Optical Film Thickness Measurements
Oxide, Nitride and Poly

Dr. Lynn Fuller
Webpage: http://people.rit.edu/lffeee
Microelectronic Engineering
Rochester Institute of Technology
82 Lomb Memorial Drive
Rochester, NY 14623-5604
Email: Lynn.Fuller@rit.edu
Department webpage: http://www.microe.rit.edu

3-5-2014 OpticalFilmThicknessMeasurements.ppt

ADOBE PRESENTER

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OUTLINE

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NanoSpec Reflectance Spectrometer
Theory of Operation
E&M Field Equations for Reflection
Excel Calculation of Reflection
Where to Measure
Spectromap
Film Thickness FT350
Ellipsometer
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Homework

INTRODUCTION

Most measurement instruments will give the user a measured value. There are many reasons why the measured value may not be correct including not using the measurement tool correctly, problems with the tool itself or not knowing what you are measuring.

To have a better chance of measuring correctly the user should:

Know the approximate value before measuring it
Know where, on the wafer, to make the measurement
Know what films (and their thickness) that are under the film to be measured
Understand the limits of the measurement tool
Understand the theory behind the measurement
Operate the tool correctly, focus, calibration, filters, etc.

This document was created to help reduce measurement errors for oxide, silicon nitride and poly using the NanoSpec, Spectromap and other optical measurement tools used at RIT.

THE NANOSPEC - REFLECTANCE SPECTROMETER

Use the correct recipe

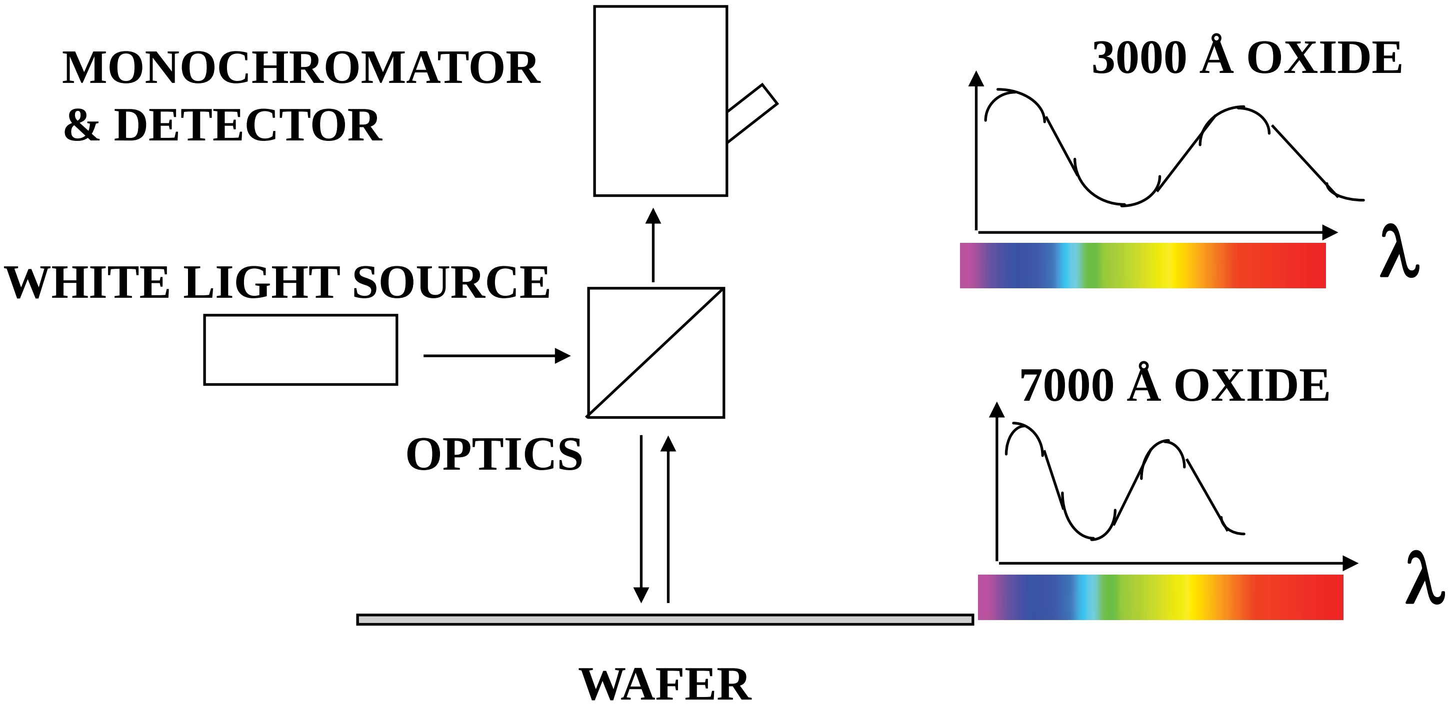
Oxide on Silicon	400-30,000 Å
Nitride	400-30,000
Neg Resist	500-40,000
Poly on Ox 300-1200 Å	400-10,000
Neg Resist on Ox 300-350	300-3500
Nitride on Oxide 300-3500	300-3500
Thin Oxide	100-500
Thin Nitride	100-500
Polyimide	500-10,000
Positive Resist	500-40,000
Pos Resist on Ox 500-15,000	4,000-30,000

Note: Place the filter in for all measurements except for nitride on oxide.

Note: For Poly on Oxide, Resist on Oxide, and Nitride on Oxide you will be asked to enter the thickness of the oxide layer under the film to be measured. (in the range specified above)

NANOSPEC - REFLECTANCE SPECTROMETER

INCIDENT WHITE LIGHT, THE INTENSITY OF THE REFLECTED LIGHT IS MEASURED VS WAVELENGTH



MONOCHROMATOR & DETECTOR

WHITE LIGHT SOURCE

OPTICS

WAFER

3000 Å OXIDE

7000 Å OXIDE

OXIDE THICKNESS COLOR CHART

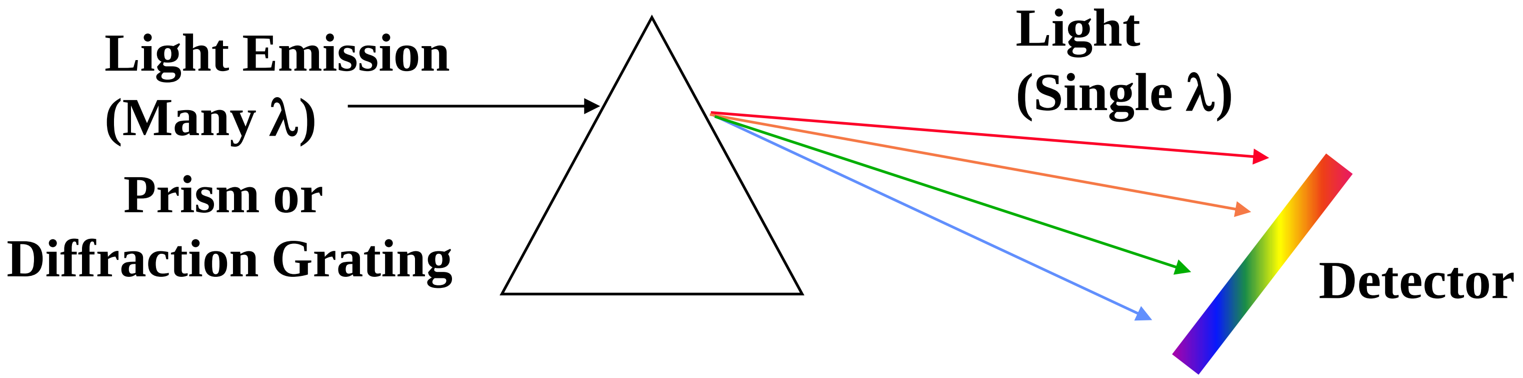
Thickness	Color
500Å	Tan
700	Brown
1000	Dark Violet - Red Violet
1200	Royal Blue Blue
1500	Light Blue - Metallic Blue
1700	Metallic - very light Yellow Green
2000	LIght Gold or Yellow - Slightly Metallic
2200	Gold with slight Yellow Orange
2500	Orange - Melon
2700	Red Violet
3000	Blue - Violet Blue
3100	Blue Blue
3200	Blue - Blue Green
3400	Light Green
3500	Green - Yellow Green
3600	Yellow Green
3700	Yellow
3900	Light Orange
4100	Carnation Pink
4200	Violet Red
4400	Red Violet
4600	Violet
4700	Blue Violet

Thickness	Color
4900	Blue Blue
5000	Blue Green
5200	Green
5400	Yellow Green
5600	GreenYellow
5700	Yellow -"Yellowish"(at times appears to be Lt gray or matel
5800	Light Orange or Yellow - Pink
6000	Carnation Pink
6300	Violet Red
6800	"Bluish"(appears violet red, Blue Green, looks Blue
7200	Blue Green - Green
7700	"Yellowish"
8000	Orange
8200	Salmon
8500	Dull, LIght Red Violet
8600	Violet
8700	Blue Violet
8900	Blue Blue
9200	Blue Green
9500	Dull Yellow Green
9700	Yellow - "Yellowish"
9900	Orange
10000	Carnation Pink

Nitride Thickness = (Oxide Thickness)(Oxide Index/Nitride Index)

Eg. Yellow Nitride Thickness = (2000)(1.46/2.00) = 1460

EMISSION SPECTROSCOPY

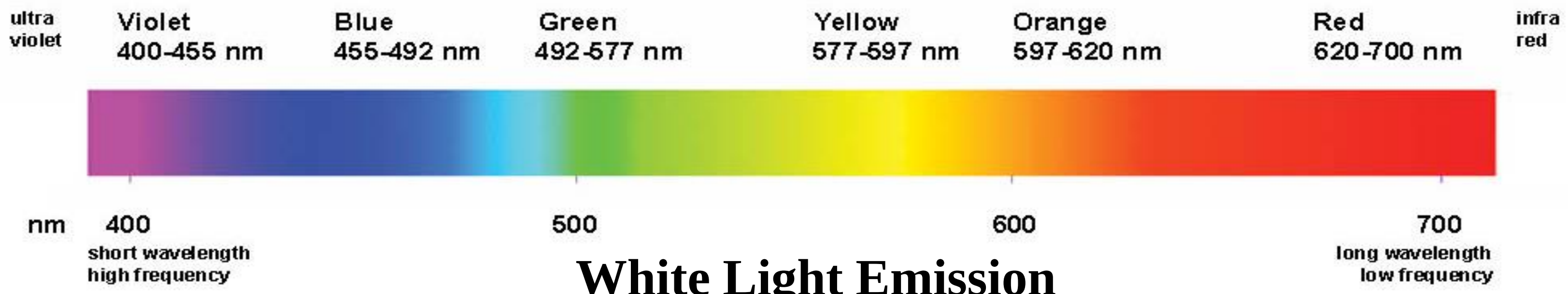


Light Emission (Many λ)

Prism or Diffraction Grating

Light (Single λ)

Detector

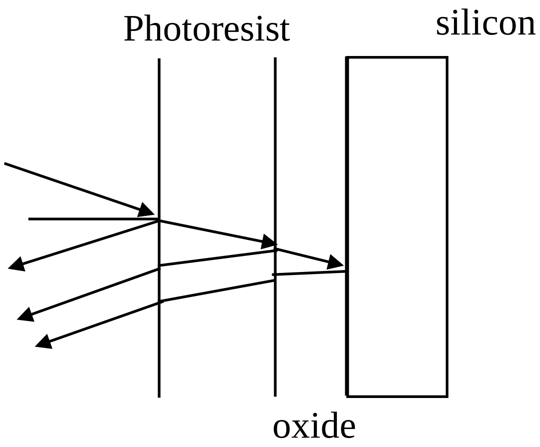


White Light Emission

NANOSPEC THEORY OF OPERATION

The NanoSpec illuminates the sample with white light and measures the reflected light versus wavelength. Thick films have many closely spaced peaks and valleys. Thinner films have fewer peaks and valleys. The difference in the wavelength at which the first peak and the first valley occurs is used to give the film thickness. A second algorithm uses the difference in the wavelength at which the first valley or the first peak occurs. For very thin films ~ < 500 Å there are no peaks or valleys so the reflectance at a fixed wavelength (470 nm) is used to give the film thickness.

CALCULATION OF IRRADIANCE IN A SYSTEM WHERE THERE ARE MULTIPLE REFLECTING LAYERS



Light is an electromagnetic wave. The electric field is calculated from the irradiance value at the surface of the photoresist. Using the reflection and transmission coefficients for the boundary of two dielectrics a system of equations is built for a multi-layer substrate. The dielectric materials are described by their complex index of refraction.

The relationship between Irradiance and electric or magntic field is:

Irradiance = ave Power / unit area

$I = c\varepsilon_o E^2 / 2$ or $I = (c / 2 \mu_o)B^2$

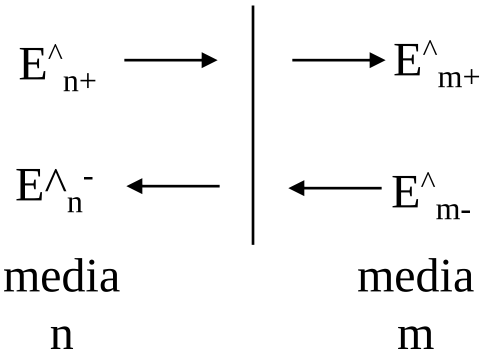
where c is speed of light 3e8m/s

ε_o is permitivitty, μ_o is permeability

REFLECTION CALCULATIONS (CONT.)

rn = (Nn -Nm)/(Nn+Nm)

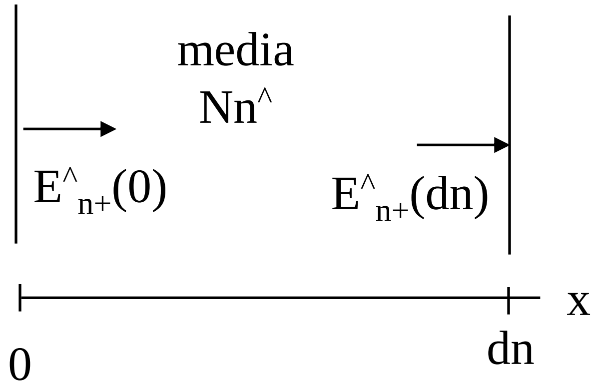
tn = (2Nn)/(Nn+Nm)



$$E^{\wedge}_{m+} = \mathrm{tn}\, E^{\wedge}_{n+} + \mathrm{rn}\, E^{\wedge}_{m-}$$

$$E^{\wedge}_{n-} = \mathrm{rn}\, E^{\wedge}_{n+} + \mathrm{tn}\, E^{\wedge}_{m-}$$

As light traverses a dielectric material there is a phase shift, δn



$$E^{\wedge}_{n+}(dn) = E^{\wedge}_{n+}(0)\ e^{\,j\delta n}$$

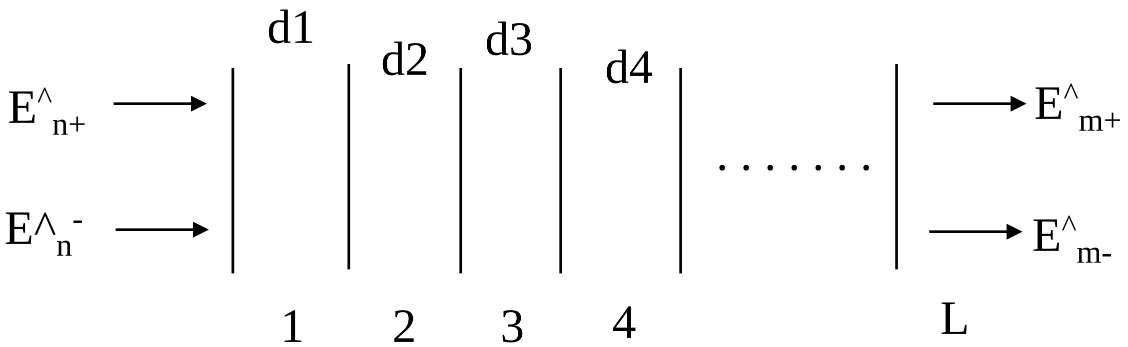
where $\delta n = 2\ \pi\ Nn^{\wedge}\ dn\ /\ \lambda$

$$E^{\wedge}_{n+}(0) = E^{\wedge}_{n+}(dn)\ e^{\,+j\delta n}$$

$$E^{\wedge}_{n-}(0) = E^{\wedge}_{n-}(dn)\ e^{\,-j\delta n}$$

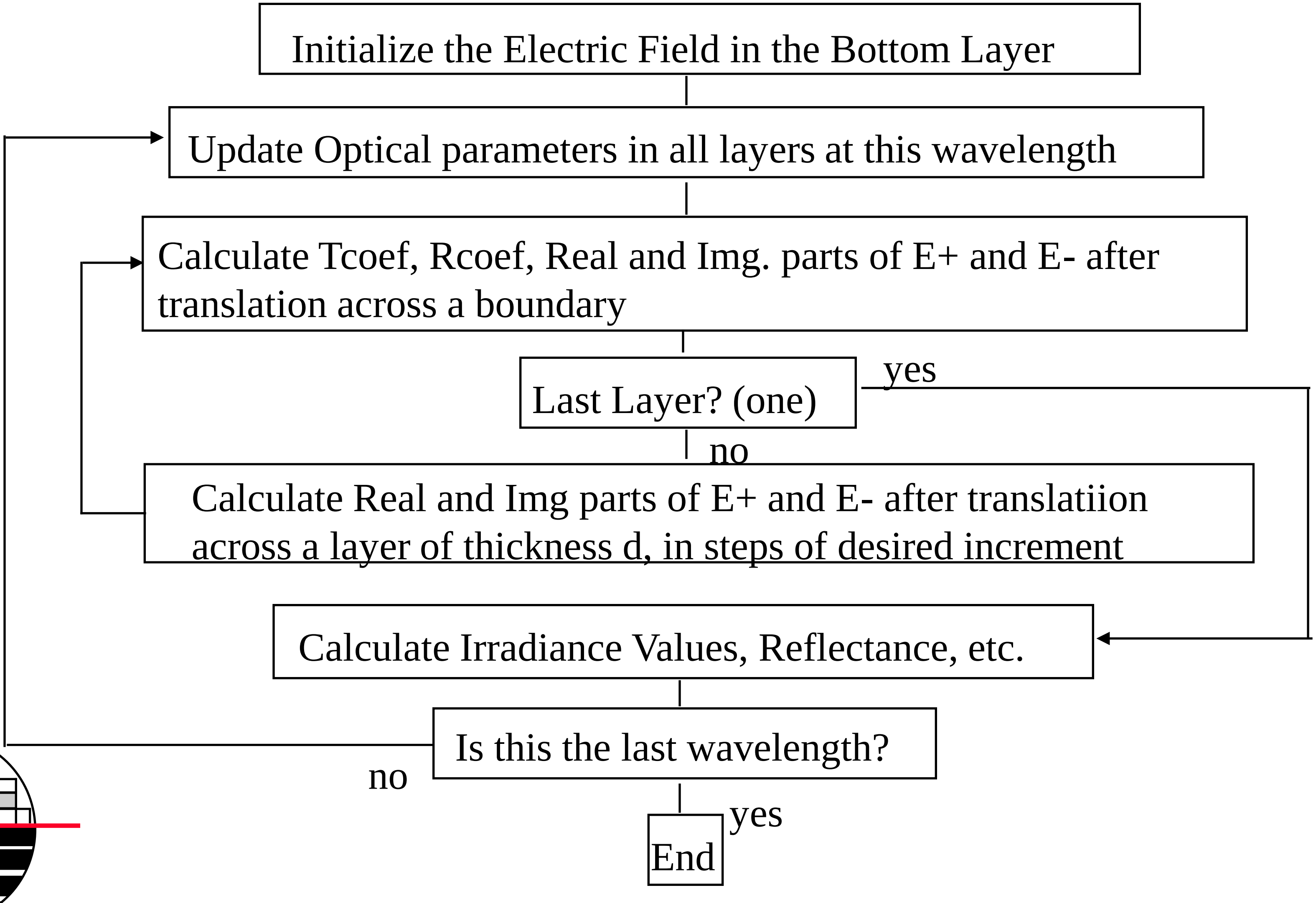
REFLECTION CALCULATIONS

The two equations on the previous page are rearrange so input quantities are on the left and output quantities are on the right. The equations are converted to matrix format for simplicity. This allows for concise a representation of a system of any number of layers.



$$\begin{vmatrix} E1+ \\ E1- \end{vmatrix} = \begin{vmatrix} R & R \\ R & R \end{vmatrix}\begin{vmatrix} T2 & 0 \\ 0 & T2 \end{vmatrix}\begin{vmatrix} R & R \\ R & R \end{vmatrix}\begin{vmatrix} T3 & 0 \\ 0 & T3 \end{vmatrix} \circ\circ\circ\circ \begin{vmatrix} TL & 0 \\ 0 & TL \end{vmatrix}\begin{vmatrix} R & R \\ R & R \end{vmatrix}\begin{vmatrix} EL+ \\ EL- \end{vmatrix}$$

FLOW CHART FOR CALCULATIONS



Initialize the Electric Field in the Bottom Layer

Update Optical parameters in all layers at this wavelength

Calculate Tcoef, Rcoef, Real and Img. parts of E+ and E- after translation across a boundary

Last Layer? (one)

yes

no

Calculate Real and Img parts of E+ and E- after translatiion across a layer of thickness d, in steps of desired increment

Calculate Irradiance Values, Reflectance, etc.

Is this the last wavelength?

no

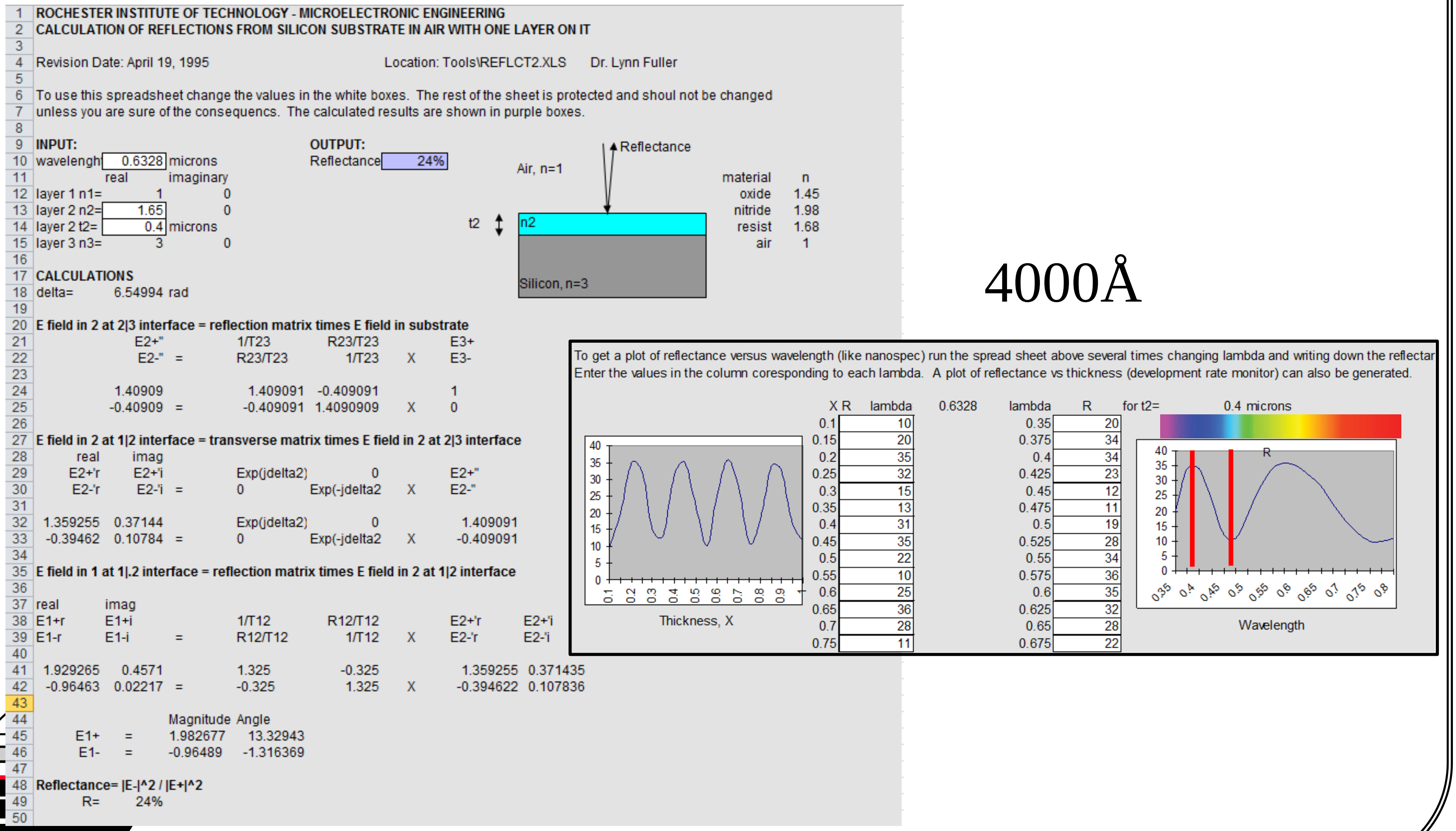
yes

End

INDEX FOR OXIDE, NITRIDE AND POLY AT DIFFERENT λ

λ	Oxide		Nitride		Poly		Silicon (Cry)	
400nm	1.47	0.0	1.98	0.0	5.51	0.4526	5.24	0.2300
425	↓	↓	↓	↓	5.09	0.2483	4.75	0.1300
450	↓	↓	↓	↓	4.76	0.1491	4.42	0.0800
475	↓	↓	↓	↓	4.50	0.1045	4.30	0.0700
500	↓	↓	↓	↓	4.31	0.0810	4.18	0.0560
525	↓	↓	↓	↓	4.17	0.0647	4.08	0.0430
550	↓	↓	↓	↓	4.06	0.0524	4.00	0.0390
575	↓	↓	↓	↓	3.98	0.0431	3.95	0.0300
600	↓	↓	↓	↓	3.92	0.0361	3.88	0.0250
625	↓	↓	↓	↓	3.86	0.0306	3.82	0.0200
650	↓	↓	↓	↓	3.81	0.0264	3.77	0.0150
675	↓	↓	↓	↓	3.76	0.0232	3.72	0.0120
700	↓	↓	↓	↓	3.72	0.0206	3.70	0.0100
725	↓	↓	↓	↓	3.62	0.0210	3.68	0.0093
750	↓	↓	↓	↓	3.65	0.0171	3.66	0.0079
775	↓	↓	↓	↓	3.67	0.0610	3.64	0.0068
800	↓	↓	↓	↓	3.60	0.0151	3.62	0.0056
825	↓	↓	↓	↓	3.63	0.1510	3.60	0.0046
850	1.47	0.0	1.98	0.0	3.55	0.0142	3.60	0.0036

REFLECTANCE CALCULATION USING EXCEL



ROCHESTER INSTITUTE OF TECHNOLOGY - MICROELECTRONIC ENGINEERING
CALCULATION OF REFLECTIONS FROM SILICON SUBSTRATE IN AIR WITH ONE LAYER ON IT

Revision Date: April 19, 1995 Location: Tools\REFLCT2.XLS Dr. Lynn Fuller

To use this spreadsheet change the values in the white boxes. The rest of the sheet is protected and shoul not be changed unless you are sure of the consequencs. The calculated results are shown in purple boxes.

INPUT:
wavelengh 0.6328 microns
real imaginary
layer 1 n1= 1 0
layer 2 n2= 1.65 0
layer 2 t2= 0.4 microns
layer 3 n3= 3 0

OUTPUT:
Reflectance 24%

material	n
oxide	1.45
nitride	1.98
resist	1.68
air	1

CALCULATIONS
delta= 6.54994 rad

E field in 2 at 2|3 interface = reflection matrix times E field in substrate
E2+" 1/T23 R23/T23 E3+
E2-" = R23/T23 1/T23 X E3-

1.40909 1.409091 -0.409091 1
-0.40909 = -0.409091 1.4090909 X 0

E field in 2 at 1|2 interface = transverse matrix times E field in 2 at 2|3 interface
real imag
E2+'r E2+'i Exp(jdelta2) 0 E2+"
E2-'r E2-'i = 0 Exp(-jdelta2 X E2-"

1.359255 0.37144 Exp(jdelta2) 0 1.409091
-0.39462 0.10784 = 0 Exp(-jdelta2 X -0.409091

E field in 1 at 1|.2 interface = reflection matrix times E field in 2 at 1|2 interface

real imag
E1+r E1+i 1/T12 R12/T12 E2+'r E2+'i
E1-r E1-i = R12/T12 1/T12 X E2-'r E2-'i

1.929265 0.4571 1.325 -0.325 1.359255 0.371435
-0.96463 0.02217 = -0.325 1.325 X -0.394622 0.107836

Magnitude Angle
E1+ = 1.982677 13.32943
E1- = -0.96489 -1.316369

Reflectance= |E-|^2 / |E+|^2
R= 24%

4000Å

To get a plot of reflectance versus wavelength (like nanospec) run the spread sheet above several times changing lambda and writing down the reflectar
Enter the values in the column coresponding to each lambda. A plot of reflectance vs thickness (development rate monitor) can also be generated.

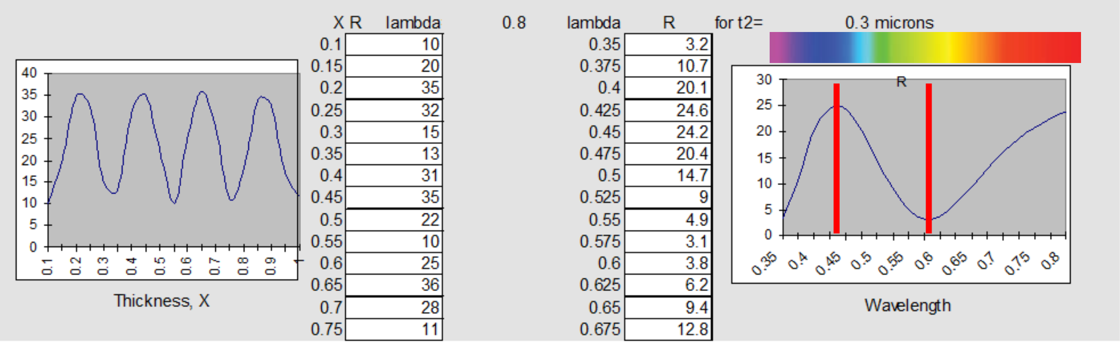
lambda 0.6328

X	R
0.1	10
0.15	20
0.2	35
0.25	32
0.3	15
0.35	13
0.4	31
0.45	35
0.5	22
0.55	10
0.6	25
0.65	36
0.7	28
0.75	11

for t2= 0.4 microns

lambda	R
0.35	20
0.375	34
0.4	34
0.425	23
0.45	12
0.475	11
0.5	19
0.525	28
0.55	34
0.575	36
0.6	35
0.625	32
0.65	28
0.675	22

CALCULATED REFLECTANCE VS WAVELENGTH



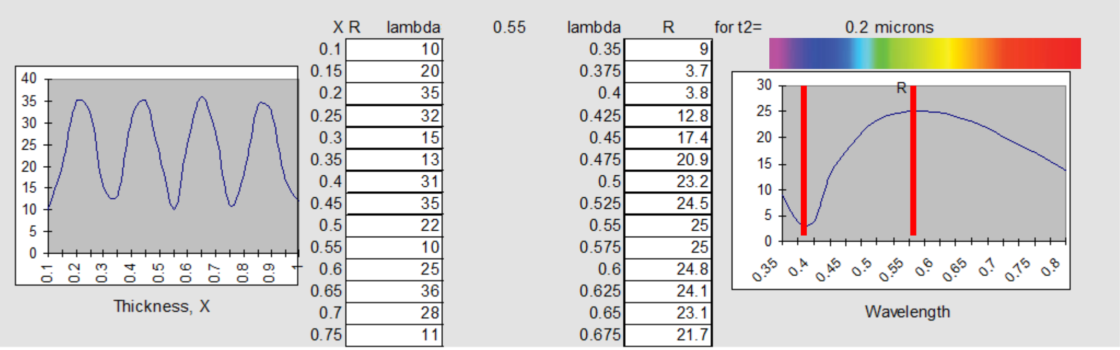
X R	lambda
0.1	10
0.15	20
0.2	35
0.25	32
0.3	15
0.35	13
0.4	31
0.45	35
0.5	22
0.55	10
0.6	25
0.65	36
0.7	28
0.75	11

0.8

lambda	R
0.35	3.2
0.375	10.7
0.4	20.1
0.425	24.6
0.45	24.2
0.475	20.4
0.5	14.7
0.525	9
0.55	4.9
0.575	3.1
0.6	3.8
0.625	6.2
0.65	9.4
0.675	12.8

for t2= 0.3 microns

3000Å



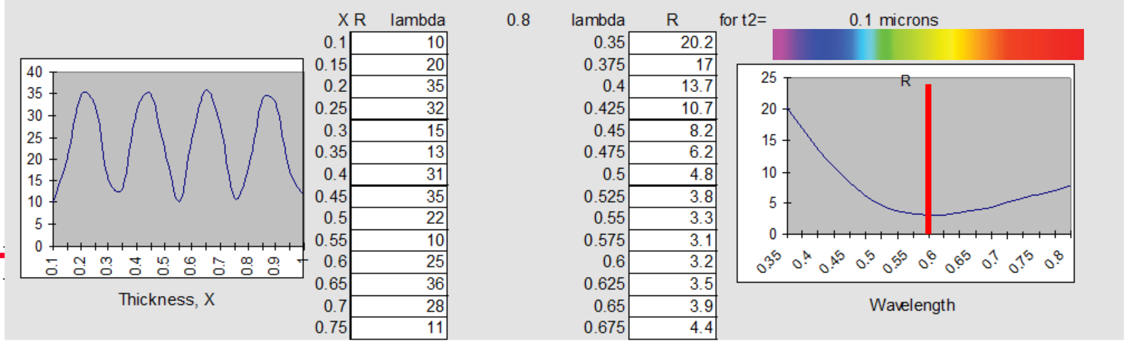
X R	lambda
0.1	10
0.15	20
0.2	35
0.25	32
0.3	15
0.35	13
0.4	31
0.45	35
0.5	22
0.55	10
0.6	25
0.65	36
0.7	28
0.75	11

0.55

lambda	R
0.35	9
0.375	3.7
0.4	3.8
0.425	12.8
0.45	17.4
0.475	20.9
0.5	23.2
0.525	24.5
0.55	25
0.575	25
0.6	24.8
0.625	24.1
0.65	23.1
0.675	21.7

for t2= 0.2 microns

2000Å



X R	lambda
0.1	10
0.15	20
0.2	35
0.25	32
0.3	15
0.35	13
0.4	31
0.45	35
0.5	22
0.55	10
0.6	25
0.65	36
0.7	28
0.75	11

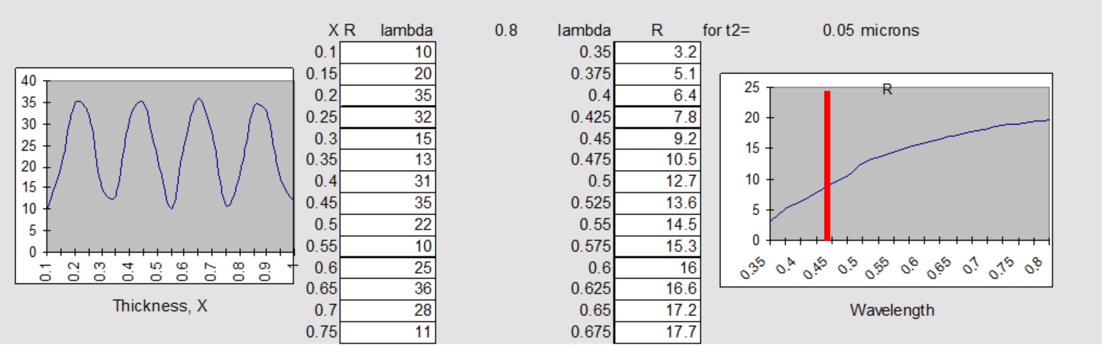
0.8

lambda	R
0.35	20.2
0.375	17
0.4	13.7
0.425	10.7
0.45	8.2
0.475	6.2
0.5	4.8
0.525	3.8
0.55	3.3
0.575	3.1
0.6	3.2
0.625	3.5
0.65	3.9
0.675	4.4

for t2= 0.1 microns

1000Å

CALCULATED REFLECTANCE VS WAVELENGTH

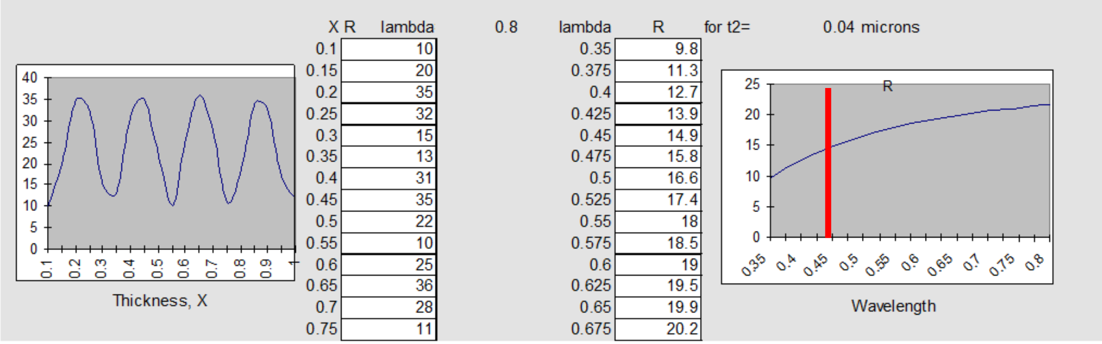


0.8 for t2= 0.05 microns

X R	lambda	lambda	R
0.1	10	0.35	3.2
0.15	20	0.375	5.1
0.2	35	0.4	6.4
0.25	32	0.425	7.8
0.3	15	0.45	9.2
0.35	13	0.475	10.5
0.4	31	0.5	12.7
0.45	35	0.525	13.6
0.5	22	0.55	14.5
0.55	10	0.575	15.3
0.6	25	0.6	16
0.65	36	0.625	16.6
0.7	28	0.65	17.2
0.75	11	0.675	17.7

500Å

R=8%

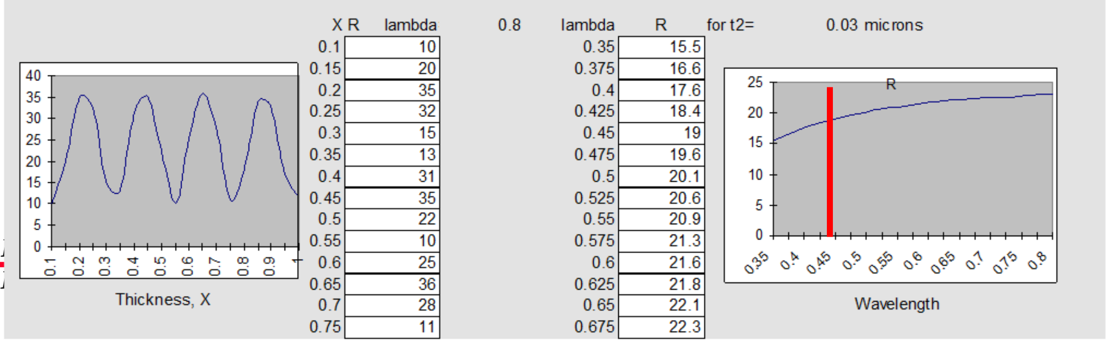


0.8 for t2= 0.04 microns

X R	lambda	lambda	R
0.1	10	0.35	9.8
0.15	20	0.375	11.3
0.2	35	0.4	12.7
0.25	32	0.425	13.9
0.3	15	0.45	14.9
0.35	13	0.475	15.8
0.4	31	0.5	16.6
0.45	35	0.525	17.4
0.5	22	0.55	18
0.55	10	0.575	18.5
0.6	25	0.6	19
0.65	36	0.625	19.5
0.7	28	0.65	19.9
0.75	11	0.675	20.2

400Å

R=14%



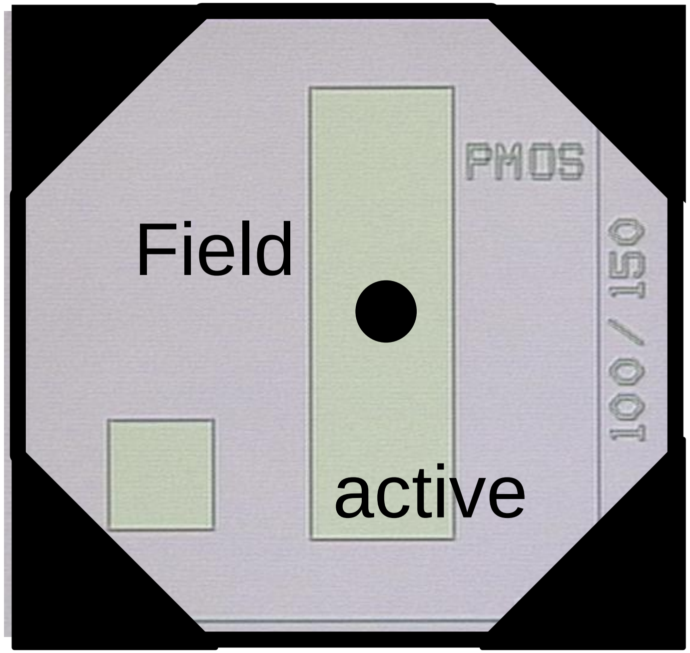
0.8 for t2= 0.03 microns

X R	lambda	lambda	R
0.1	10	0.35	15.5
0.15	20	0.375	16.6
0.2	35	0.4	17.6
0.25	32	0.425	18.4
0.3	15	0.45	19
0.35	13	0.475	19.6
0.4	31	0.5	20.1
0.45	35	0.525	20.6
0.5	22	0.55	20.9
0.55	10	0.575	21.3
0.6	25	0.6	21.6
0.65	36	0.625	21.8
0.7	28	0.65	22.1
0.75	11	0.675	22.3

300Å

R=18%

HOW TO MEASURE A SPECIFIC SPOT ON THE WAFER



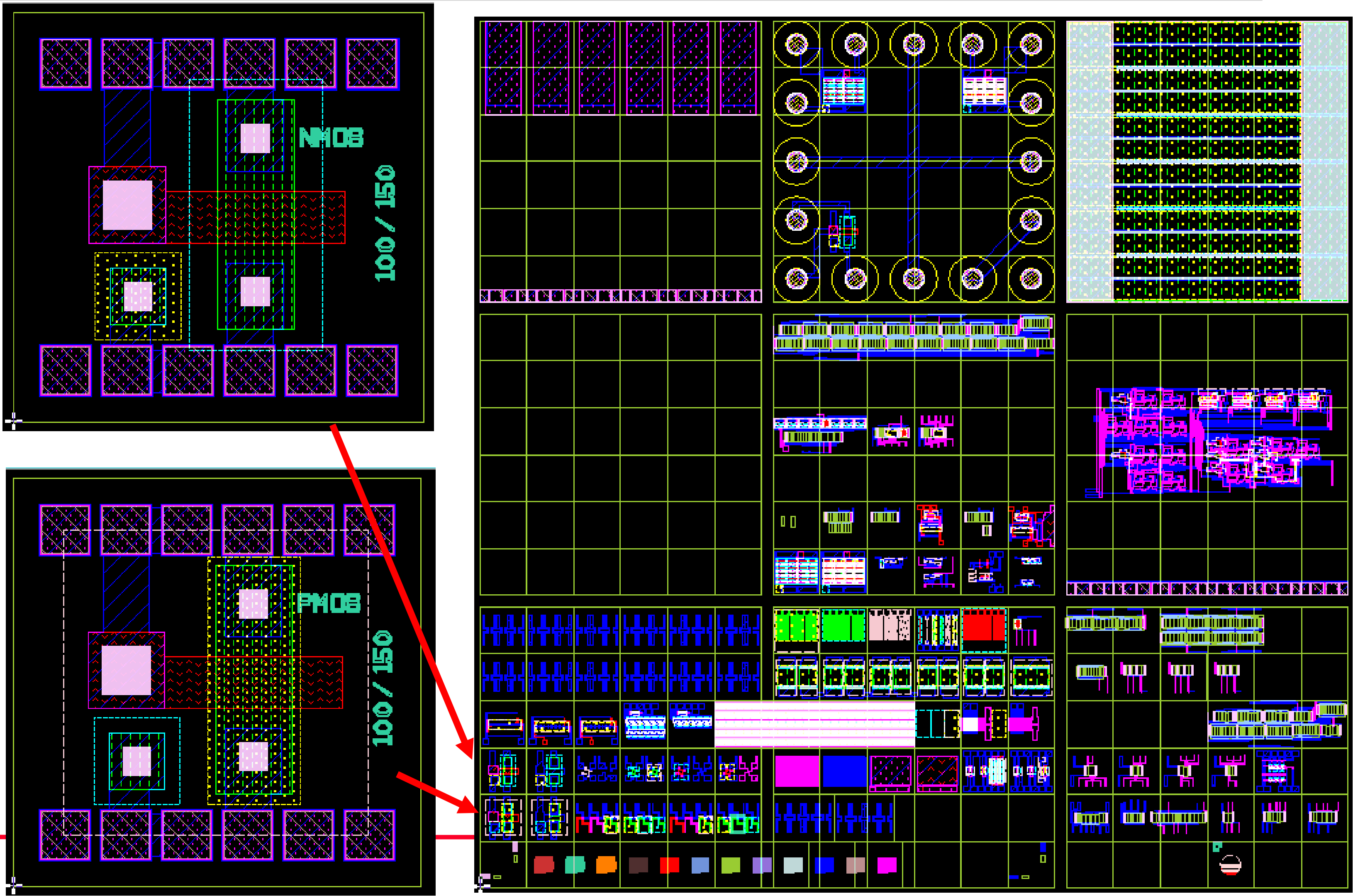
To measure film thickness, focus on the feature that will be measured. The black circle in the center of the view is the area that will be measured. If the black circle is too large, go back and select a different objective lens. Measure the reference wafer again with the higher magnification lens.

Know what the thickness should be and what films (and their thickness) that are under the film to be measured.

JOHN GALT CMOS TEST CHIP

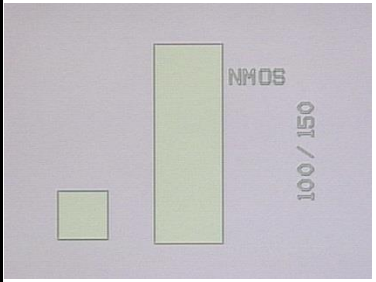
BIG NMOS

BIG PMOS

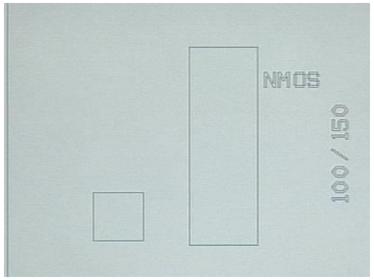


Optical Film Thickness Measurements

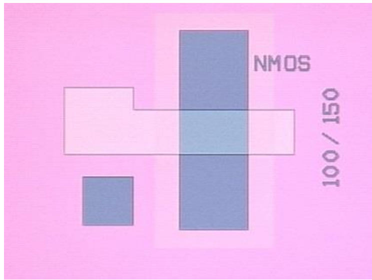
KNOW WHERE TO MEASURE



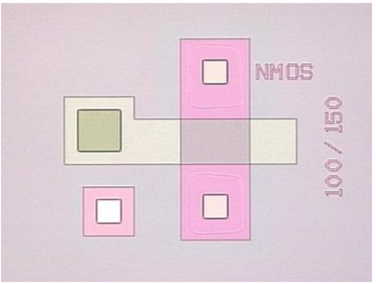
Step 21



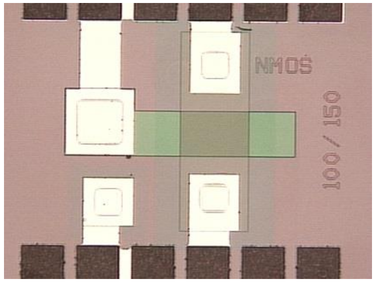
Step 37



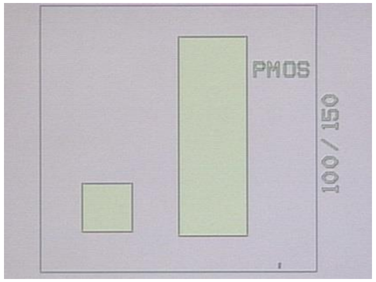
Step 53



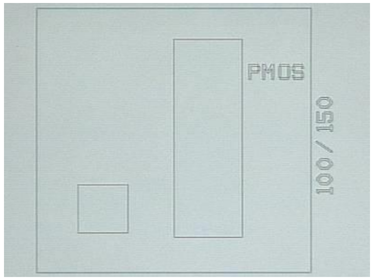
Step 63



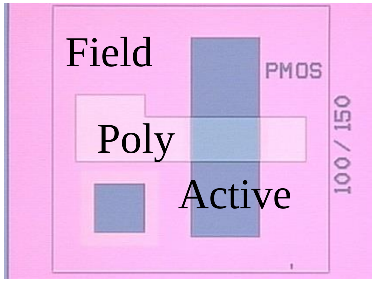
Step 67



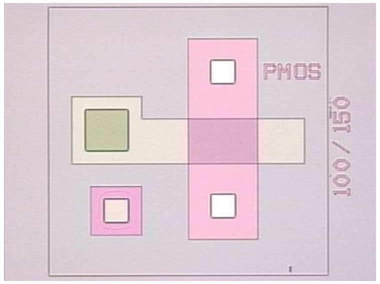
After Well Drive



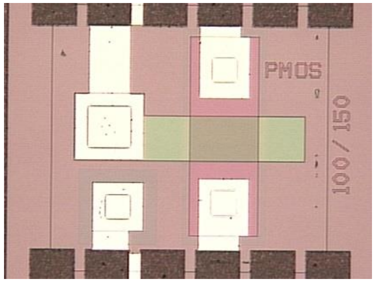
After Poly Deposition



After Poly Etch



After CC Etch



After Metal 1 Etch

SUB-CMOS 150 PROCESS

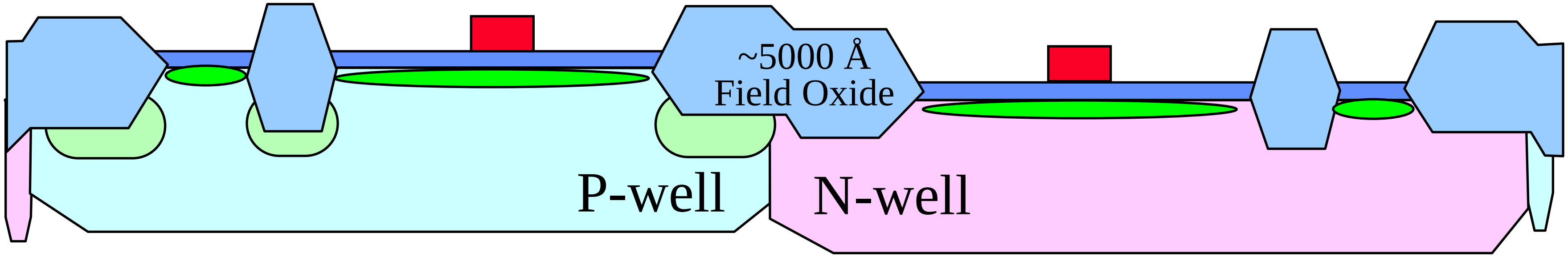
SUB-CMOS Versions 150

1. CL01
2. OX05--- pad oxide, Tube 4
3. CV02- Si3N4-1500Å
4. PH03 –1- JG nwell
5. ET29 – Nitride Etch
6. IM01 – n-well
7. ET07 – Resist Strip
8. CL01
9. OX04 – well oxide, Tube 1
10. ET19 – Hot Phos Si3N4
11. IM01 – p-well
12. OX06 – well drive, Tube 1
13. ET06 - Oxide Etch
14. CL01
15. OX05 – pad oxide, Tube 4
16. CV02 – Si3N4 -1500 Å
17. PH03 – 2 – JG Active
18. ET29 – Nitride Etch
19. ET07 – Resist Strip
20. PH03 - -Pwell Stop
21. IM01- stop
22. ET07 Resist Strip
23. CL01
24. OX04 – field, Tube 1
25. ET19 – Hot Phos Si3N4
26. ET06 – Oxide Etch
27. OX04 – Kooi, Tube 1
28. IM01 – Blanket Vt
29. PH03 – 4-PMOS Vt Adjust
30. IM01 - Vt
31. ET07 – Resist Strip
32. ET06 – Oxide Etch
33. CL01
34. OX06 – gate, Tube 4
35. CV01 – Poly 5000A
36. IM01 - dope poly
37. OX08 – Anneal, Tube 3
38. DE01 – 4 pt Probe
39. PH03-5-JG poly
40. ET08 – Poly Etch
41. ET07 – Resist Strip
42. PH03 – 6 - n-LDD
43. IM01
44. ET07 – Resist Strip
45. PH03 – 7 - p-LDD
46. IM01
47. ET07 – Resist Strip
48. CL01
49. CV03 –TEOS, 5000A
50. ET10 - Spacer Etch
51. PH03 – 8 - N+D/S
52. IM01 – N+D/S
53. ET07 – Resist Strip
54. PH03 – 9 P+ D/S
55. IM01 – P+ D/S
56. ET07 – Resist Strip
57. CL01 Special - No HF Dip
58. OX08 – DS Anneal, Tube 2
59. CV03 – TEOS, 4000A
60. PH03 – 10 CC
61. ET26 - CC Etch
62. ET07 – Resist Strip
63. CL01 Special - Two HF Dips
64. ME01 – Metal 1 Dep
65. PH03 -11- metal
66. ET15 – plasma Etch Al
67. ET07 Resist Strip
68. SI01 - Sinter
69. CV03 – TEOS- 4000Å
70. PH03 – VIA
71. ET26 – Via Etch
72. ET07 – Resist Strop
73. ME01 – Metal 2 Dep
74. PH03- M2
75. ET15 – plasma Etch Al
76. ET07 - Resist Strip
77. SEM1
78. TE01
79. TE02
80. TE03
81. TE04

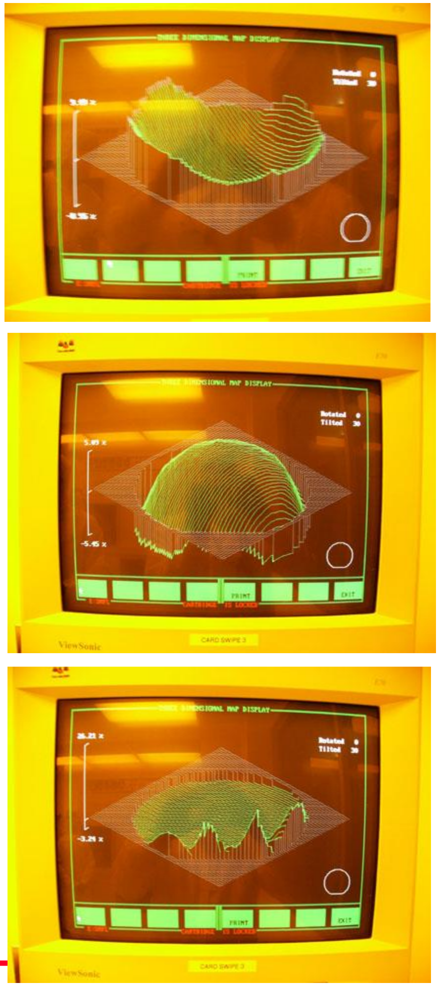
AFTER POLY ETCH AND STRIP RESIST

Poly Target Thickness 5000Å
Gate Oxide Target 150Å
Field Oxide Target 5000Å

Do lot history to get exact thickness values of underlying layers



SPECTROMAP



Mean
Std Deviation
Min
Max
No of Points

TENCORE SPECTROMAP

The Spectromap illuminates the sample with white light and collects the reflected light intensity versus wavelength. The raw data is compared to theoretical simulated intensity versus wavelength. The best fit is determined and the film thickness is determined. This tool can be programed to make measurements at many locations on the wafer and provide statistical information about the measurements such as mean, standard deviation, minimum, and maximum. The programmed locations are not precise enough to measure inside small features on the wafer and no alignment mechanism is available for aligning the wafer with the x and y axis of the stage. Best results are obtained on uniformly coated blank wafers. Multi-layer films can be measured if the underlying film properties (index and thickness) are known.

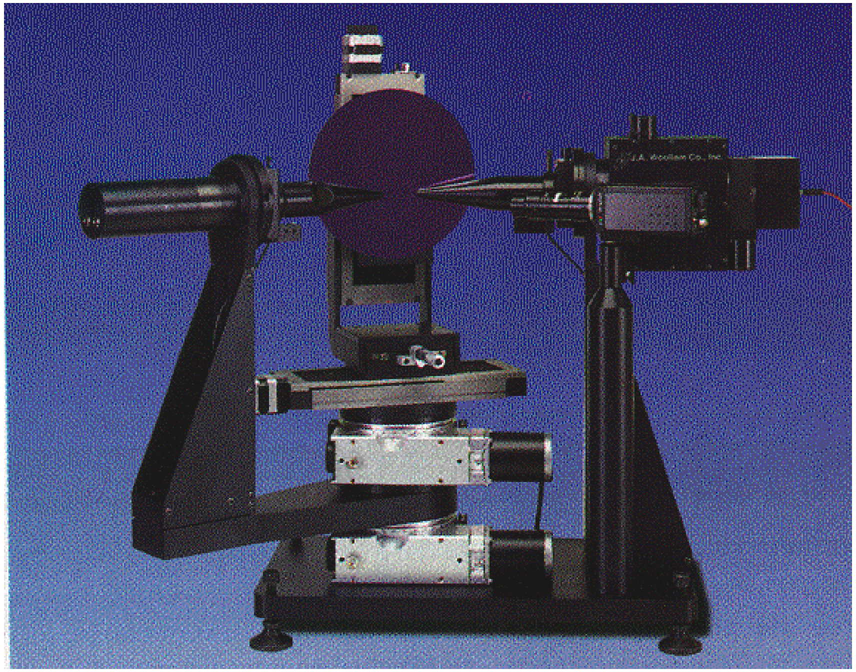
TENCORE FILM THICKNESS FT350

TENCORE FT350

The FT350 is an optical film thickness measurement tool that is very similar to the Tencore Spectromap. However, it does have accurate programmable stage positioning that provides for precise measurement in preprogramed locations on a patterned wafer.

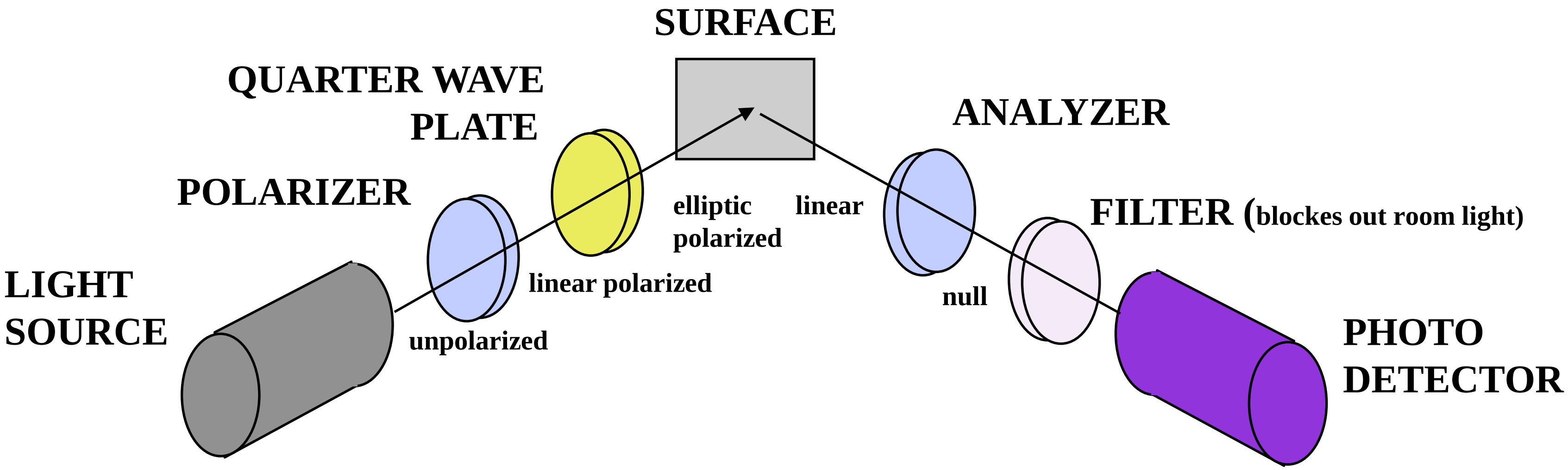
ELLIPSOMETER

Rudolph Ellipsometer



Variable Angle Spectroscopic Ellipsometer

ELLIPSOMETRY



The light source is unpolarized, upon traversing the polarizer the light becomes linearly polarized. Turning the polarizer adjusts the azimuth of linearly polarized light with respect to the fast axis of the quarter-wave plate in such a way as to vary the ellipticity of the light incident on the surface. This ellipticity is adjusted until it is just cancelled by the ellipticity introduced by the reflection. The result is again linearly polarized light. The analyzer polarizing prism is rotated until its axis of polarization is perpendicular to the azimuth of the linearly polarized light, creating a null. Thus no light is transmitted to the dedector. The common technique is to fix the quarter-wave plate with fast axis at 45 ° to the plane of incidence, and to alternately move the polarizer and analyzer, continuously reducing the transmitted light until a null is reached. The relevant light parameters Δ and Ψ are readily calculated from the instrument parameters (P, polarizer angle, Q, quarter-wave plate angle, and A, analyzer angle. Values for film thickness and index of refraction are found. Thickness values that correspond to these parameters repeat with multiples of the light source wavelength so the approximate thickness must be known.

REFERENCES

1. "Modeling of Light Absorption in Solid State Imagers," Robert Philbrick, MS Thesis in Electrical Engineering at RIT, Jan. 1990.
2. Next

HOMEWORK

1. Calculate the reflection…..