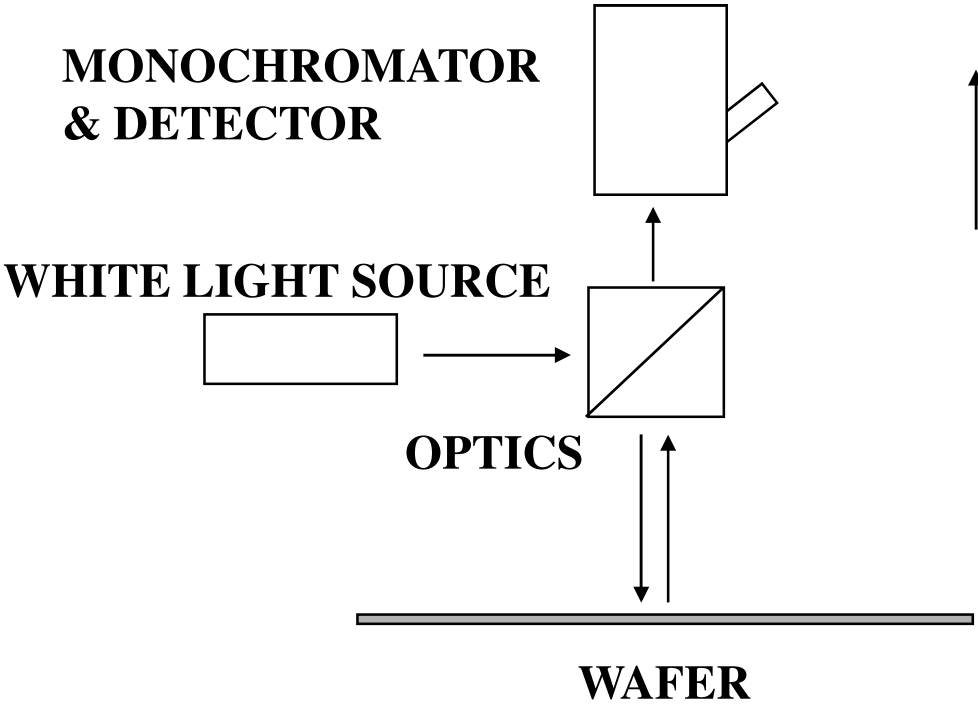
HOW THE NANOSPEC WORKS

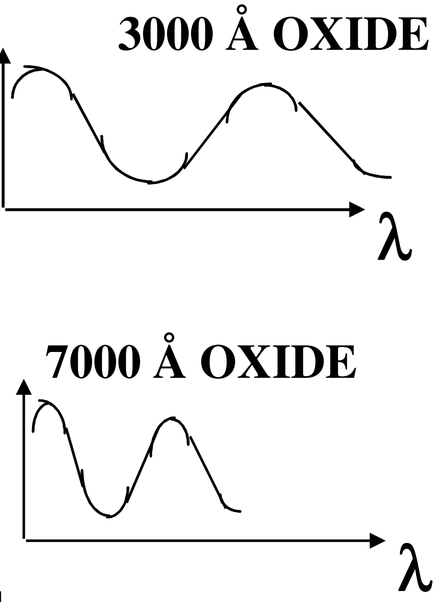
Dr. Lynn Fuller

The nanospec 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 and 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.

NANOSPEC - REFLECTANCE SPECTROMETER

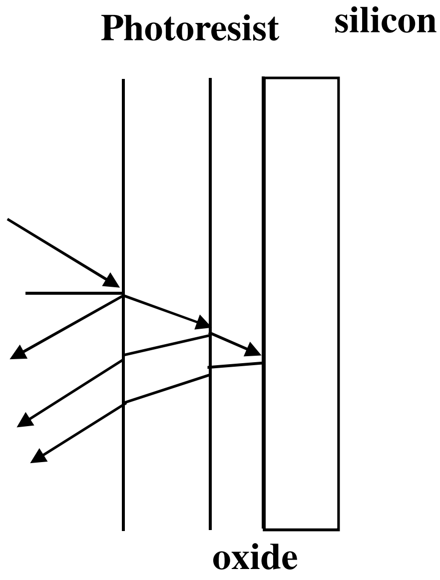
INCIDENT WHITE LIGHT, THE INTENSITY OF THE REFLECTED LIGHT IS MEASURED VS WAVELENGTH





Oxide on Silicon	400-30,000 Å
Nitride	400-30,000
Neg Resist	500-40,000
Poly on 300-1200 Ox	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

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

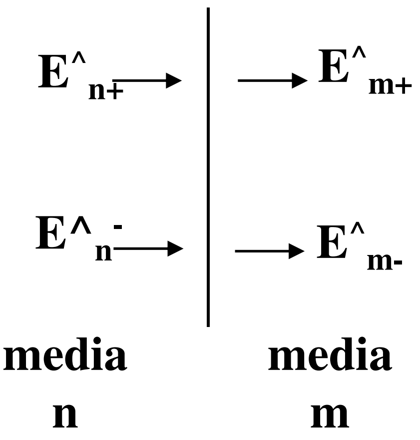
$I = c\varepsilon_o E^2 / 2$ or $I = (c / 2 \mu_o)B^2$

where c is speed of light 3e8m/s
ε_o is permitivitty, μ_o is permeability

REFLECTION CALCULATIONS (CONT.)

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

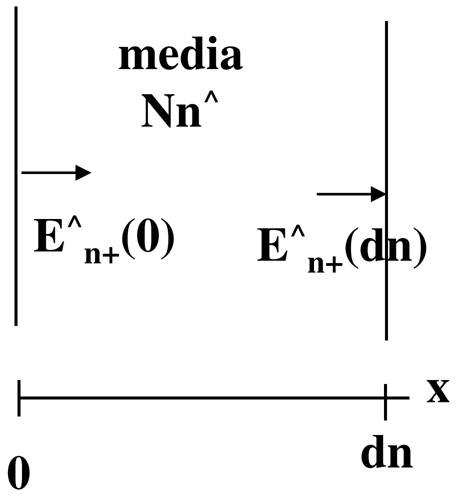
tn = (2Nn)/(Nn+Nm)



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

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

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



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

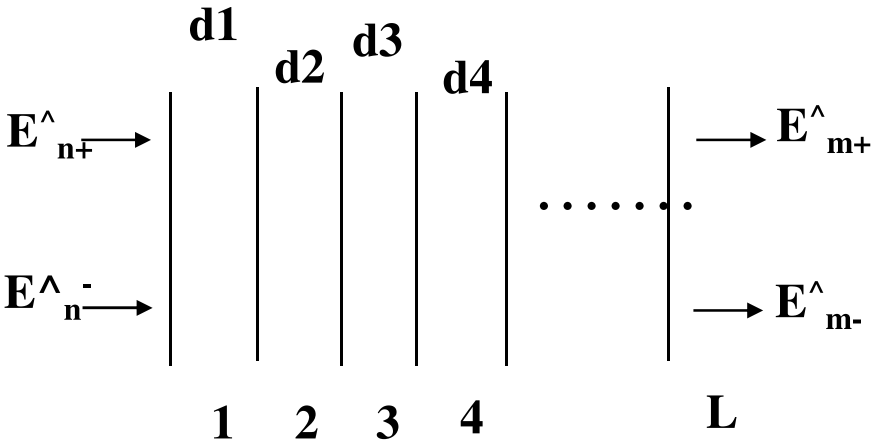
where $\delta n = 2\,\pi\, Nn^{\wedge}\, dn / \lambda$

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

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

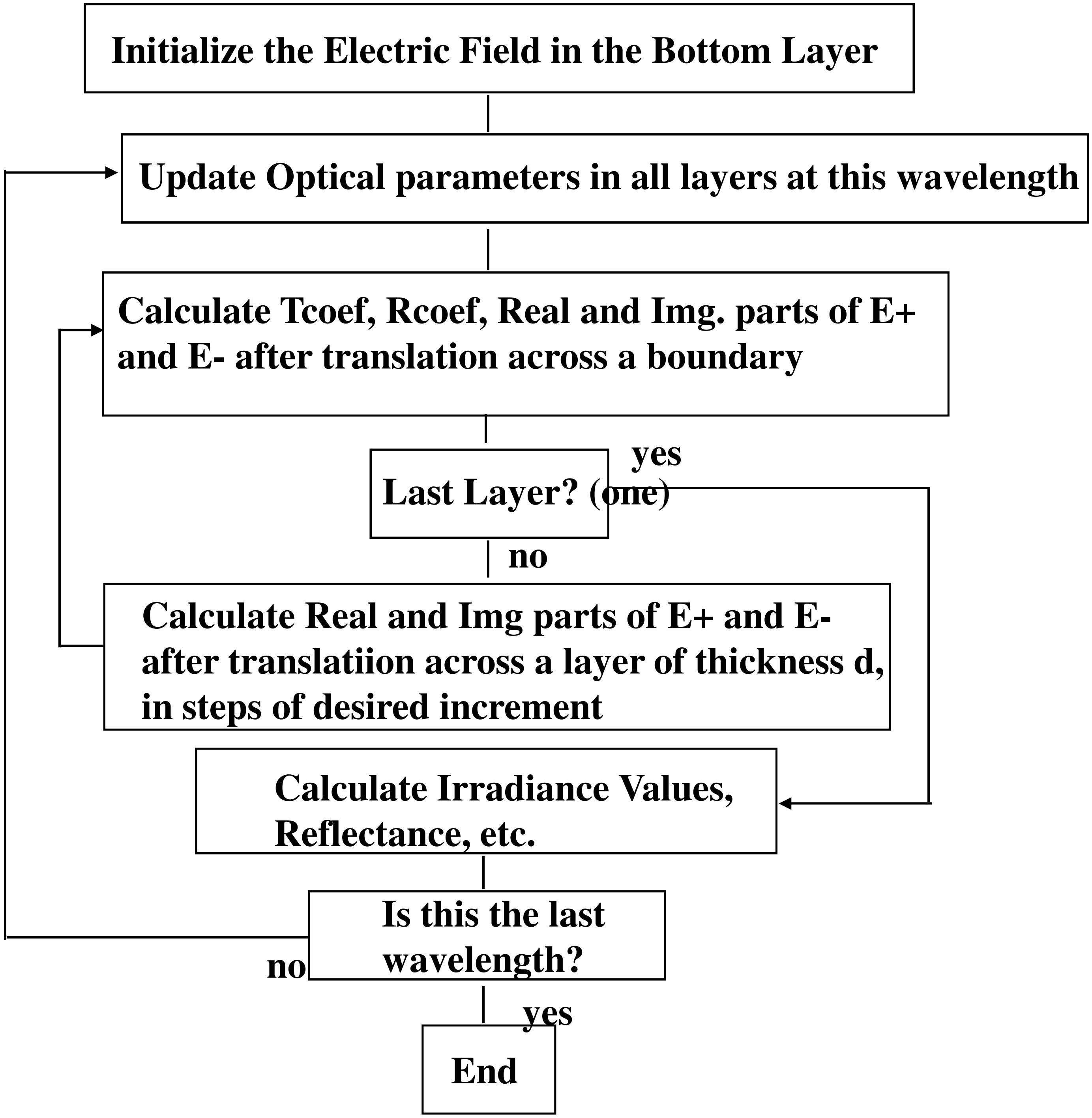
REFLECTION CALCULATIONS

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.

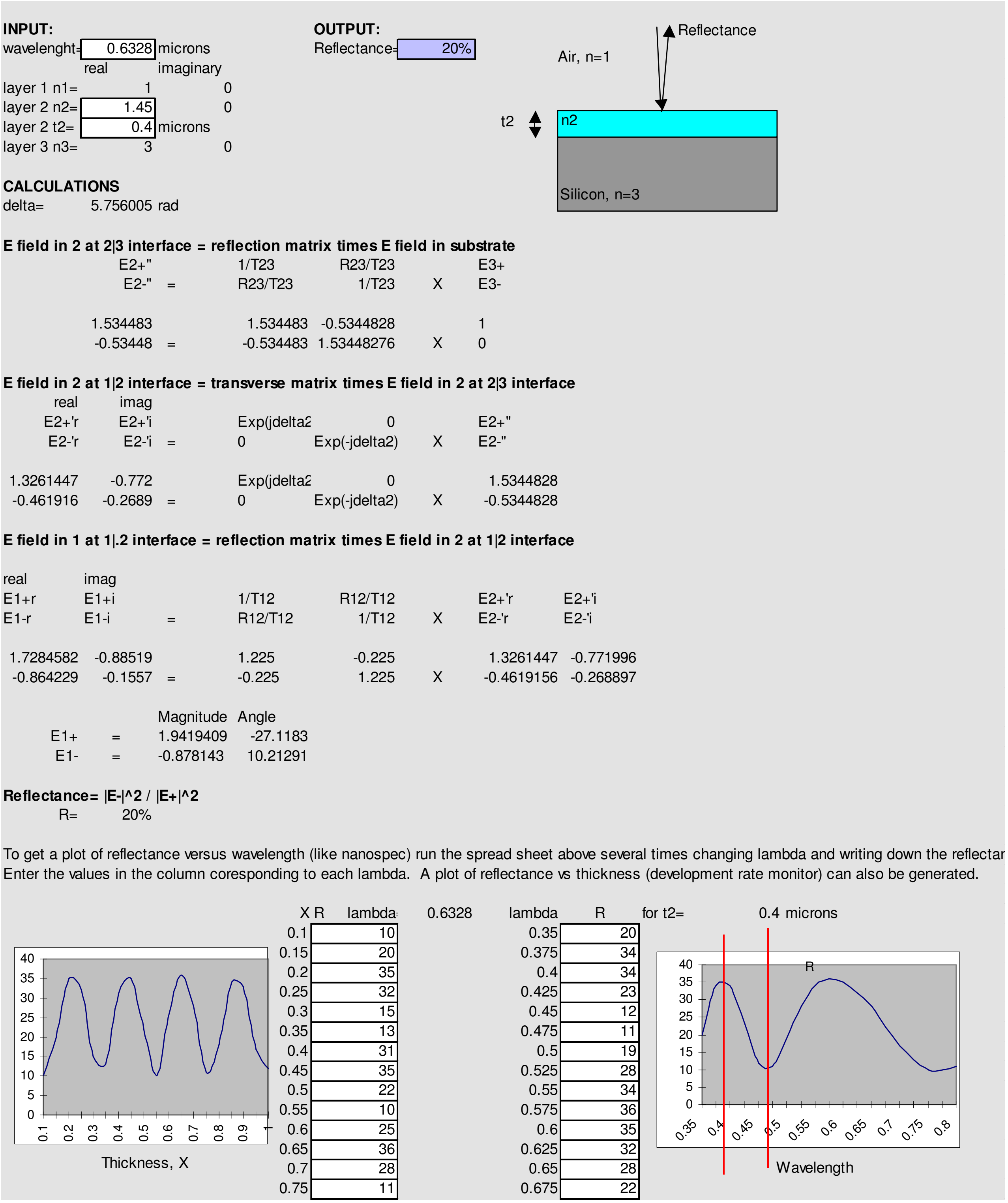
Is this the last wavelength?

no

yes

End

4000 Å Oxide on Silicon



INPUT:

wavelenght=	0.6328	microns	
	real	imaginary	
layer 1 n1=	1	0	
layer 2 n2=	1.45	0	
layer 2 t2=	0.4	microns	
layer 3 n3=	3	0	

OUTPUT:
Reflectance= 20%

CALCULATIONS
delta= 5.756005 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-
1.534483		1.534483	-0.5344828		1
-0.53448	=	-0.534483	1.53448276	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-"
1.3261447	-0.772		Exp(jdelta2	0		1.5344828
-0.461916	-0.2689	=	0	Exp(-jdelta2)	X	-0.5344828

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
1.7284582	-0.88519		1.225	-0.225		1.3261447	-0.771996
-0.864229	-0.1557	=	-0.225	1.225	X	-0.4619156	-0.268897

		Magnitude	Angle
E1+	=	1.9419409	-27.1183
E1-	=	-0.878143	10.21291

Reflectance= |E-|^2 / |E+|^2
R= 20%

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.

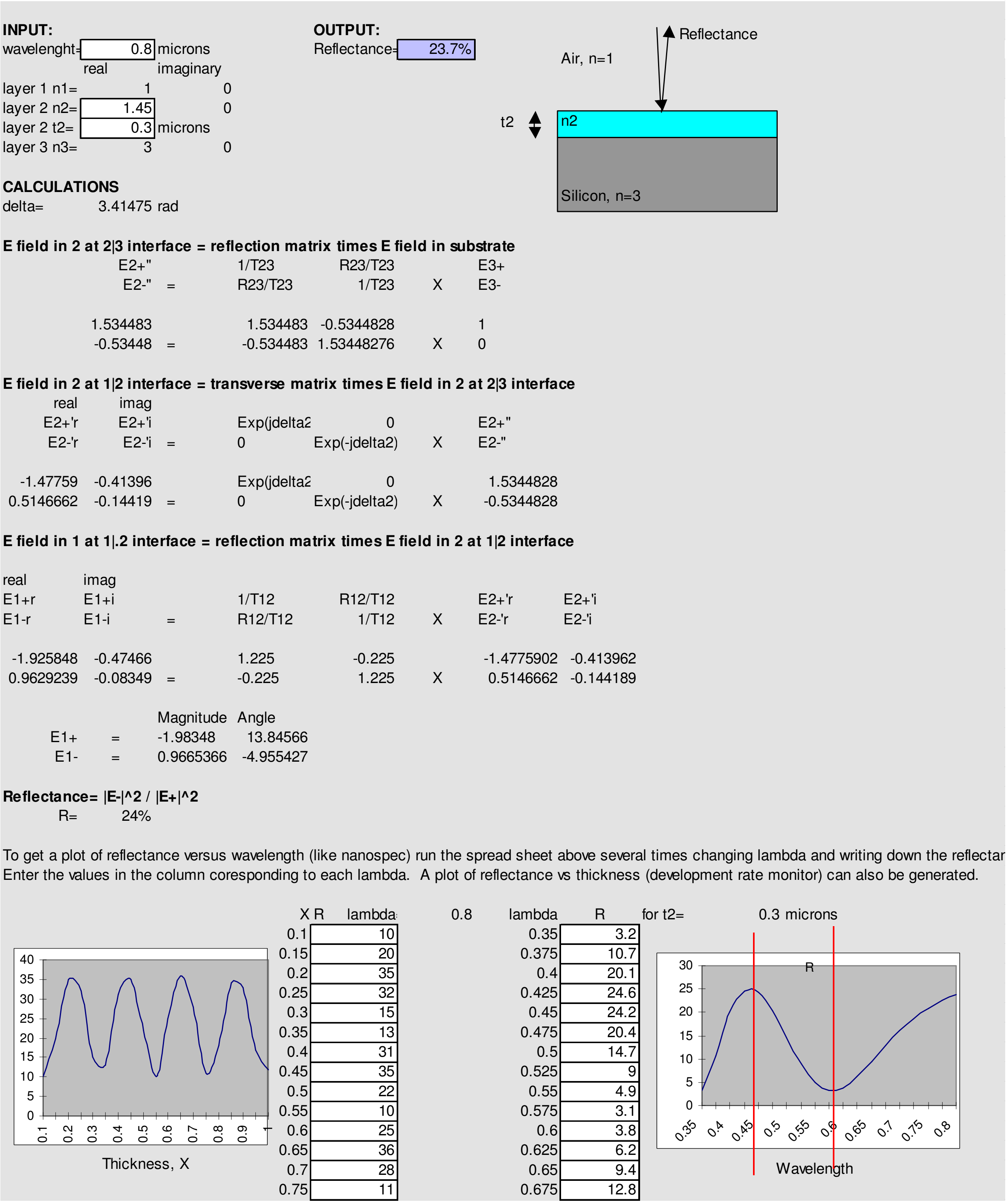
lambda 0.6328

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

3000 Å Oxide on Silicon



INPUT:
wavelenght= 0.8 microns

	real	imaginary
layer 1 n1=	1	0
layer 2 n2=	1.45	0
layer 2 t2=	0.3	microns
layer 3 n3=	3	0

OUTPUT:
Reflectance= 23.7%

CALCULATIONS
delta= 3.41475 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-

1.534483   1.534483 -0.5344828   1
-0.53448 = -0.534483 1.53448276 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-"

-1.47759 -0.41396   Exp(jdelta2   0   1.5344828
0.5146662 -0.14419 = 0   Exp(-jdelta2) X -0.5344828

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

-1.925848 -0.47466   1.225   -0.225   -1.4775902 -0.413962
0.9629239 -0.08349 = -0.225   1.225 X 0.5146662 -0.144189

		Magnitude	Angle
E1+	=	-1.98348	13.84566
E1-	=	0.9665366	-4.955427

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

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.

X	R lambda: 0.8
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

lambda	R for t2= 0.3 microns
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

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Rochester Institute of Technology

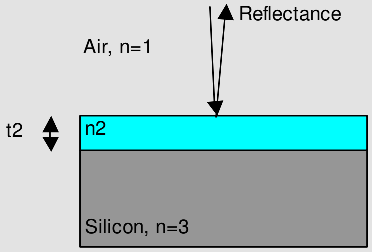
2000 Å Oxide on Silicon

INPUT:

wavelenght=	0.55	microns
	real	imaginary
layer 1 n1=	1	0
layer 2 n2=	1.45	0
layer 2 t2=	0.2	microns
layer 3 n3=	3	0

OUTPUT:

Reflectance= 24.5%



CALCULATIONS

delta= 3.311273 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-
1.534483		1.534483	-0.5344828		1
-0.53448	=	-0.534483	1.53448276	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-"
-1.512446	-0.25912		Exp(jdelta2	0		1.5344828
0.526807	-0.09026	=	0	Exp(-jdelta2)	X	-0.5344828

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

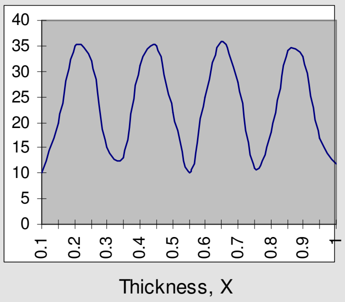
real	imag						
E1+r	E1+i		1/T12	R12/T12		E2+'r	E2+'i
E1-r	E1-i	=	R12/T12	1/T12	X	E2-'r	E2-'i
-1.971278	-0.29712		1.225	-0.225		-1.5124458	-0.259124
0.9856388	-0.05226	=	-0.225	1.225	X	0.526807	-0.090257

		Magnitude	Angle
E1+	=	-1.993543	8.571327
E1-	=	0.9870234	-3.035147

Reflectance= |E-|^2 / |E+|^2

R= 25%

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.

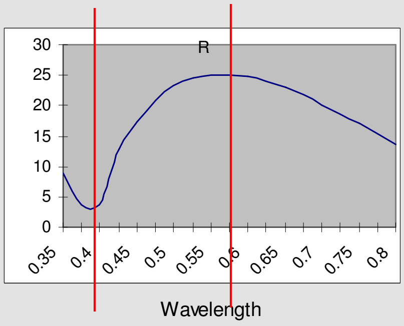


lambda= 0.55

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= 0.2 microns

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



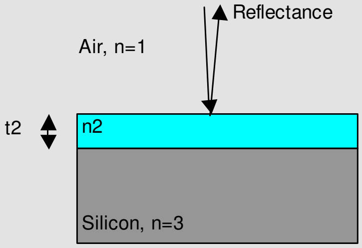
1000 Å Oxide on Silicon

INPUT:

	real	imaginary
wavelenght=	0.8	microns
layer 1 n1=	1	0
layer 2 n2=	1.45	0
layer 2 t2=	0.1	microns
layer 3 n3=	3	0

OUTPUT:

Reflectance= 7.8%



CALCULATIONS

delta= 1.13825 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-
1.534483		1.534483	-0.5344828		1
-0.53448	=	-0.534483	1.53448276	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-"
0.6432306	1.393159		Exp(jdelta2	0		1.5344828
-0.224047	0.485258	=	0	Exp(-jdelta2)	X	-0.5344828

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

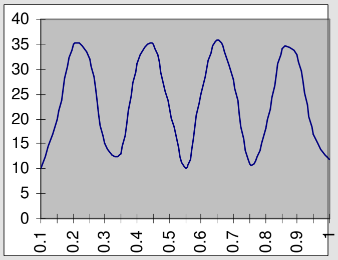
real	imag						
E1+r	E1+i		1/T12	R12/T12		E2+'r	E2+'i
E1-r	E1-i	=	R12/T12	1/T12	X	E2-'r	E2-'i
0.8383679	1.597437		1.225	-0.225		0.6432306	1.3931589
-0.419184	0.28098	=	-0.225	1.225	X	-0.2240466	0.4852576

		Magnitude	Angle
E1+	=	1.804069	62.3086
E1-	=	-0.504643	-33.83403

Reflectance= |E-|^2 / |E+|^2

R= 8%

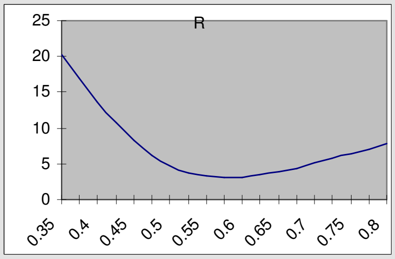
To get a plot of reflectance versus wavelength (like nanospec) run the spread sheet above several times changing lambda and writing down the reflectar
Enter the values in the column coresponding to each lambda. A plot of reflectance vs thickness (development rate monitor) can also be generated.



Thickness, X

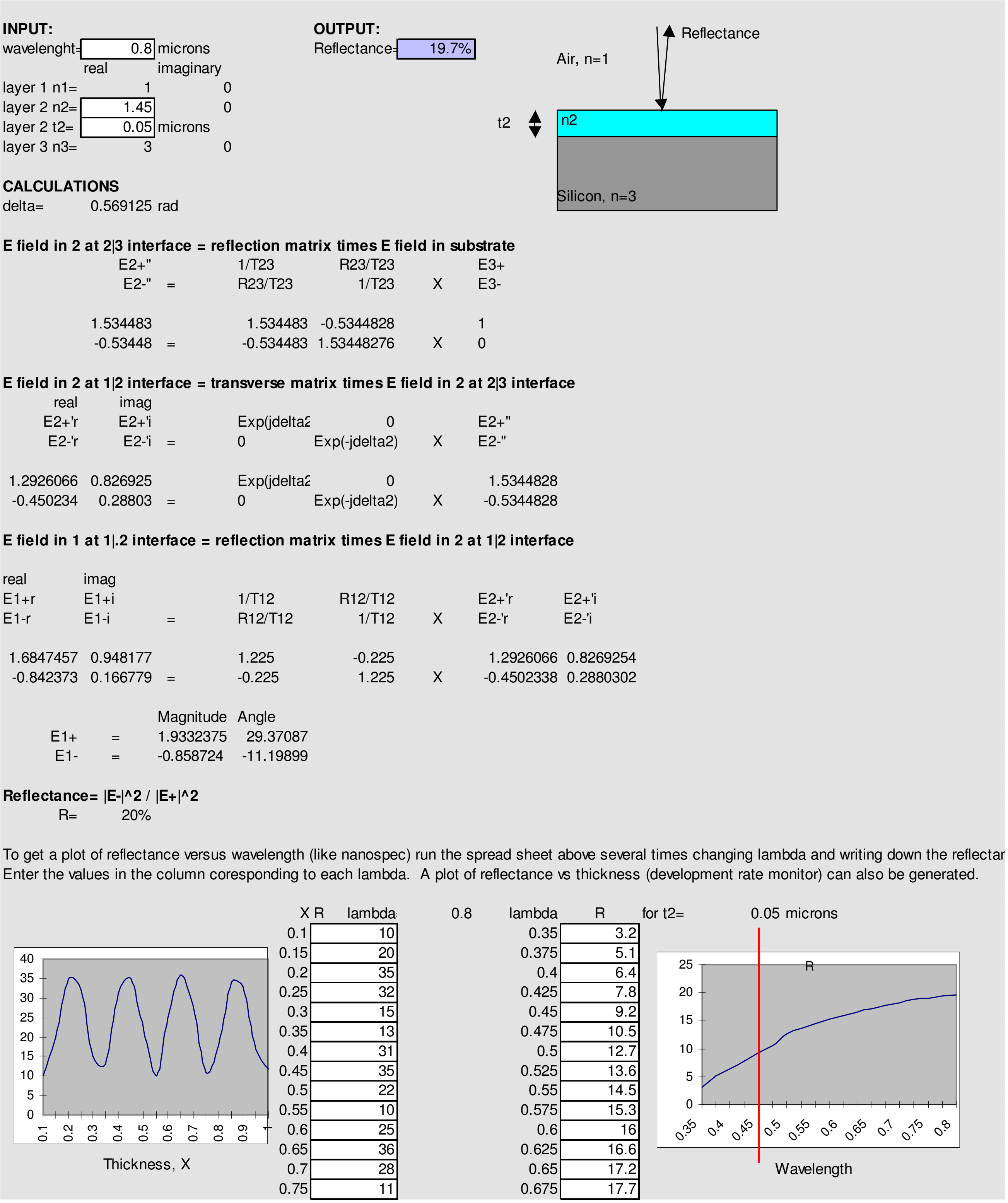
X	R lambda= 0.8
0.1	10
0.15	20
0.2	35
0.25	32
0.3	15
0.35	13
0.4	31
0.45	35
0.5	22
0.55	10
0.6	25
0.65	36
0.7	28
0.75	11

lambda	R for t2= 0.1 microns
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



Wavelength

500 Å Oxide on Silicon



INPUT:

wavelenght=	0.8	microns
	real	imaginary
layer 1 n1=	1	0
layer 2 n2=	1.45	0
layer 2 t2=	0.05	microns
layer 3 n3=	3	0

OUTPUT:

Reflectance= 19.7%

CALCULATIONS

delta= 0.569125 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-
1.534483		1.534483	-0.5344828		1
-0.53448	=	-0.534483	1.53448276	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-"
1.2926066	0.826925		Exp(jdelta2	0		1.5344828
-0.450234	0.28803	=	0	Exp(-jdelta2)	X	-0.5344828

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
1.6847457	0.948177		1.225	-0.225		1.2926066	0.8269254
-0.842373	0.166779	=	-0.225	1.225	X	-0.4502338	0.2880302

		Magnitude	Angle
E1+	=	1.9332375	29.37087
E1-	=	-0.858724	-11.19899

Reflectance= |E-|^2 / |E+|^2

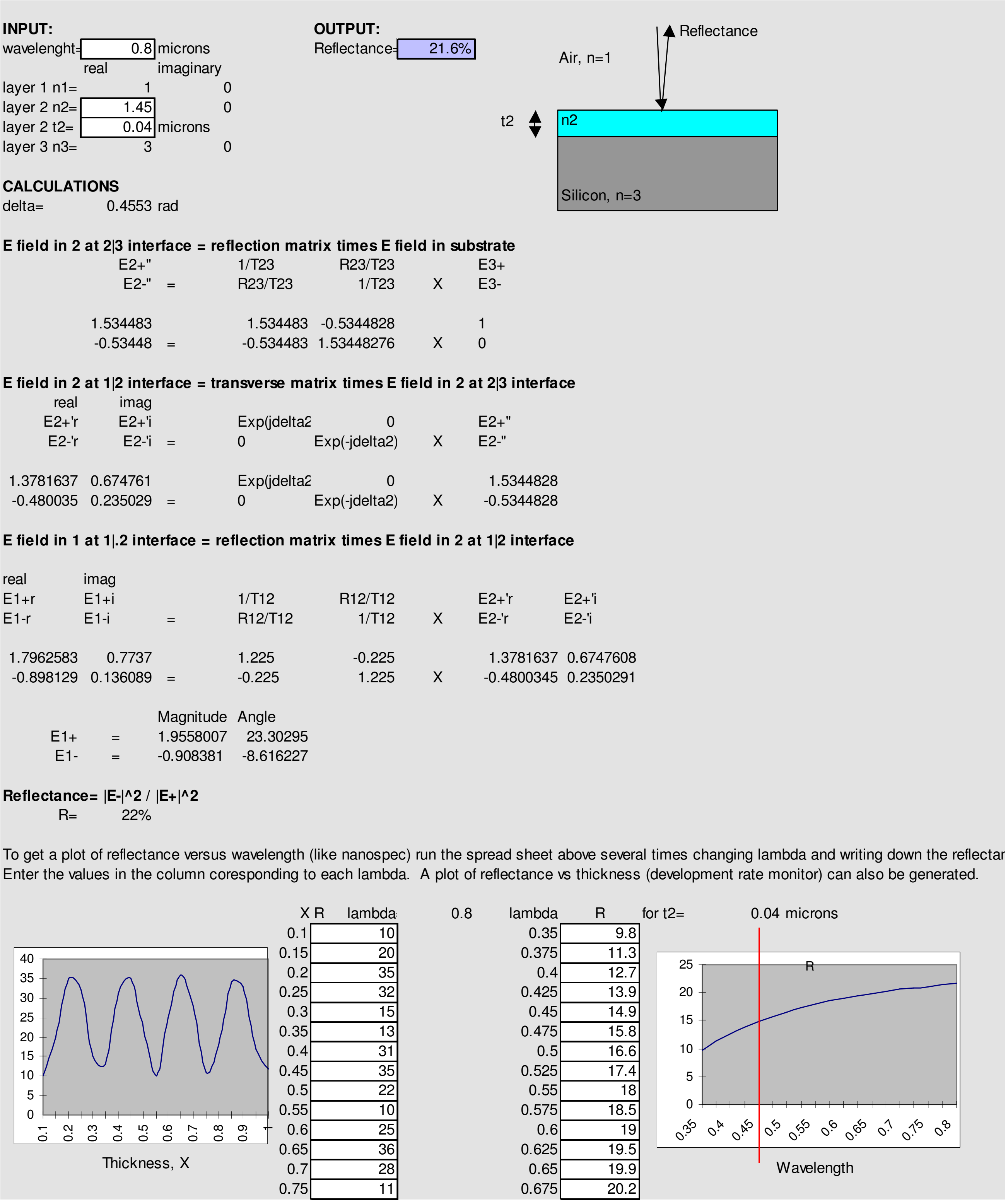
R= 20%

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.

X	R	lambda	0.8
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		

lambda	R	for t2=	0.05 microns
0.35	3.2		
0.375	5.1		
0.4	6.4		
0.425	7.8		
0.45	9.2		
0.475	10.5		
0.5	12.7		
0.525	13.6		
0.55	14.5		
0.575	15.3		
0.6	16		
0.625	16.6		
0.65	17.2		
0.675	17.7		

400 Å Oxide on Silicon



INPUT:

wavelenght=	0.8	microns	
	real	imaginary	
layer 1 n1=	1	0	
layer 2 n2=	1.45	0	
layer 2 t2=	0.04	microns	
layer 3 n3=	3	0	

OUTPUT:

Reflectance= 21.6%

CALCULATIONS

delta= 0.4553 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-
1.534483		1.534483	-0.5344828		1
-0.53448	=	-0.534483	1.53448276	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-"
1.3781637	0.674761		Exp(jdelta2	0		1.5344828
-0.480035	0.235029	=	0	Exp(-jdelta2)	X	-0.5344828

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
1.7962583	0.7737		1.225	-0.225		1.3781637	0.6747608
-0.898129	0.136089	=	-0.225	1.225	X	-0.4800345	0.2350291

		Magnitude	Angle
E1+	=	1.9558007	23.30295
E1-	=	-0.908381	-8.616227

Reflectance= |E-|^2 / |E+|^2

R= 22%

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= 0.8

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= 0.04 microns

lambda	R
0.35	9.8
0.375	11.3
0.4	12.7
0.425	13.9
0.45	14.9
0.475	15.8
0.5	16.6
0.525	17.4
0.55	18
0.575	18.5
0.6	19
0.625	19.5
0.65	19.9
0.675	20.2

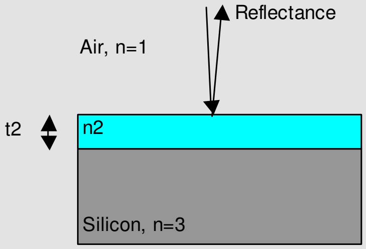
300 Å Oxide on Silicon

INPUT:

wavelenght=	0.8	microns	
	real	imaginary	
layer 1 n1=	1	0	
layer 2 n2=	1.45	0	
layer 2 t2=	0.03	microns	
layer 3 n3=	3	0	

OUTPUT:

Reflectance= 23.0%



CALCULATIONS

delta= 0.341475 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-
1.534483		1.534483	-0.5344828		1
-0.53448	=	-0.534483	1.53448276	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-"
1.4458844	0.513863		Exp(jdelta2	0		1.5344828
-0.503623	0.178986	=	0	Exp(-jdelta2)	X	-0.5344828

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

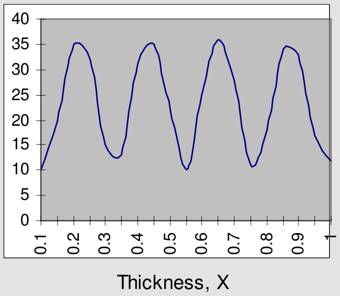
real	imag						
E1+r	E1+i		1/T12	R12/T12		E2+'r	E2+'i
E1-r	E1-i	=	R12/T12	1/T12	X	E2-'r	E2-'i
1.8845235	0.589211		1.225	-0.225		1.4458844	0.5138634
-0.942262	0.103639	=	-0.225	1.225	X	-0.5036227	0.1789861

		Magnitude	Angle
E1+	=	1.9744868	17.36226
E1-	=	-0.947944	-6.276697

Reflectance= |E-|^2 / |E+|^2

R= 23%

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= 0.8

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= 0.03 microns

lambda	R
0.35	15.5
0.375	16.6
0.4	17.6
0.425	18.4
0.45	19
0.475	19.6
0.5	20.1
0.525	20.6
0.55	20.9
0.575	21.3
0.6	21.6
0.625	21.8
0.65	22.1
0.675	22.3