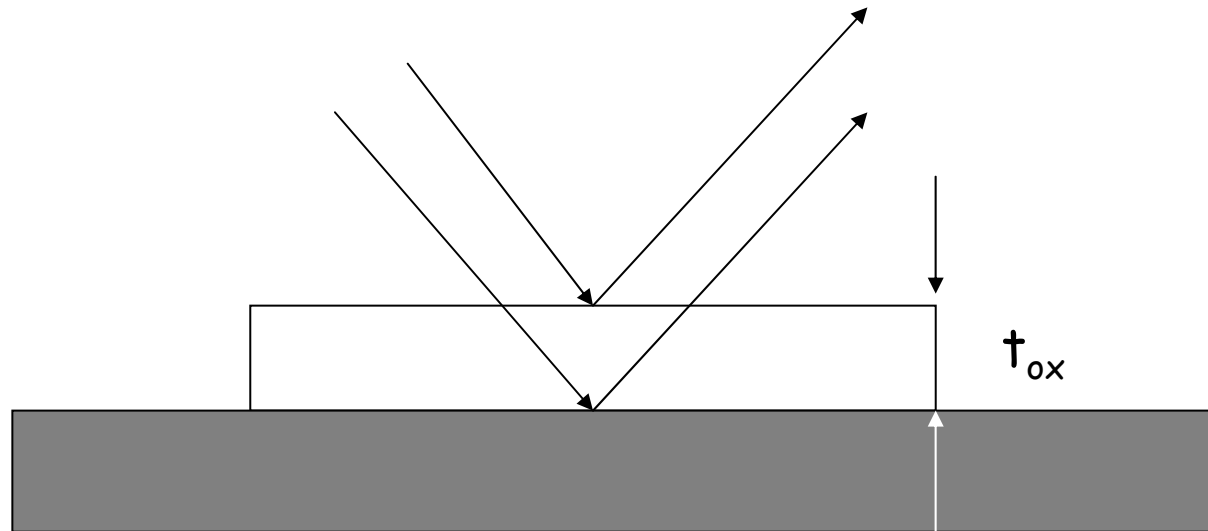
BUT, as we deplete F from HF in solution, we diminish our ability to etch SiO<sub>2</sub>, so ....

We add



To BUFFER the HF (control the pH), and also minimizes the attack on photoresist

How do you measure an oxide thickness, and what are you measuring?



Look at constructive interference at top and bottom surfaces of the oxide:

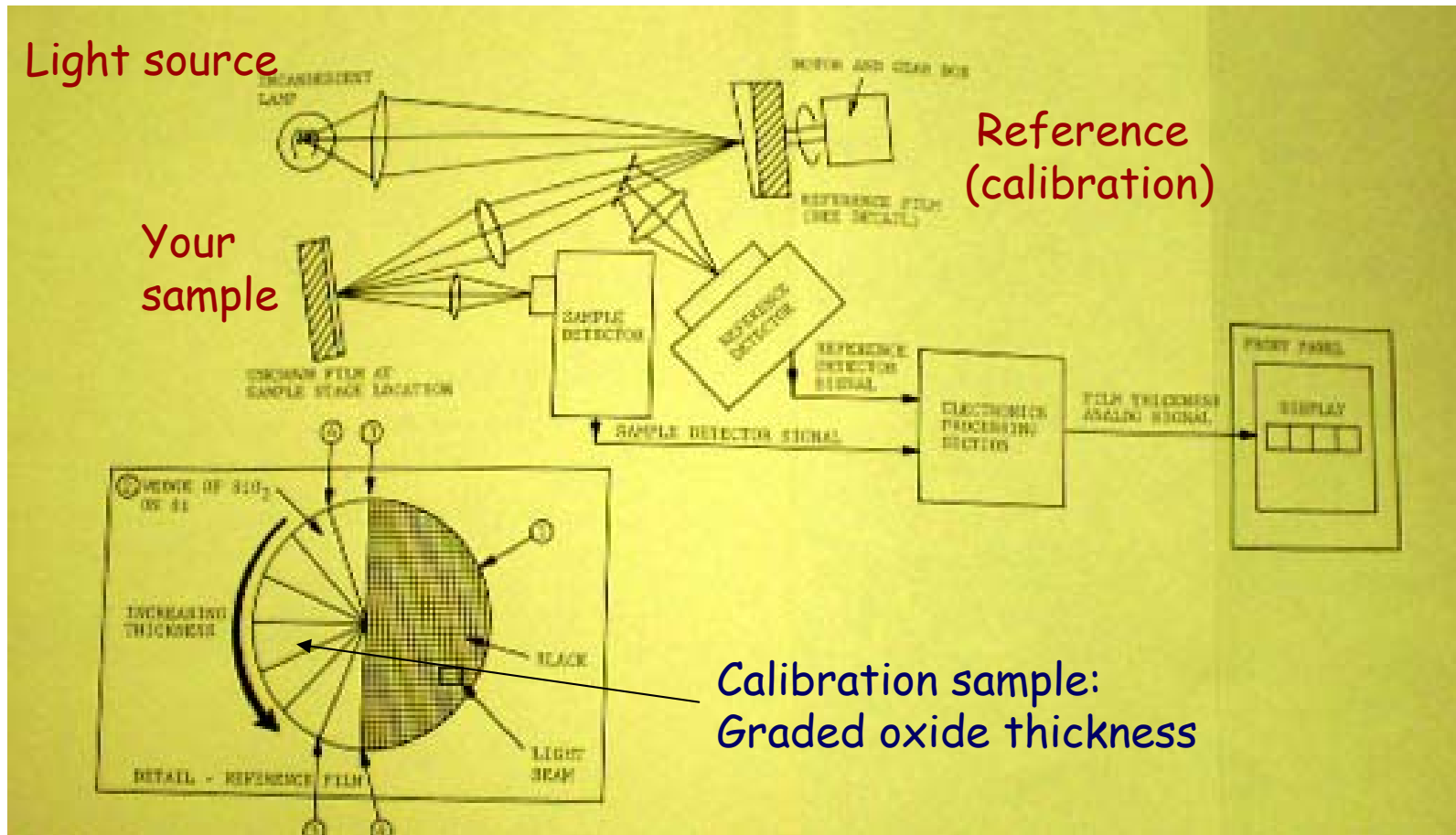
Monochromatic light, normal incidence:  
measure number of wavelengths or half-wavelengths equivalent to  $t_{ox}$  :  $\lambda/n_{ox}$

White light: see what colors are transmitted

When you compare your oxide to 'color samples': what might the sources of error be?

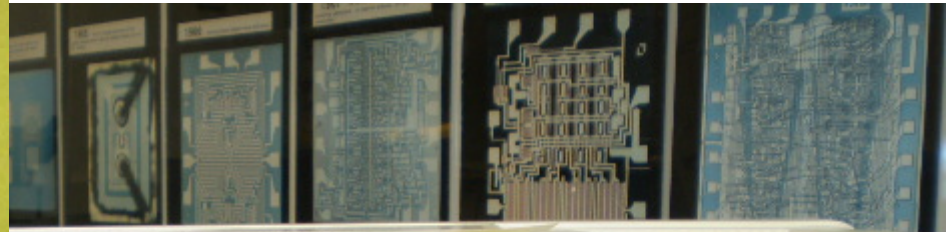
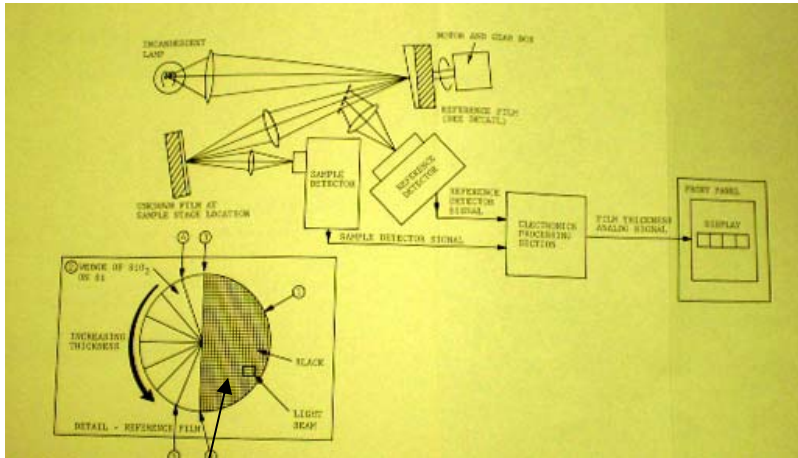


# Rudolph Thin Film Monitor

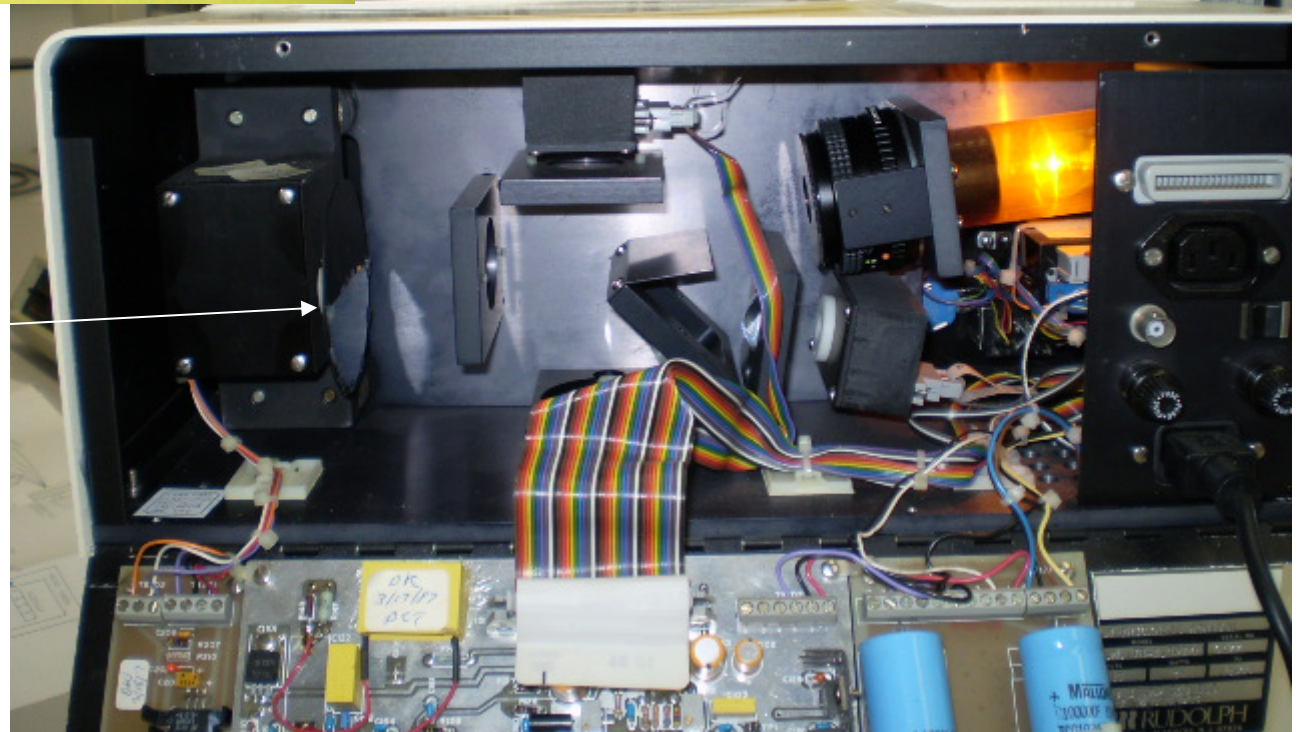


- Principle of operation: use a calibration sample; match optical signal from calibration sample and sample to be measured
- What sources of error might apply to this way of measurement?

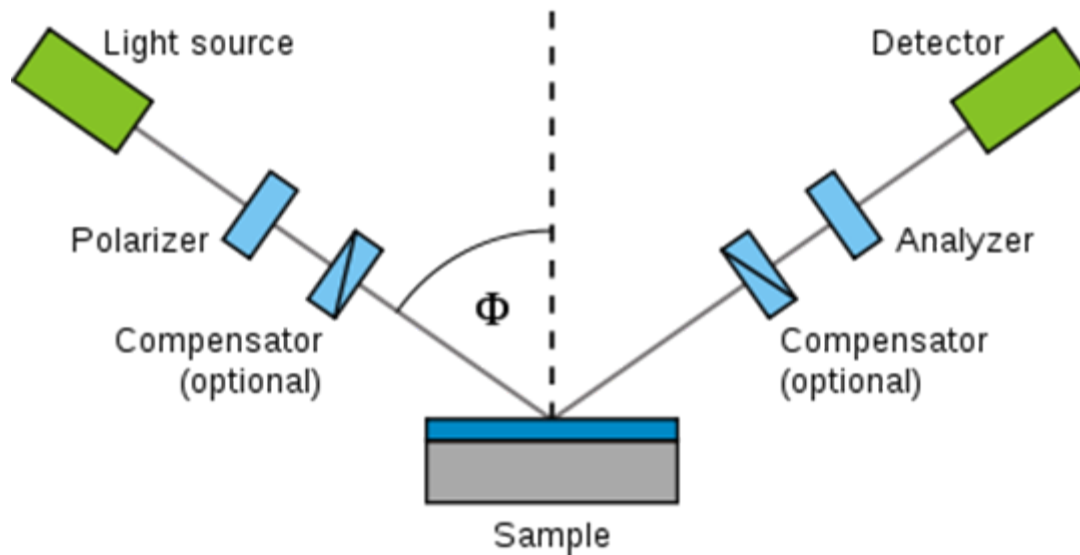
# Rudolph Thin Film Monitor



Reference  
(calibration)



# Ellipsometer

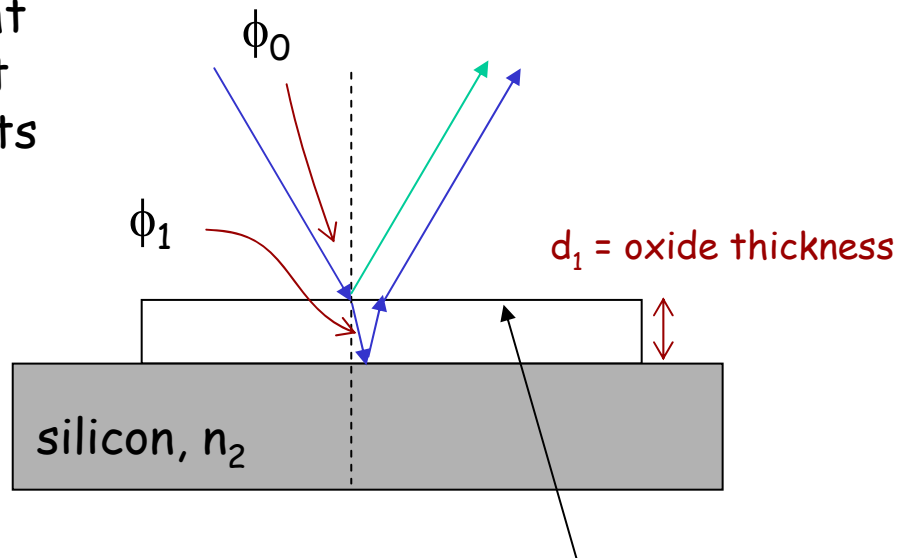


TE-polarized\* and TM-polarized\*\* light incident on a dielectric, have different reflection and transmission coefficients

At the air-SiO<sub>2</sub> interface:

$$r_{01,TE} = \frac{n_0 \cos \phi_0 - n_1 \cos \phi_1}{n_0 \cos \phi_0 + n_1 \cos \phi_1}$$

$$r_{01,TM} = \frac{n_0 \cos \phi_1 - n_1 \cos \phi_0}{n_0 \cos \phi_1 + n_1 \cos \phi_0}$$



Dielectric (oxide),  $n_1$

At the SiO<sub>2</sub>-Si interface:

$$r_{12,TE} = \frac{n_1 \cos \phi_1 - n_2 \cos \phi_2}{n_1 \cos \phi_1 + n_2 \cos \phi_2}$$

$$r_{12,TM} = \frac{n_1 \cos \phi_2 - n_2 \cos \phi_1}{n_1 \cos \phi_2 + n_2 \cos \phi_1}$$

$$n_0 \sin \phi_0 = n_1 \sin \phi_1 = n_2 \sin \phi_2$$

Look at NET reflected amplitude for BOTH polarizations:

$$r_{TE} = \frac{A_{R,TE}}{A_{I,TE}} = \frac{r_{01,TE} + r_{12,TE} e^{-i\delta}}{1 + r_{01,TE} r_{12,TE} e^{-i\delta}}$$

$$r_{TM} = \frac{A_{R,TM}}{A_{I,TM}} = \frac{r_{01,TM} + r_{12,TM} e^{-i\delta}}{1 + r_{01,TM} r_{12,TM} e^{-i\delta}}$$

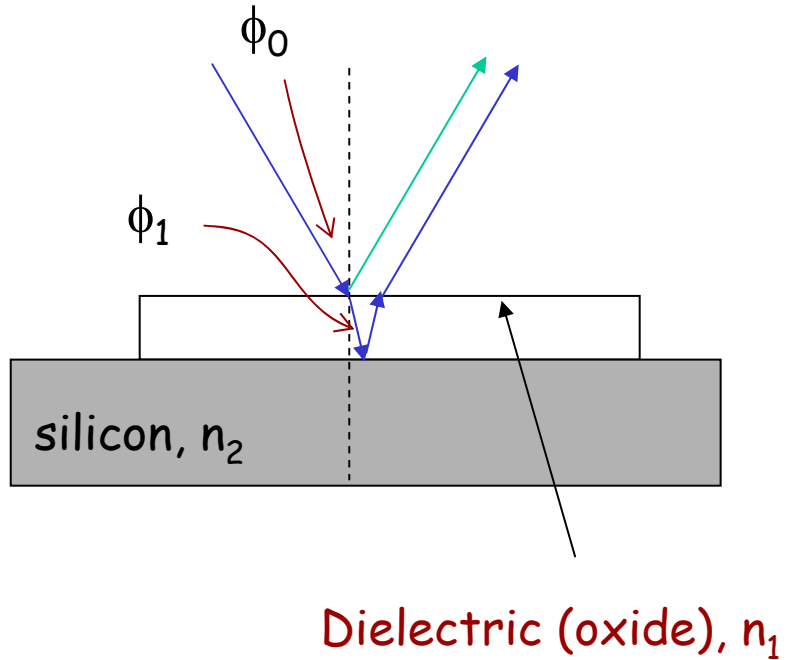
$$\delta = \frac{4\pi n_1 d_1 \cos \phi_1}{\lambda}$$

\* E parallel to interface, \*\* H parallel to interface

$$r_{TE} = \frac{A_{R,TE}}{A_{I,TE}} = \frac{r_{01,TE} + r_{12,TE} e^{-i\delta}}{1 + r_{01,TE} r_{12,TE} e^{-i\delta}}$$

$$r_{TM} = \frac{A_{R,TM}}{A_{I,TM}} = \frac{r_{01,TM} + r_{12,TM} e^{-i\delta}}{1 + r_{01,TM} r_{12,TM} e^{-i\delta}}$$

$$\delta = \frac{4\pi n_1 d_1 \cos \phi_1}{\lambda}$$



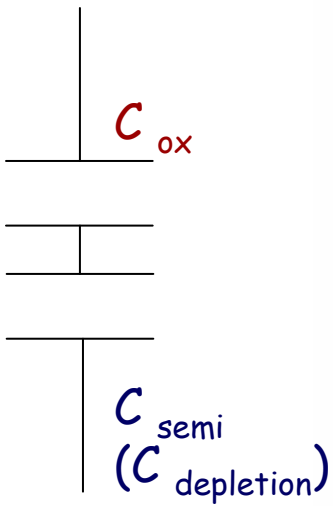
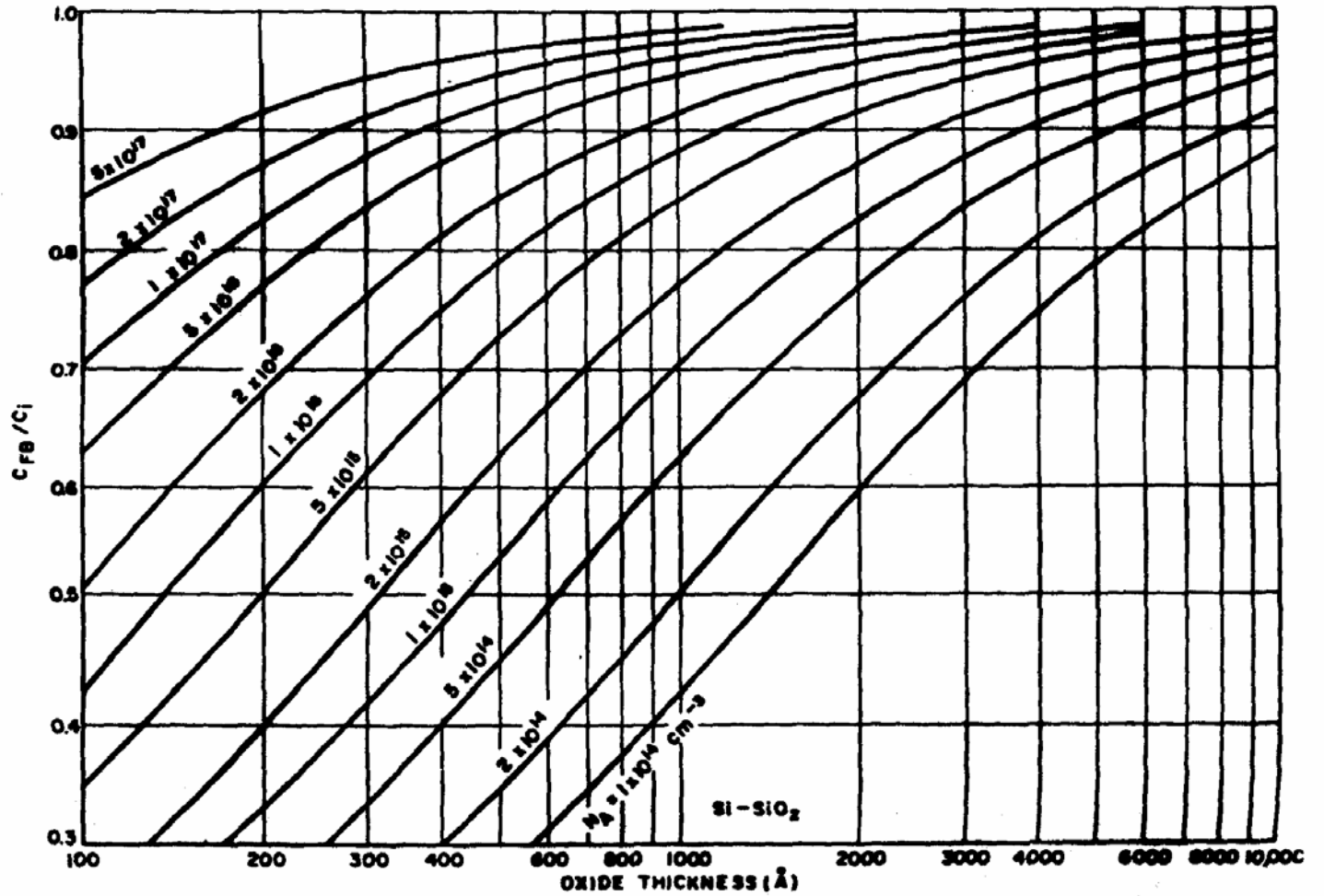
$$\frac{r_{TM}}{r_{TE}} = \tan \Psi e^{i\Delta}$$

Ultimately, we compare the TE and TM reflectivities,  
Look at an AMPLITUDE and a PHASE SHIFT

What sources of error might apply to this way of measurement?

\* E parallel to interface, \*\* H parallel to interface

# Capacitance vs. oxide thickness (for different substrate doping)





What are you actually measuring?  
What are the assumptions?  
Where are the errors?

Measuring oxide thickness:

- Selective etch: actually measure a 'length'
- Compare colors with samples
- Use Film Thickness Monitor
- Use Ellipsometer
- Measure capacitance
- Other ways? And WHY are you measuring the oxide thickness? Why does the thickness matter?

# Laboratory Procedures and 'cookbook recipes'

## Jenna's A to Z Everything But The Kitchen Sink Chocolate Chip Cookies

Now that the wafers were clean, they and 15 the suring etch the 0:1

beads eventually begin to form on the surface. This is because the surface is becoming hydrophobic as the glass is etched off and the doped substrate is exposed. For the last



three points on each determine the for sample 1, 523 were measured. mΩ, and 490 mΩ show that the m across the the resistance of derable after n- d because carriers trate.

ab was beneficial use the diffusion also learned the which type of cleaning is appropriate for a given task.

To complete my report (i.e. to get 2 pages), I have included the following supplemental material:



Figure 3. One of the reasons to be careful when working with the furnaces!



A to Z Everything-but-the-Kitchen-Sink Chocolate Chip Cookies

### Ingredients

- 1 1/2 cups all-purpose flour
- 1 1/4 teaspoons baking soda
- 1 teaspoon salt
- 1 1/2 teaspoons ground cinnamon
- 1/2 teaspoon ground mace
- 1/8 teaspoon ground nutmeg
- 1/8 teaspoon ground cloves
- 1 cup butter, softened
- 1 1/2 cups packed brown sugar
- 1 cup white sugar
- 2 eggs
- 1 tablespoon milk
- 1 1/2 teaspoons vanilla extract
- 1 cup cornflakes cereal, crumbled
- 3 cups rolled oats
- 1/2 cup flaked coconut
- 2 cups semisweet chocolate chips
- 1 cup chopped walnuts

*samples?*

### Directions

1. Preheat oven to 350 degrees F (175 degrees C). Grease cookie sheets. Sift together flour, baking soda, salt, cinnamon, mace, nutmeg, and cloves; set aside.
2. In a large bowl, cream together butter, brown sugar, and white sugar until smooth. Beat in the eggs one at a time, then stir in milk and vanilla. Gradually mix in the sifted ingredients until well blended. Using a wooden spoon, stir in the cornflakes, oats, coconut, chocolate chips, and walnuts. Roll the dough into walnut sized balls, and place 2 inches apart on prepared cookie sheets; flatten slightly.
3. Bake for 8 to 10 minutes in preheated oven. Allow cookies to cool on baking sheet for 5 minutes before transferring to a wire rack to cool completely. I found that slightly under baking these yields wonderfully chewy cookies!