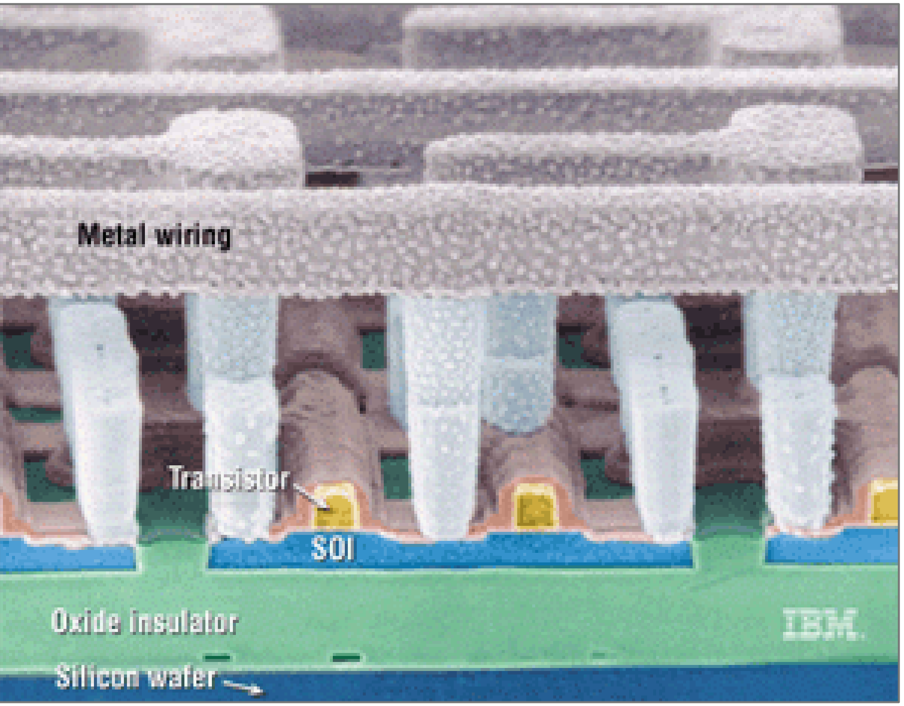
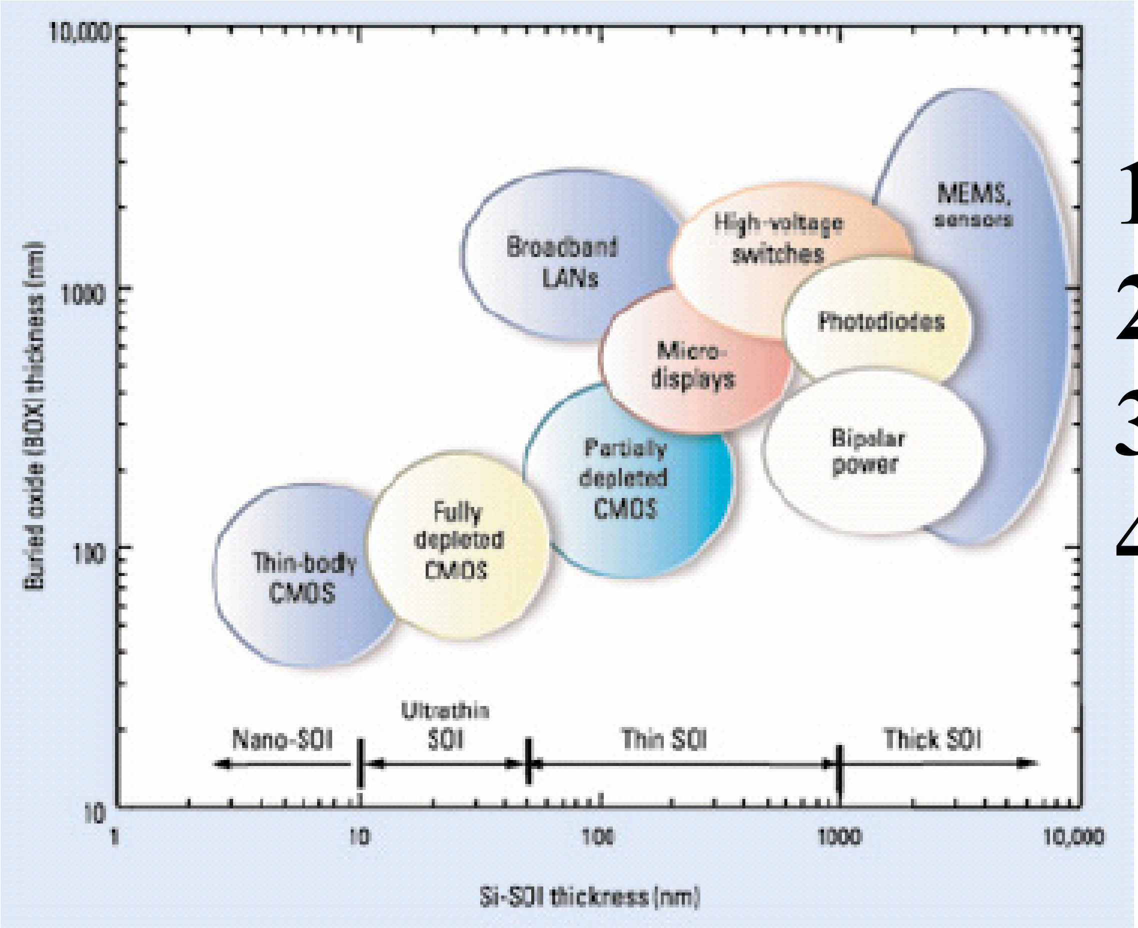
IRSE300



Metrology of:

- **SOI**
- **SiGe / SGOI**
- **Strained Si**
- **Bipolar and others**

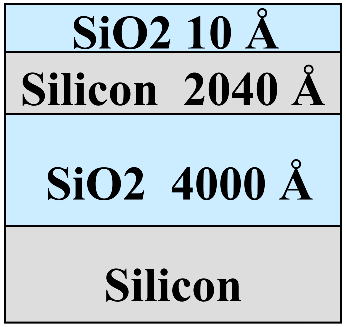
1) SOI



1. SOI is relevant to a wide range of applications, each taking advantage of a different thickness of the silicon layer. (Source: SiGen)

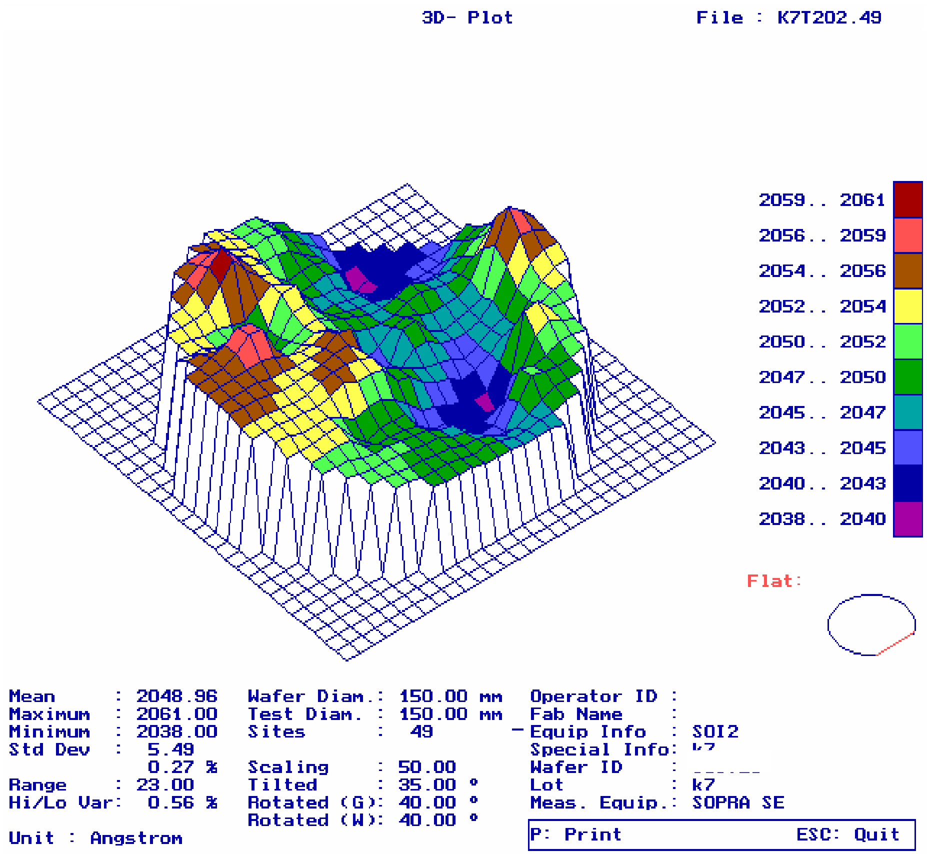
1. Thick SOI
2. Thin SOI
3. Ultra thin SOI
4. SOI for MEMS

Thick SOI

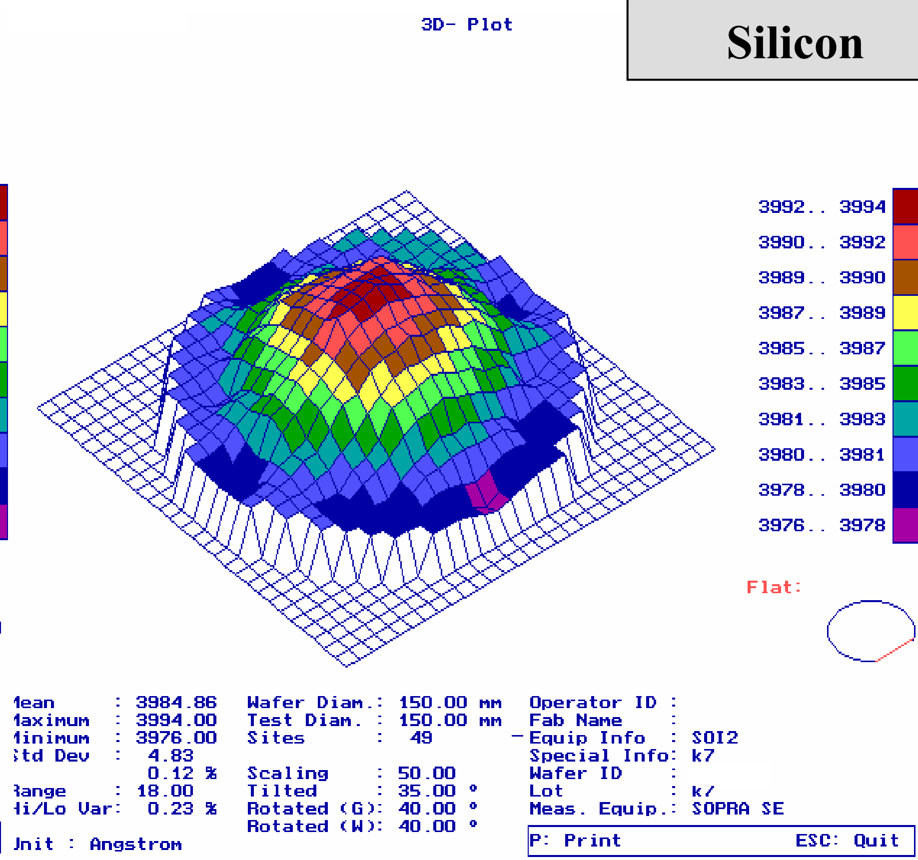


Thickness mapping on 49 points in CCD mode

Silicon

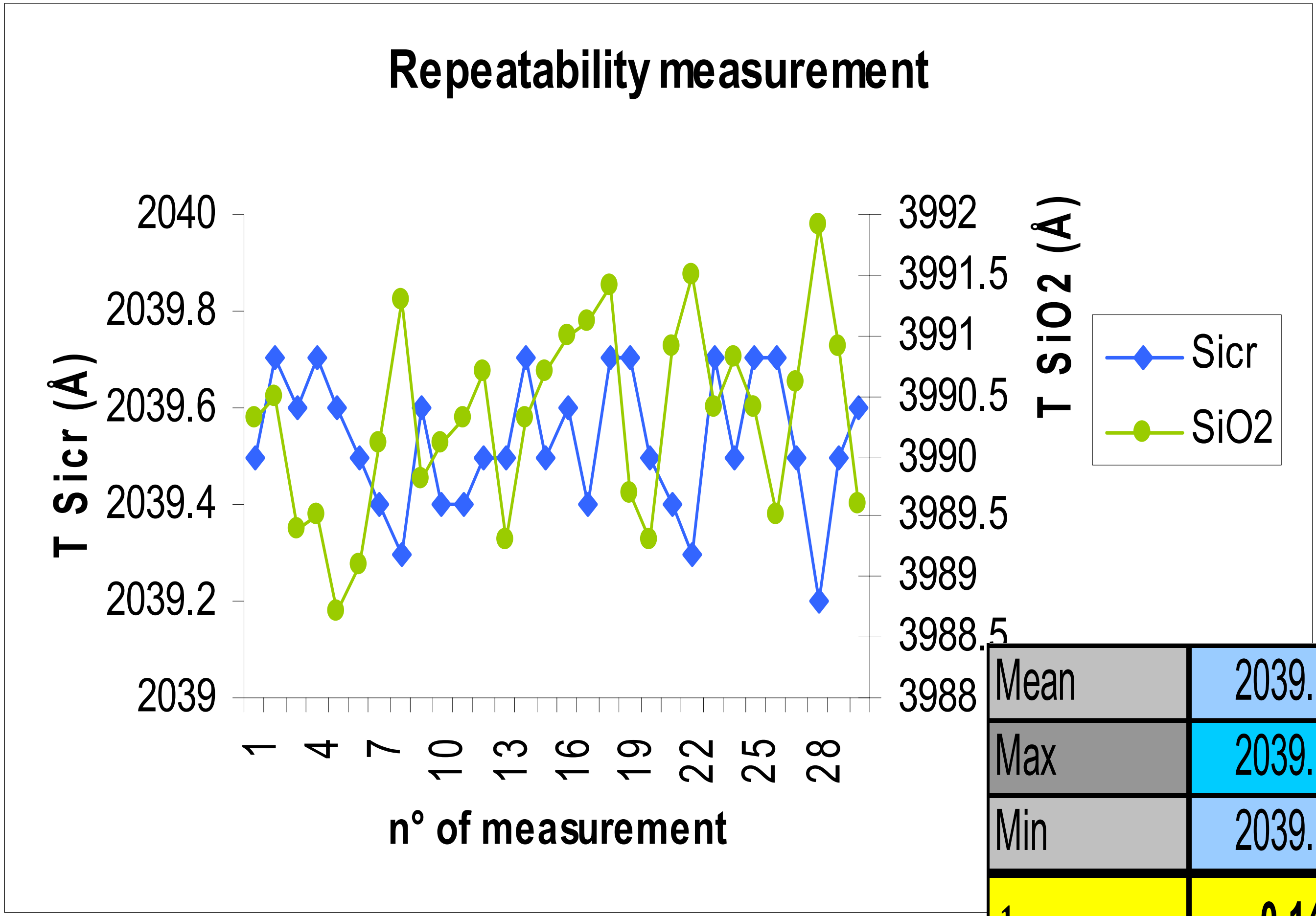


SiO_2



Thick SOI : Repeatability

30 Static measurements in CCD mode

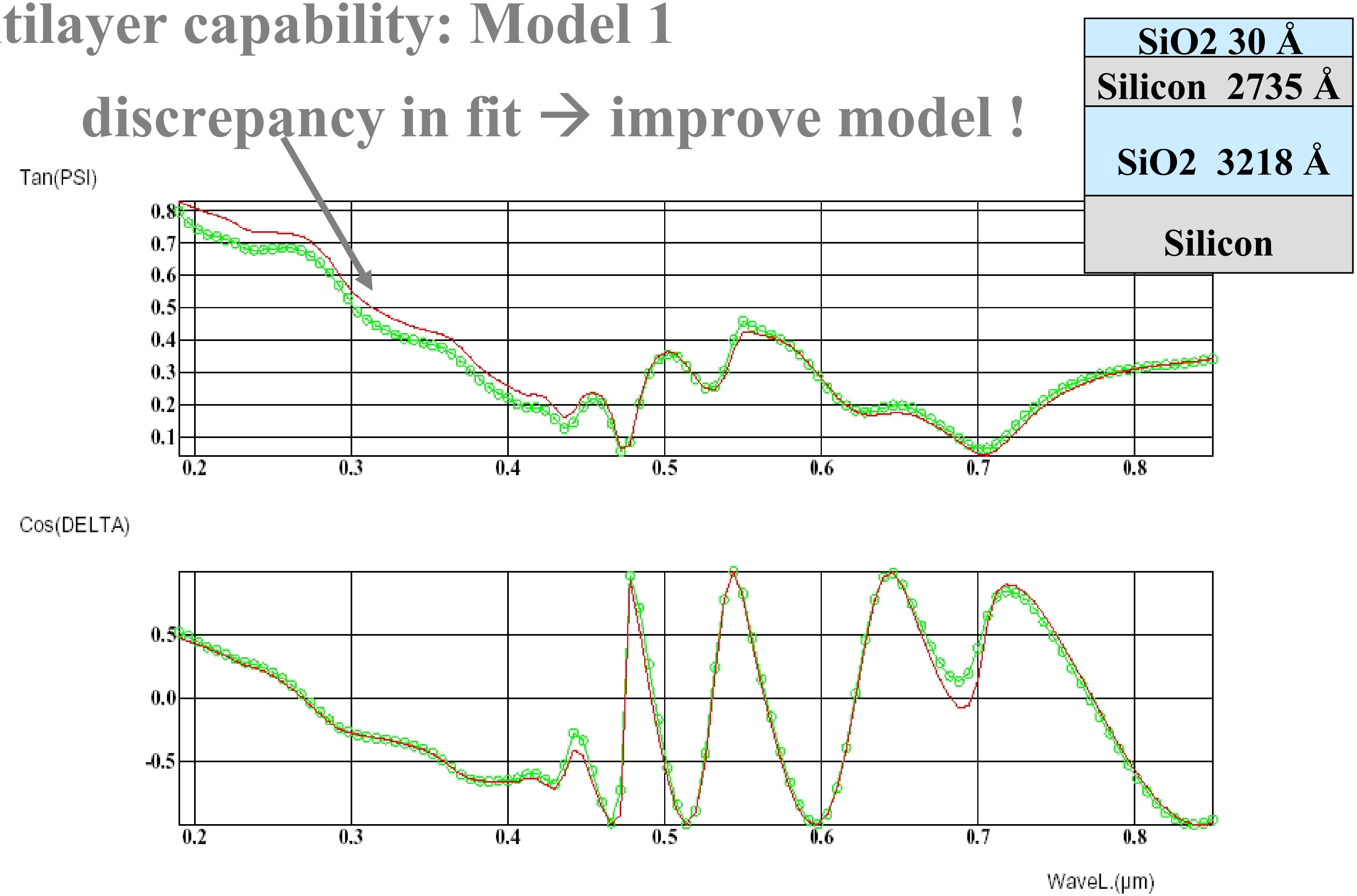


Mean	2039.53	Å	3990.30	Å
Max	2039.70	Å	3991.90	Å
Min	2039.20	Å	3988.70	Å
1 σ	**0.14**	**Å**	**0.78**	**Å**

Sensitivity to Roughness

Multilayer capability: Model 1

discrepancy in fit → improve model !

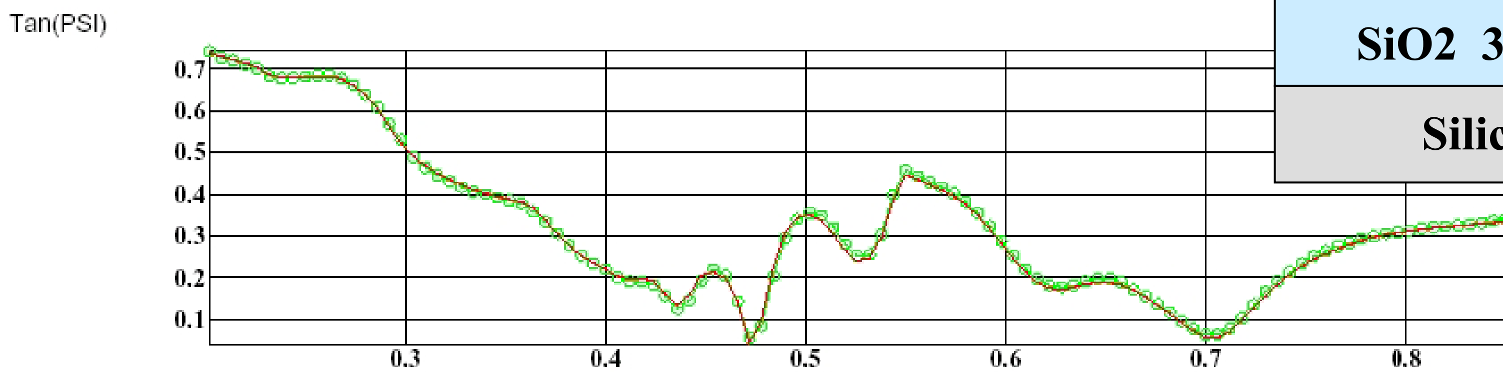


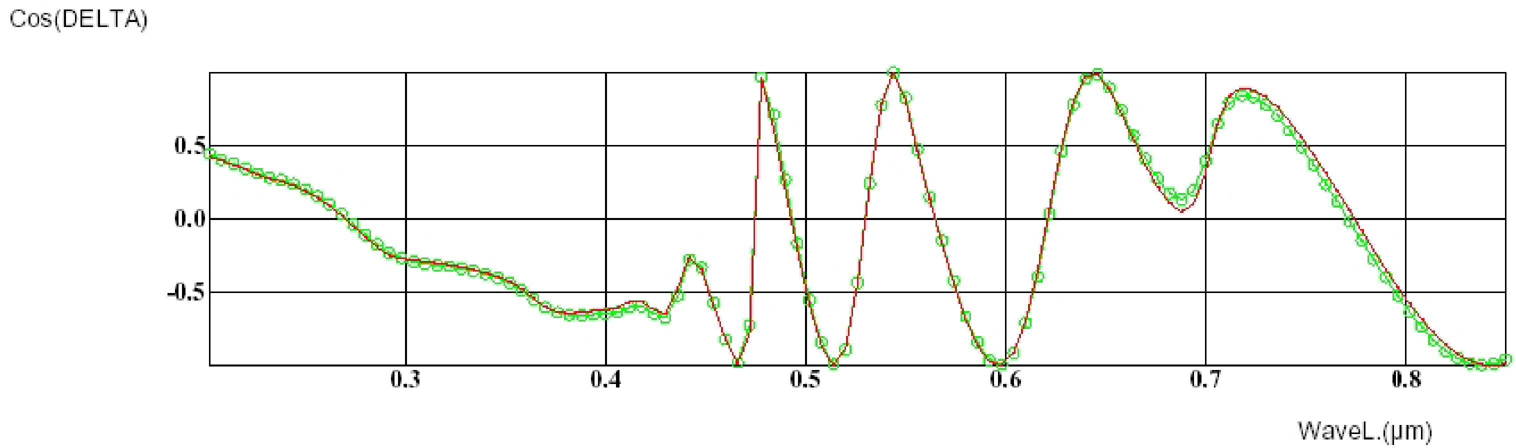
Sensitivity to Roughness

Multilayer capability: Model 2

Very good fit all over spectrum
→ model 2 best describes the stack

SiO2 23 Å
Roughness 29 Å
Polysilicon 142 Å
Silicon 2591 Å
SiO2 3218 Å
Silicon





Thin SOI : Mapping 200 mm

121 points mapping on SOI :

SOI / BOX layer

Wafer Remarks

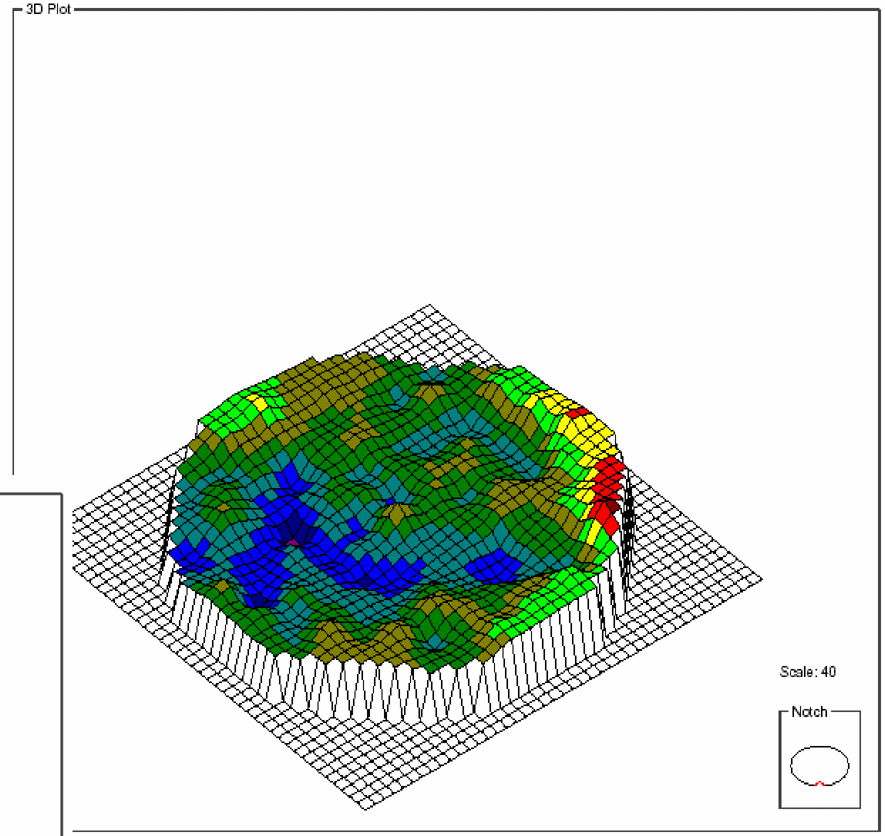
Operator ID: Patrice HEIN
FAB Name:
Equip Info: SE-200
Wafer ID: Bottom SiO2
Lot: Slot 5
Meas. Equip:
Special: Thickness

Wafer Size

Wafer Diam: 200.00 mm
Test Diam: 190.00 mm
No. Sites: 121
Style: Notch

Wafer Statistics

Mean: 996.34
Maximum: 1016.37
Minin 980.29
Std. [



Wafer Remarks

Operator ID: Patrice HEIN
FAB Name: SOITEC
Equip Info: SE-200
Wafer ID: Si (400 A)
Lot: Slot 5
Meas. Equip:
Special: Thickness

Wafer Size

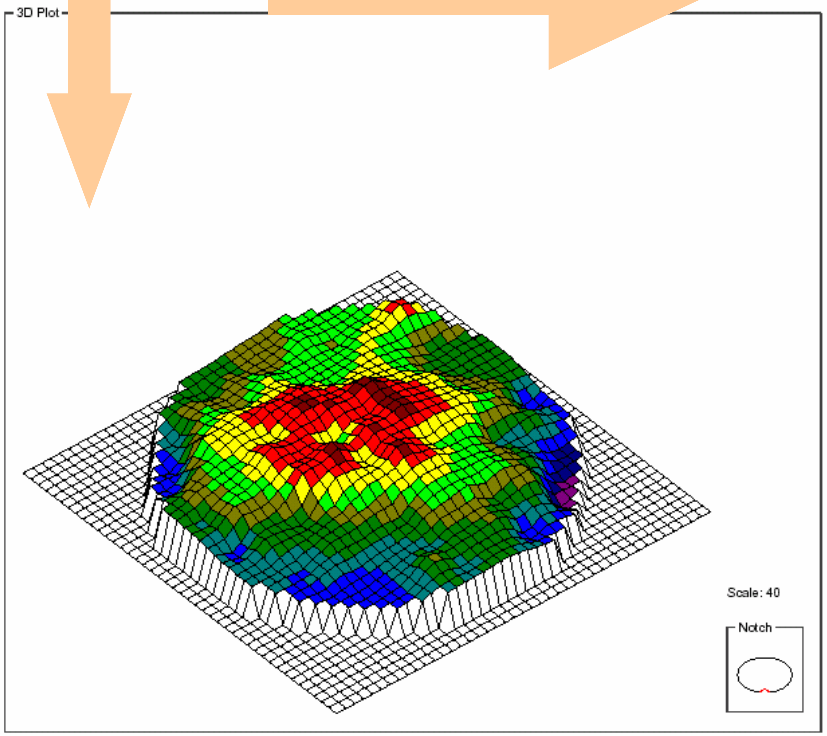
Wafer Diam: 200.00 mm
Test Diam: 190.00 mm
No. Sites: 121
Style: Notch

Wafer Statistics

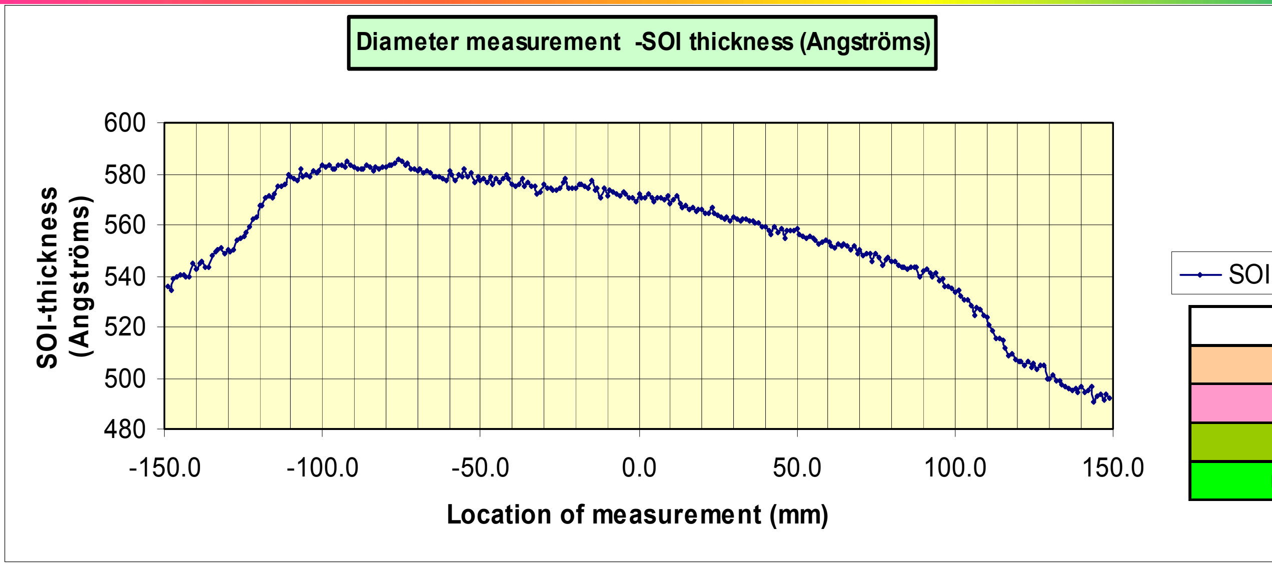
Mean: 423.93
Maximum: 438.21
Minimum: 403.85
Std. Dev: 7.57
1.79 %
Range: 34.36
Hi/Lo Var: 4.08 %
Unit: Angstrôms

Legend

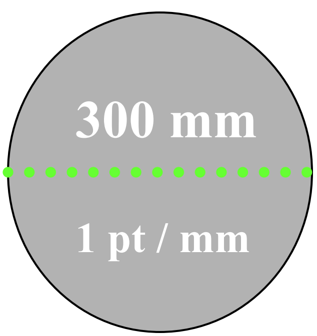
434.8 - 438.2
431.3 - 434.8
427.9 - 431.3
424.5 - 427.9
421.0 - 424.5
417.6 - 421.0
414.2 - 417.6
410.7 - 414.2
407.3 - 410.7
403.9 - 407.3

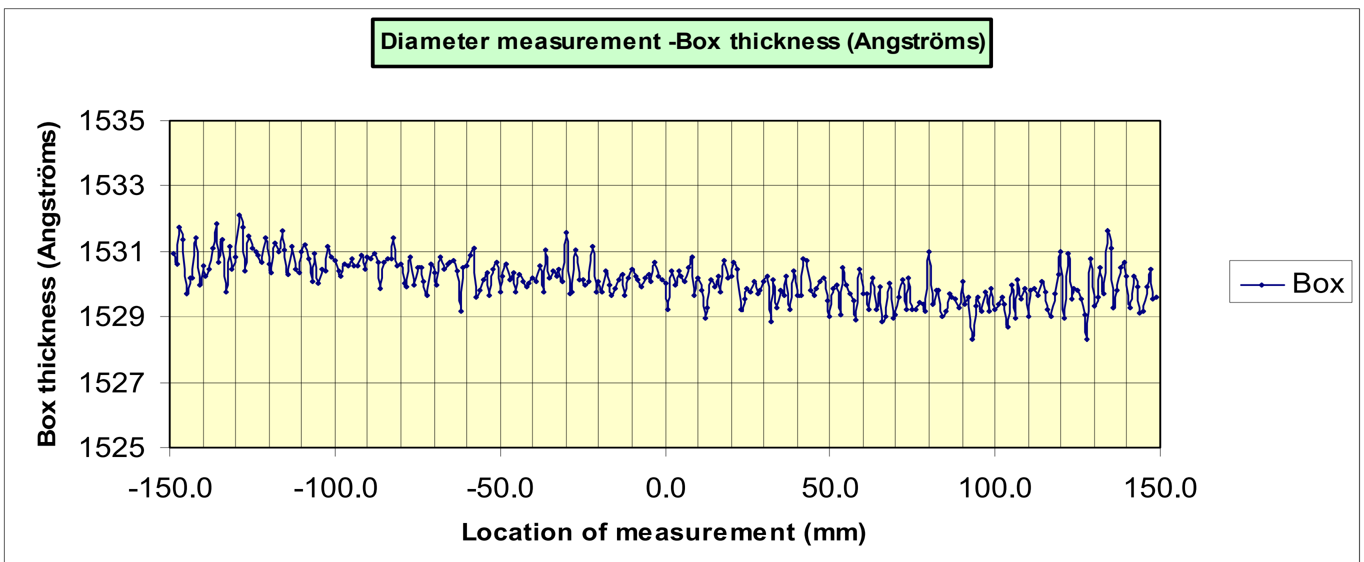


Thin SOI on 300 mm



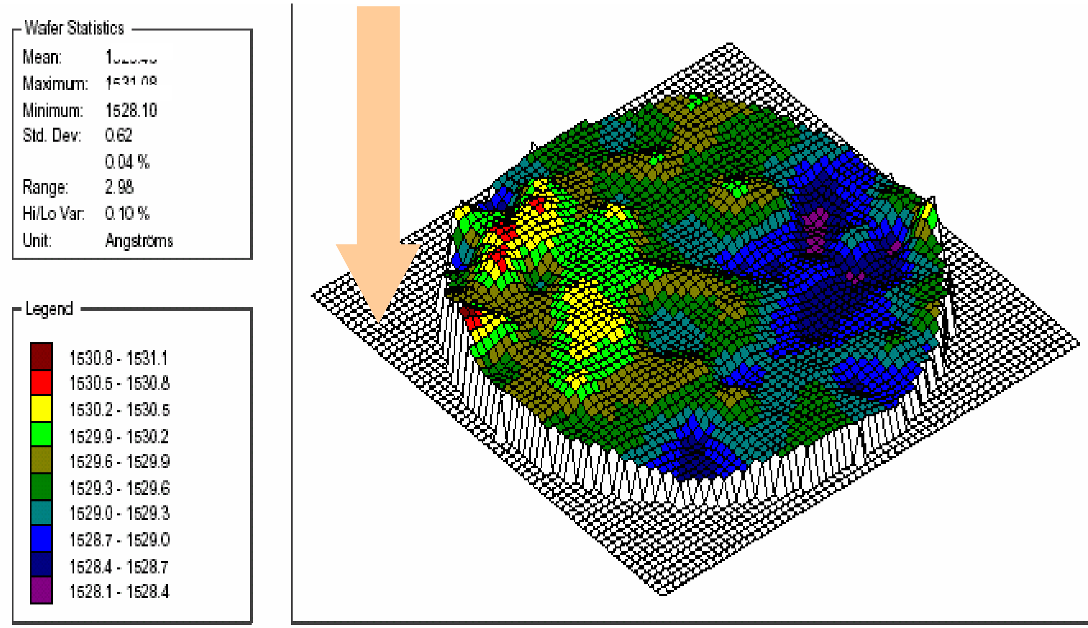
	SOI	BOX
Minimum (Å)	490.65	1528.33
Maximum (Å)	585.56	1532.09
Mean (Å)	555.78	1530.12
Uniformity (%)	8.82	0.12



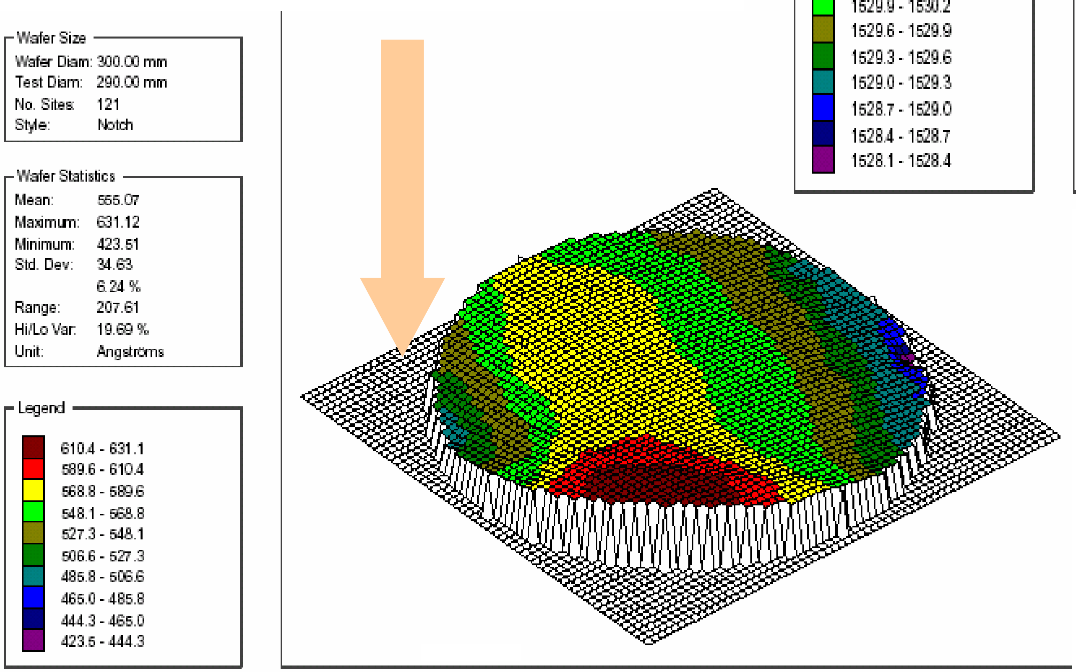


Thin SOI on 300 mm : mapping.

121 points mapping: BOX layer



121 points mapping: SOI



Static repeatbility SOI / Box

Minimum	**670.06**	**1399.61**	Å
maximum	**670.45**	**1399.79**	Å
Mean	**670.24**	**1399.69**	Å
Std	**0.11**	**0.05**	Å

Thin SOI on 300 mm : Dynamic Repeatability

Dynamic Repeatability test

CCD mode measurement
5 dynamic measurement on 5 sites with load/unload.
1 second measure per point.

SOI / SiO2.
The Thicknesses are in Å.
SOI layer.

Measurement	1	2	3	4	5	Standart deviation / site
Site 1	436.77	437.6	436.75	436.44	436.57	0.45
Site 2	391.19	392.14	391.31	391.06	391.02	0.46
Site 3	427.34	426.93	426.35	427.18	427.44	0.44
Site 4	446.36	445.75	445.82	446.08	445.56	0.31
Site 5	375.34	373.42	374.38	373.88	373.27	0.84
Wafer Mean value	415.40	415.17	414.92	414.93	414.77	

Mean of standart deviation: 0.50

Standart deviation of mean: 0.25

Bottom oxide layer.

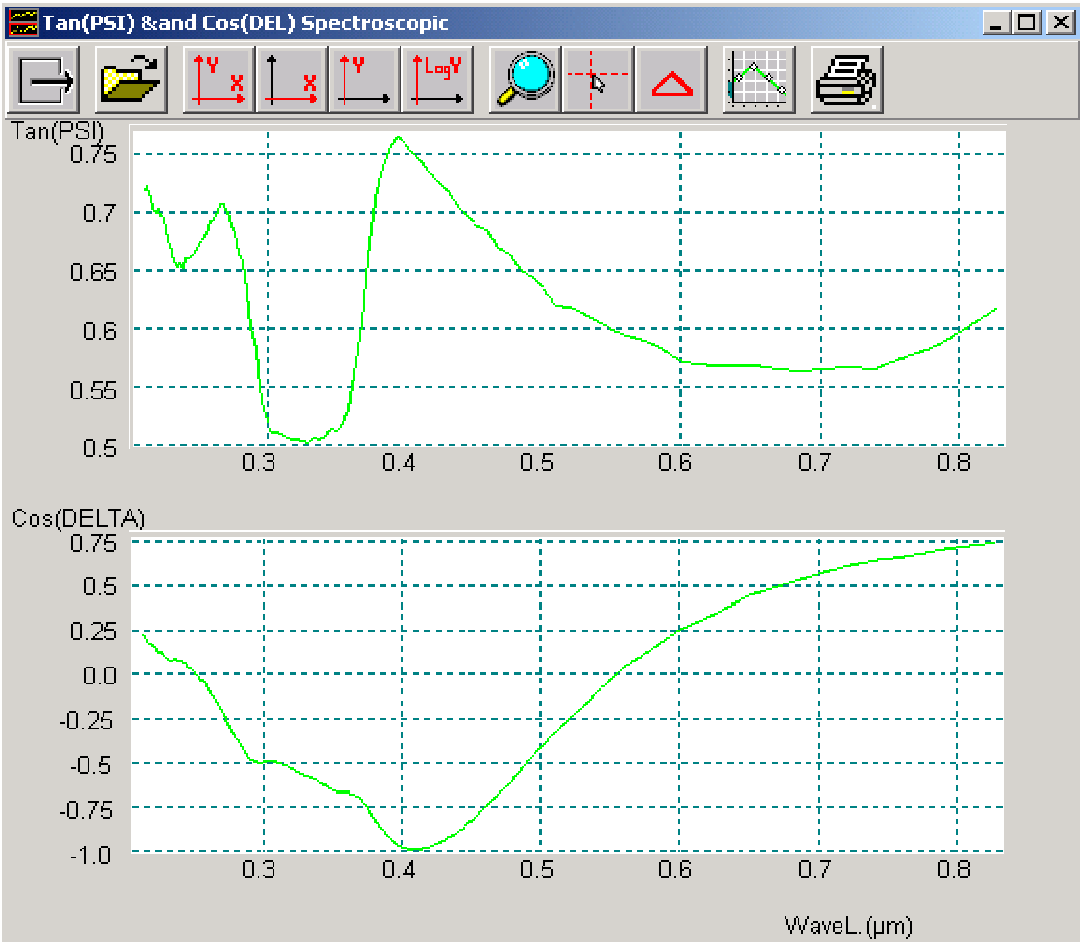
Measurement	1	2	3	4	5	Standart deviation / site
Site 1	2019.85	2019.25	2019.62	2020.05	2020.08	0.34
Site 2	2000.99	2001.09	2000.63	2000.68	2001.06	0.22
Site 3	2010.9	2010.54	2010.78	2010.85	2010.66	0.15
Site 4	2021.04	2021.29	2020.98	2021.9	2021.29	0.36
Site 5	2009.43	2009.64	2009.39	2009.83	2009.82	0.21
Wafer Mean value	2012.44	2012.36	2012.28	2012.66	2012.58	

Mean of standart deviation: 0.26

Standart deviation of mean: 0.16

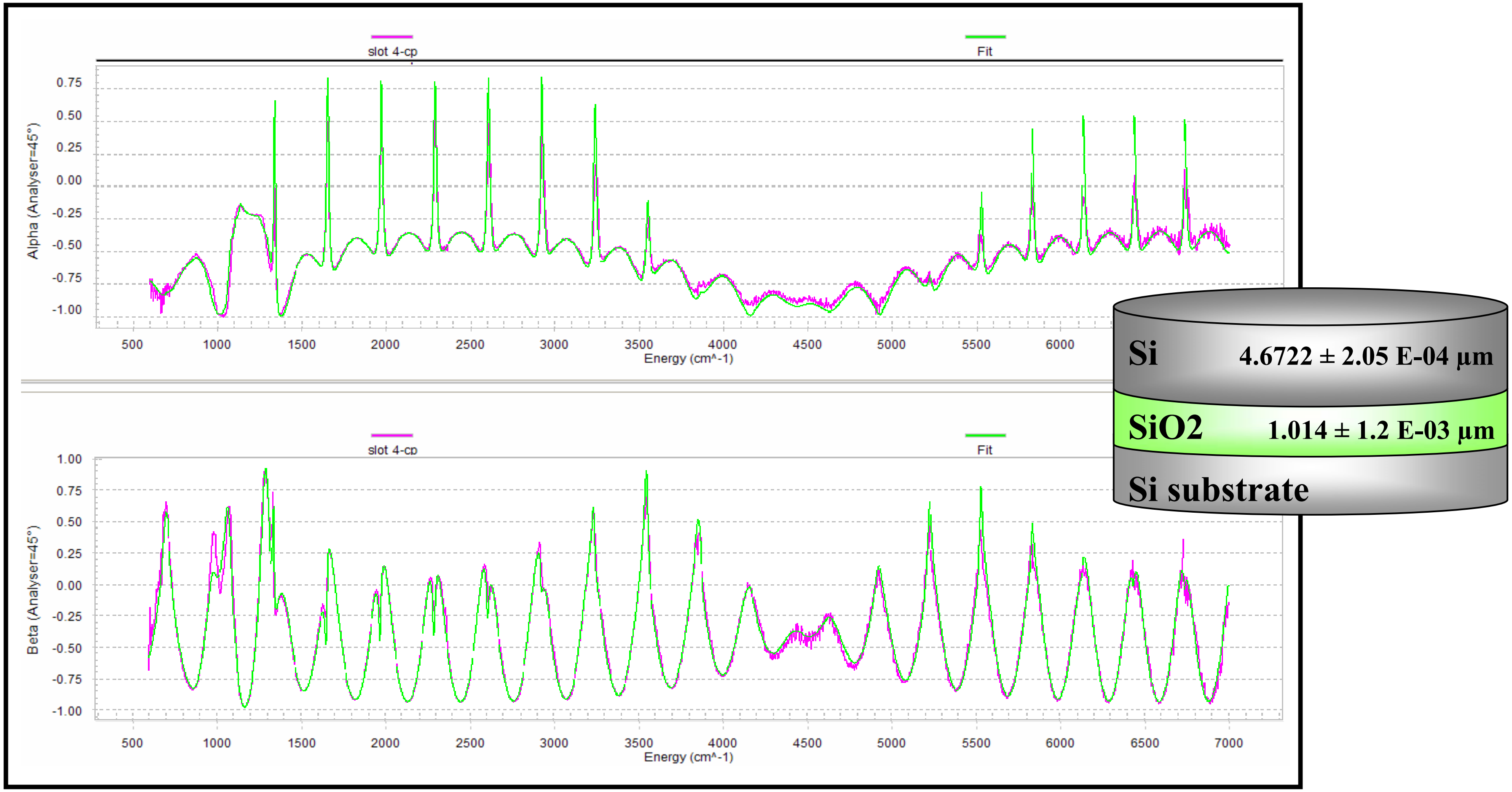
Ultra-Thin SOI

Fitted and Measurements Curves



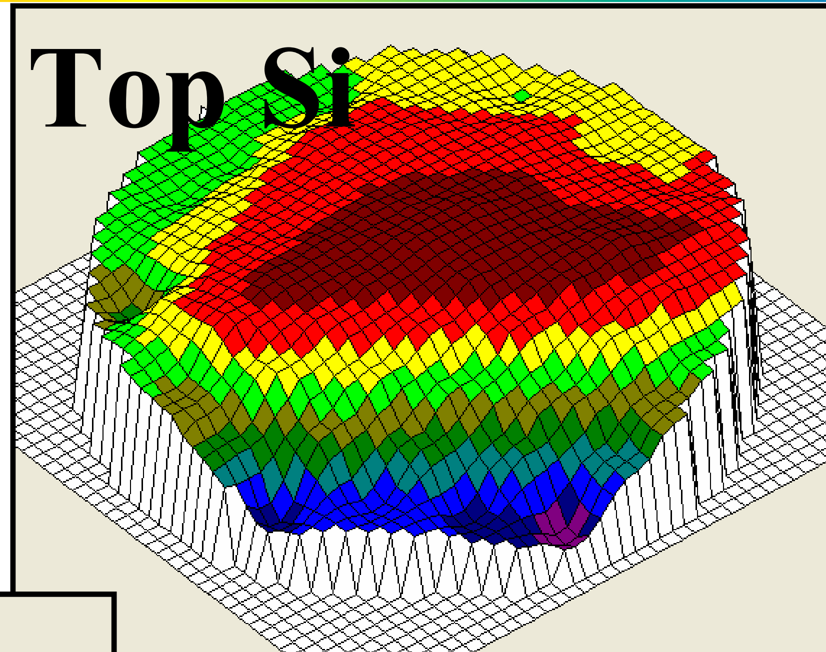
Native oxide
Silicon 174 Å
SiO_2 1020 Å
Silicon

Ultra thick SOI / MEMS applications

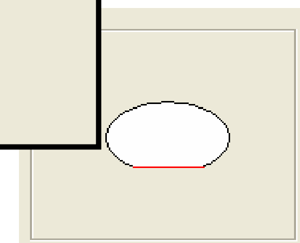


62 points mapping

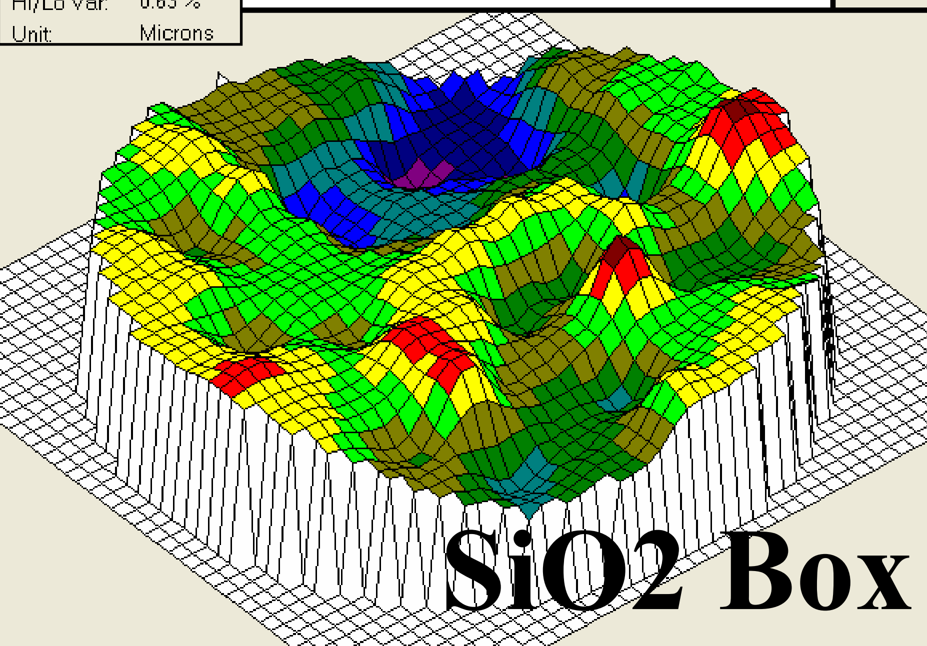
Wafer Statistics	
Mean:	4.5145
Maximum:	4.6886
Minimum:	4.0167
Std. Dev:	0.1533578
	3.40 %
Range:	0.6719003
Hi/Lo Var:	7.72 %
Unit:	Microns



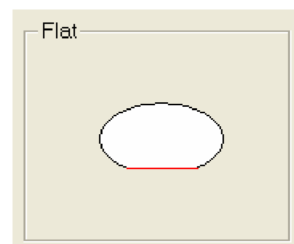
Legend
4.6214 - 4.6886
4.5542 - 4.6214
4.487 - 4.5542
4.4198 - 4.487
4.3527 - 4.4198
4.2855 - 4.3527
4.2183 - 4.2855
4.1511 - 4.2183
4.0839 - 4.1511
4.0167 - 4.0839



Wafer Statistics	
Mean:	1.0172
Maximum:	1.0227
Minimum:	1.0099
Std. Dev:	0.002853
	0.28 %
Range:	0.0128
Hi/Lo Var:	0.63 %
Unit:	Microns



Legend
1.0214 - 1.0227
1.0201 - 1.0214
1.0189 - 1.0201
1.0176 - 1.0189
1.0163 - 1.0176
1.015 - 1.0163
1.0137 - 1.015
1.0125 - 1.0137
1.0112 - 1.0125
1.0099 - 1.0112

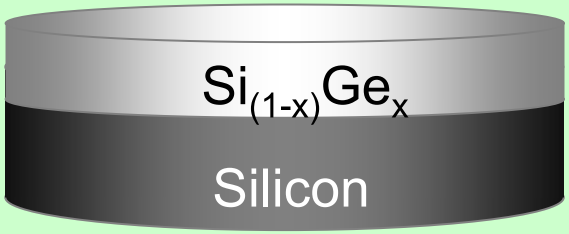


2) SiGe / SGOI

- SiGe analysis
  - Alloy model
  - Strained stacks
  - Relaxed stacks
  - Graded stacks
  - Strained Si
  - SGOI/SSOI

- Infra Red S.E. characterization
  - Boron concentration

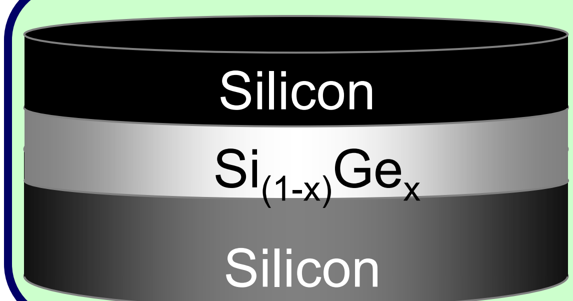
Methodology



Process Development

- **T** : Thickness determination (by GXR, SE)
- **%Ge** : Germanium content determination (by SIMS, RBS, SE)
- **n,k** : Determination of calibrated refractive indices (by SE)

Building of an alloy model

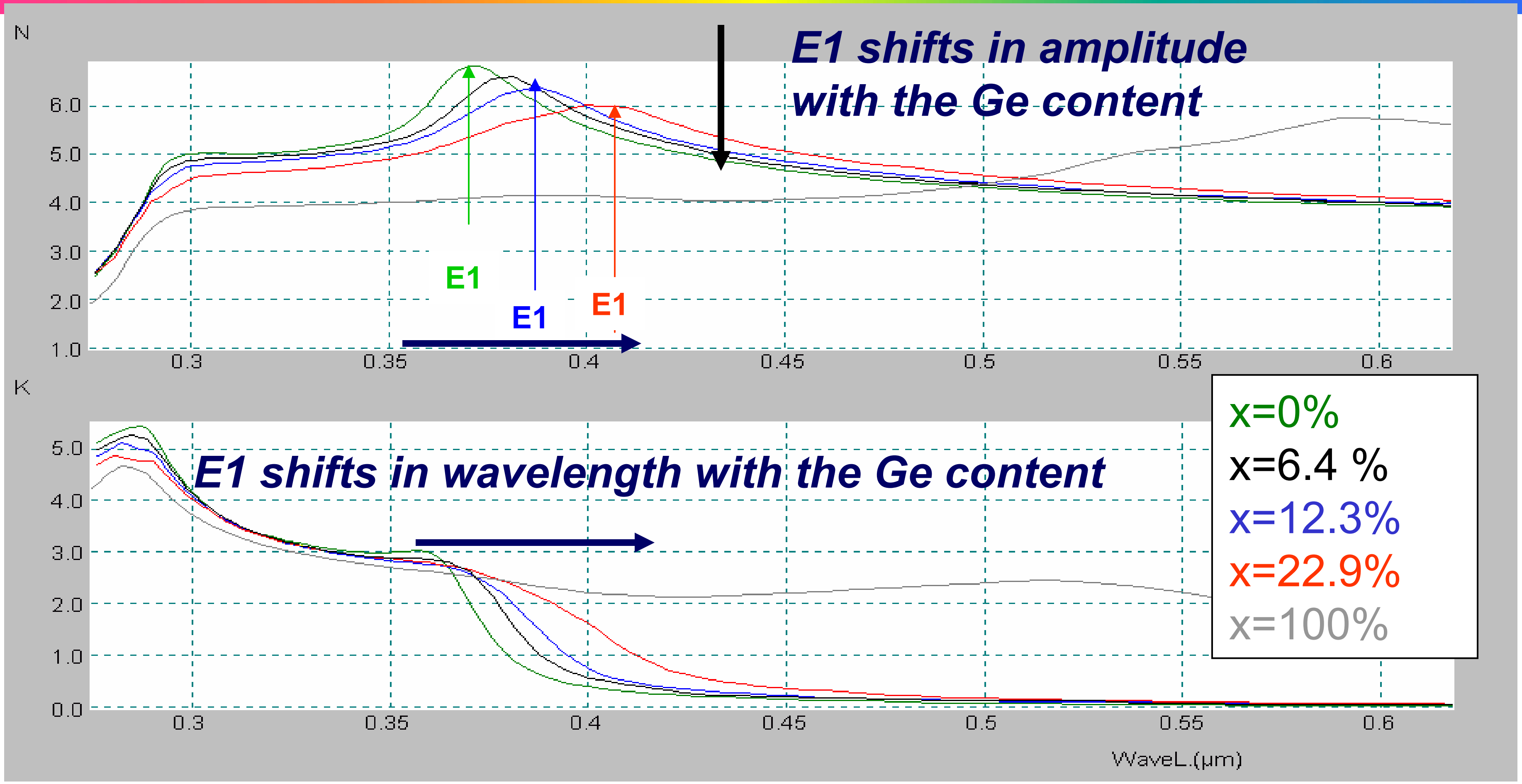


Process control

SE ⇔ % Ge and T

(multilayer, gradual layer)

Why Alloy versus EMA



EMA model takes only into account changes in amplitude
Alloy takes into account both changes: wavelength and amplitude

Building of the strained Alloy model

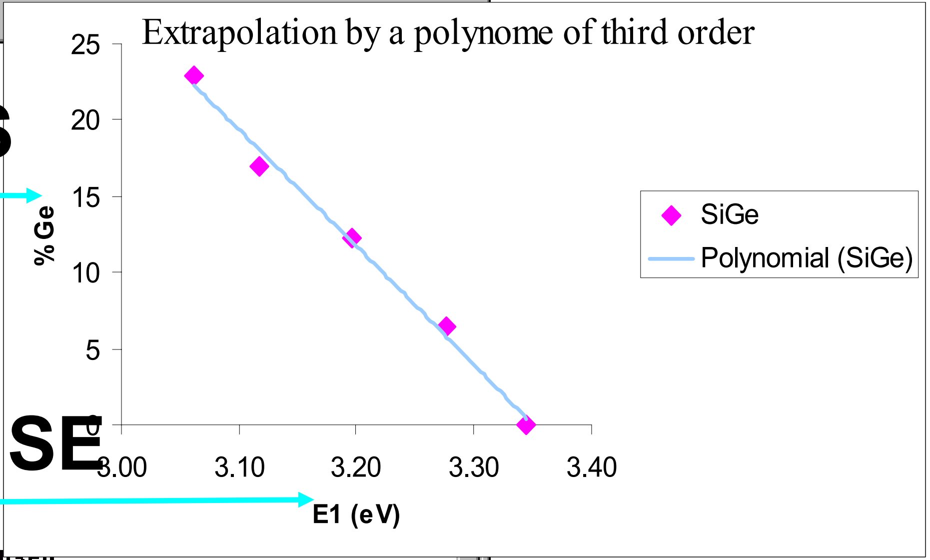
Stsg.all - Notepad

File Edit Search Help

```
5
STSG0,0
STSG064,0.064
STSG123,0.123
STSG169,0.169
STSG229,0.229
5
1.1053,-0.896,0.396,0
3.31,-0.28,0,0
3.393,-1.335,0.0365,0
3.423,-0.794,0.193,0
4.42,-0.03,0,0

'Comments:
These are data for alloy modelization:
the first number represents the number of files which are used
then comes the list of the files with the corresponding concentrations
then the number of critical points which are used in the calculation
then the coefficients of third order polynomials describing the dependance
of the critical points with the concentration
(from top to bottom: increasing order of the critical point,
from left to right: increasing power of concentration for a given c

IMPORTANT: the name of this file MUST be the generic name of the i
(six first characters) plus the extension .ALL .

DATA prepared after Pickering's results for strained SixGe(1-x):
x has to be less than 0.029
CPs are:  Eindgap, E1, E1+d1, E2

References:
```

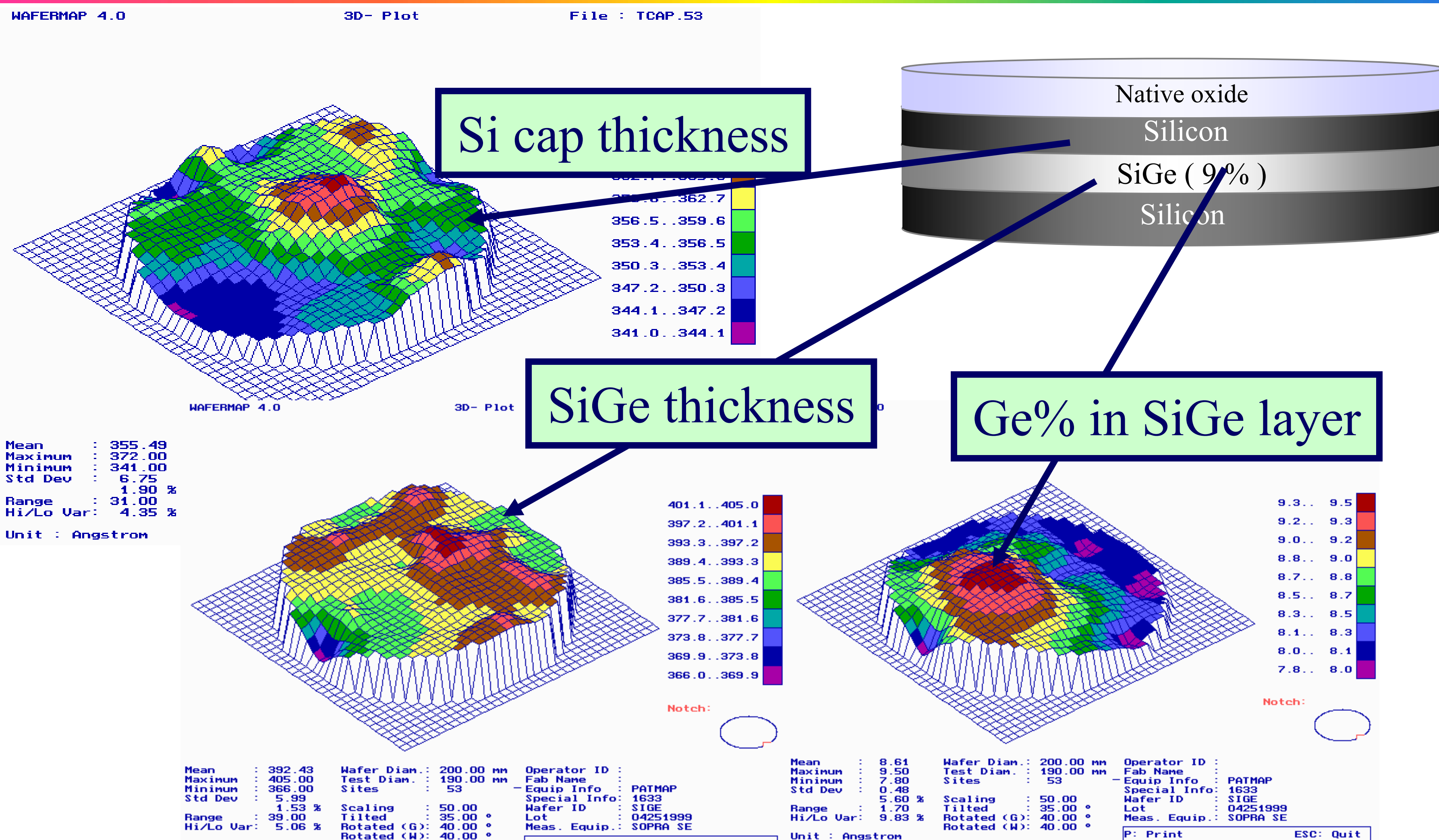
Measured by SIMS

Measured by SE



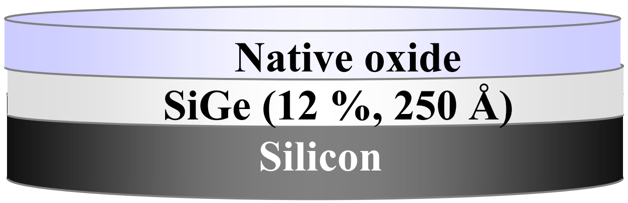
% Ge	E1(eV)	E1 + Δ1 (eV)	E2 (eV)
0	3.35	3.42	4.27
6.4	3.28	3.42	4.28
12.3	3.20	3.42	4.28
16.9	3.12	3.31	4.30
22.9	3.06	3.27	4.30

300 mm Mapping capability

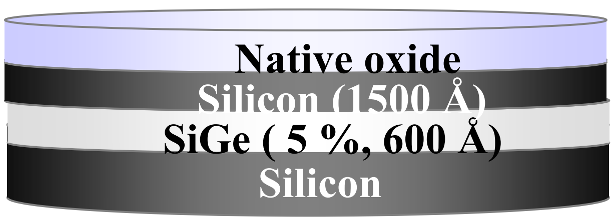


These 3 parameters are obtained in only one measurement !

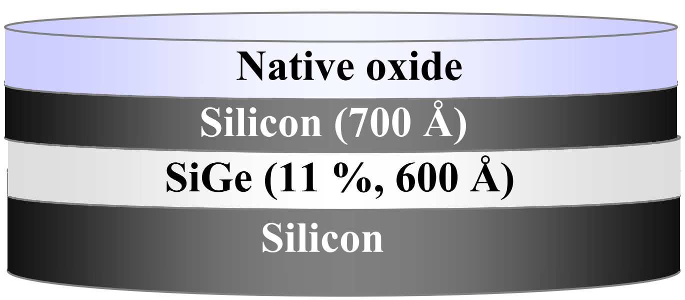
Repeatability



	SiGe		% Ge	
Average	248.45	Å	11.61	%
Max	252.16	Å	11.78	%
Min	245.26	Å	11.39	%
σ	2.039	Å	0.090	%
3σ	6.118	Å	0.271	%



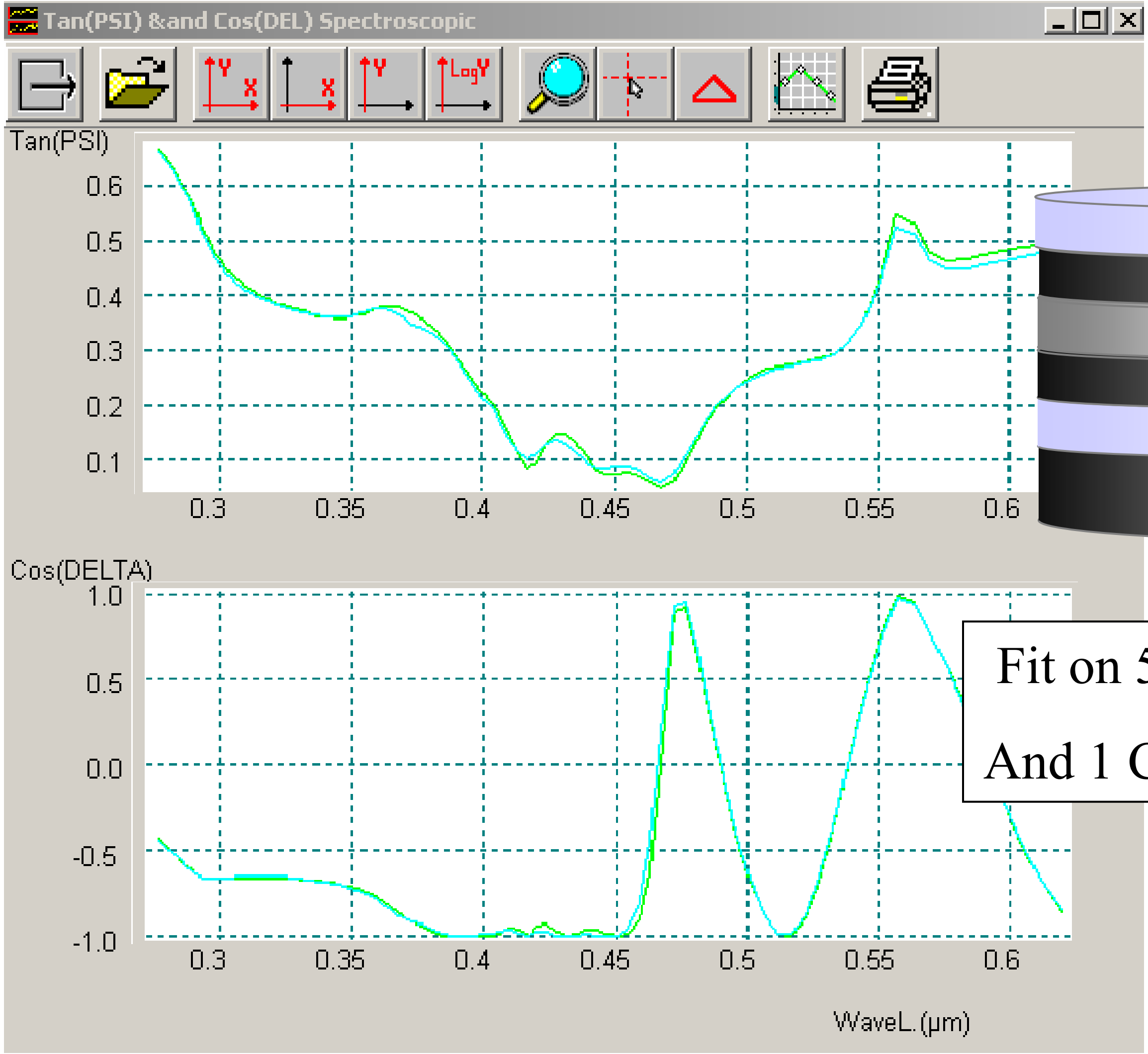
	Si cap		SiGe		% Ge	
Average	1491.67	Å	579.91	Å	4.83	%
Max	1496.49	Å	585.09	Å	5.18	%
Min	1487.51	Å	573.86	Å	4.52	%
σ	2.259	Å	2.560	Å	0.136	%
3σ	6.776	Å	7.680	Å	0.407	%

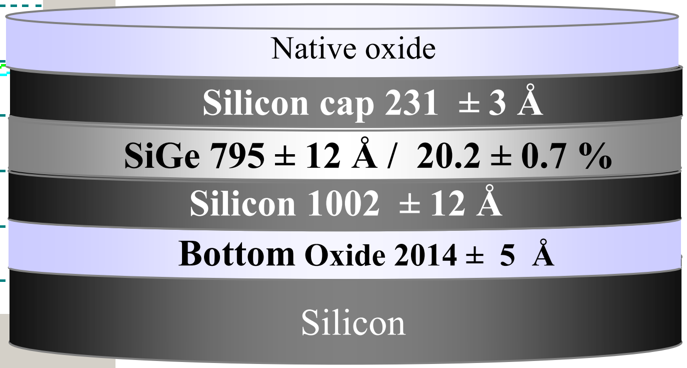


	Si cap		SiGe		% Ge	
Average	693.89	Å	641.59	Å	10.64	%
Max	699.01	Å	648.20	Å	10.94	%
Min	682.98	Å	637.54	Å	10.22	%
σ	2.090	Å	1.449	Å	0.142	%
3σ	6.269	Å	4.348	Å	0.427	%

50 static measurements

Si on SiGe on SOI





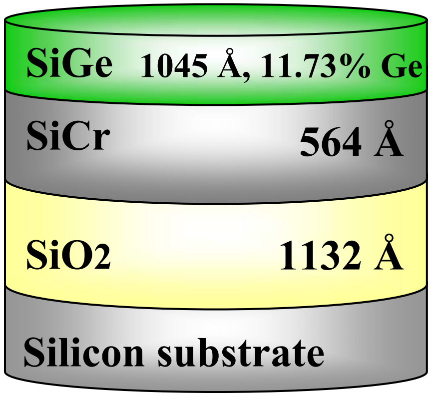
Fit on 5 thicknesses

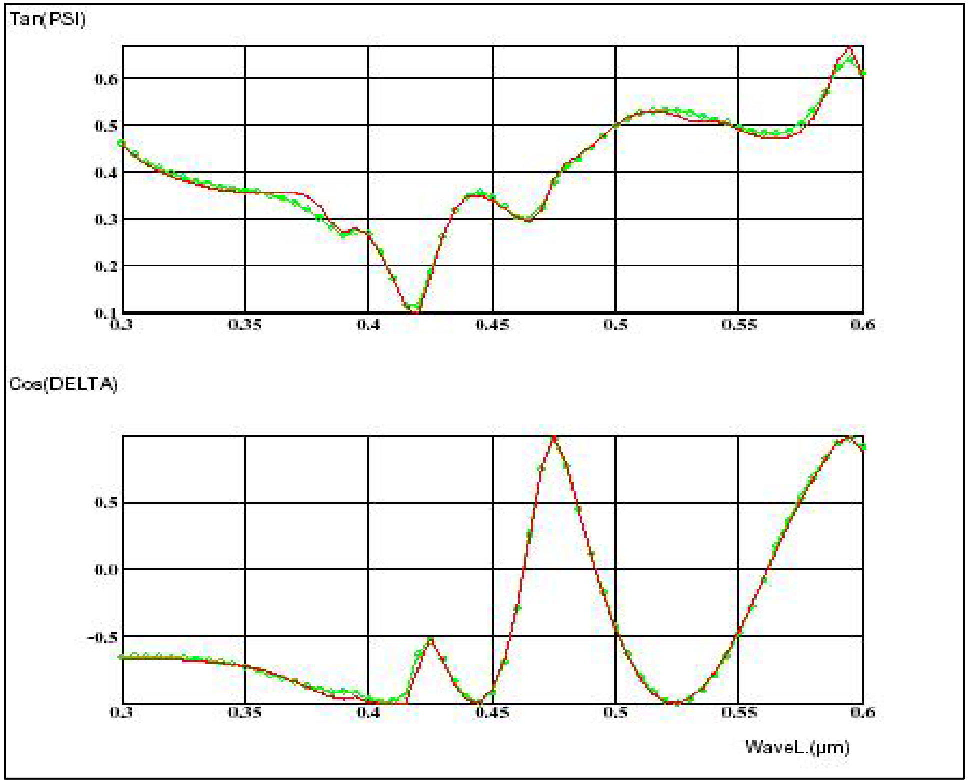
And 1 Concentration at the same time

SiGe on Insulator (SGOI)

S.E. measurement & regression on SiGe on Insulator :

- thickness and concentration of SiGe
- thickness of Si
- thickness of BOX.

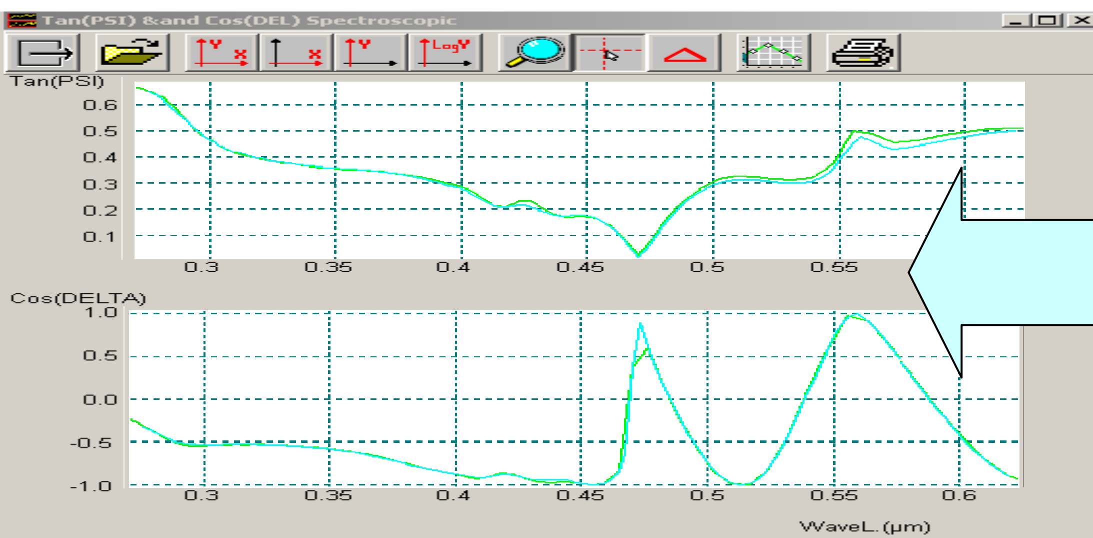


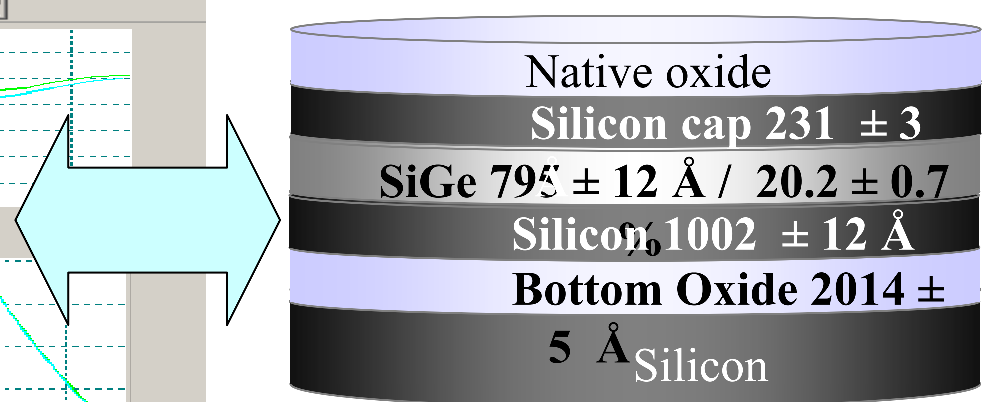


SGOI-SSOI

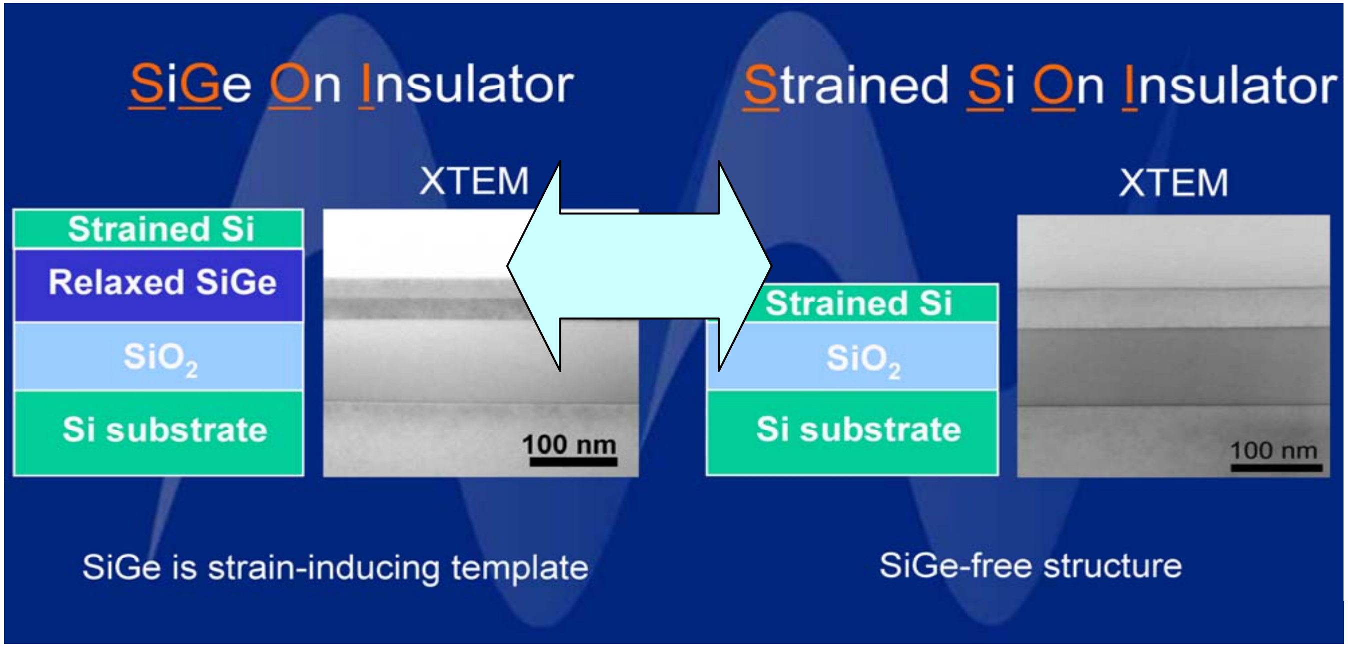
	Native Oxide Thickness (Å)	Si Layer Thickness (Å)	SiGe Layer Thickness (Å)	Ge Concentration in SiGe (%)	SiO2 Layer Thickness (Å)
Min.	21.6	201.5	374.7	23.5	1323.7
Max.	21.9	202.0	376.3	23.6	1333.4
Range	0.3	0.5	1.6	0.1	9.7
Average	21.7	201.7	375.4	23.6	1328.7
St.Dev.	0.07	0.13	0.32	0.03	2.08

Measurement at 75 degrees AOI

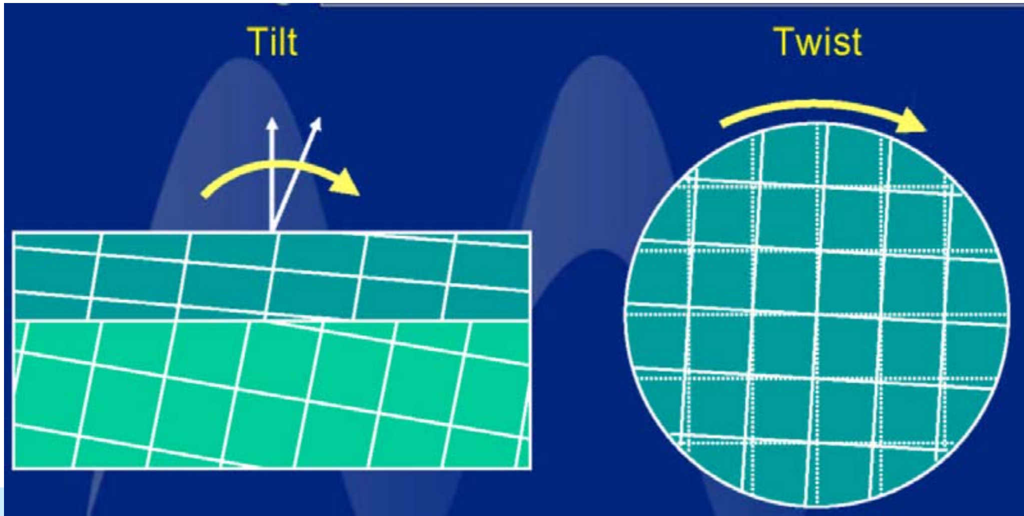




SGOI-SSOI

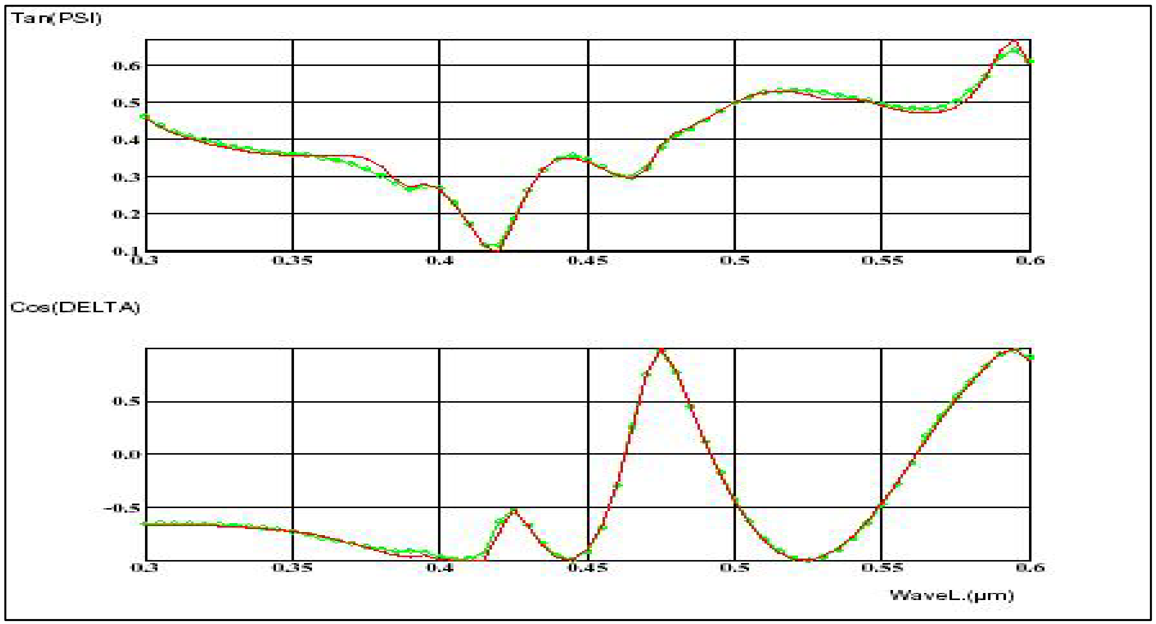


No influence of tilt or twist

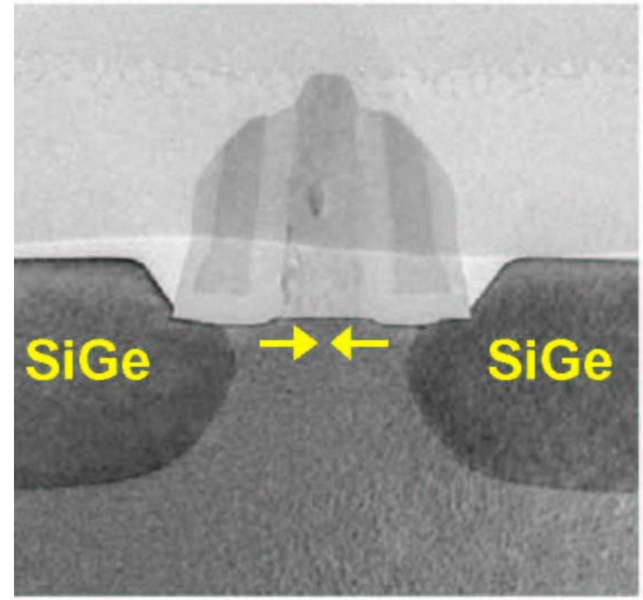


Strained PMOS gate

SE measurement of the SD stack
=> PMOS on SOI



LEVEL	TYPE	MIX/LAW	THICKNESS	
AMBIENT	SINGLE		0	VOID.nk
LAYER 1	SINGLE		0.000678	Sio2.nk
LAYER 2	SINGLE		0.036192	Stsg.all Alloy Conc. = 13.326%
LAYER 3	SINGLE		0.044048	Si100_2.nk
LAYER 4	SINGLE		0.14136	Sio2.nk
SUBSTRATE	SINGLE		0	SICR.nk

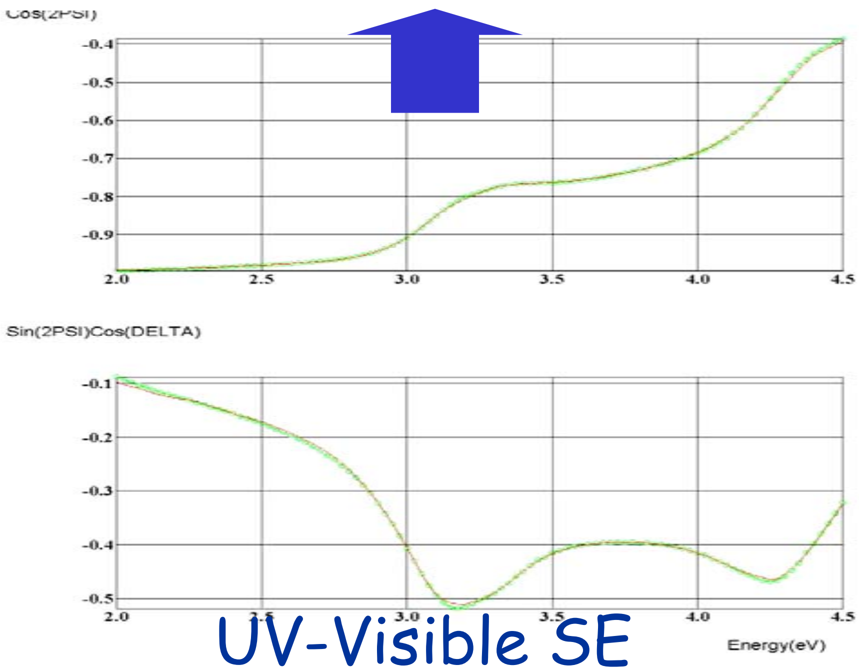


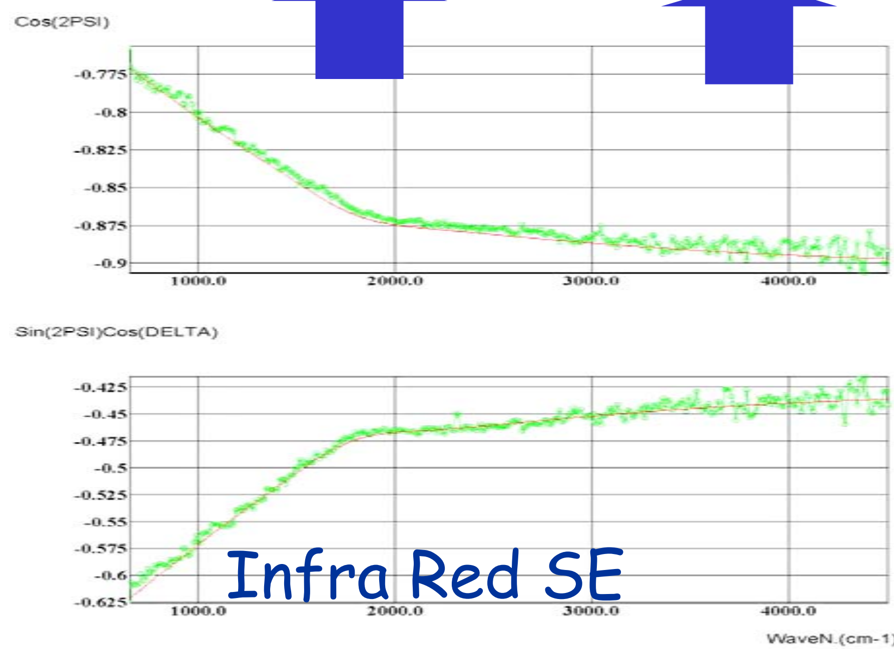
Picture from: T Ghani, Portland technology dept, Intel Corp, IEDM 2003

- The SD region is etched.
- Selective Epitaxial growth of SiGe in the SD region
- The SiGe induces a compressive uniaxial strain in the channel region.

B doped SiGe

Slot #	sige Thickness (A)	Sige %	dopant	thickness IR	N (at/cm3)	dN (at/cm3)	Sheet resistance
2	895	14.7	B	NA	1.60E+19	2.18681E+18	507.2
3	450	14.8	B	NA	NA	NA	NA
4	952	14.3	B	983	7.72704E+19	3.17191E+18	239.5
5	520	14.4	B	476	1.35011E+20	3.89018E+18	290.1
6	564	14.3	B	546	2.17502E+20	4.49871E+18	158.6





Model: Drude Law

Drude law:

$$\varepsilon_1(\omega) = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 - \omega_\tau^2}$$

$$\varepsilon_2(\omega) = \frac{\omega_p^2 \omega_\tau}{\omega(\omega^2 - \omega_\tau^2)}$$

ω_p : plasma frequency

ω_τ : scattering frequency

Material analysis

Electrical properties

Conductivity of the film

$$\sigma = \varepsilon_0 \frac{\omega_p^2}{\omega_\tau}$$

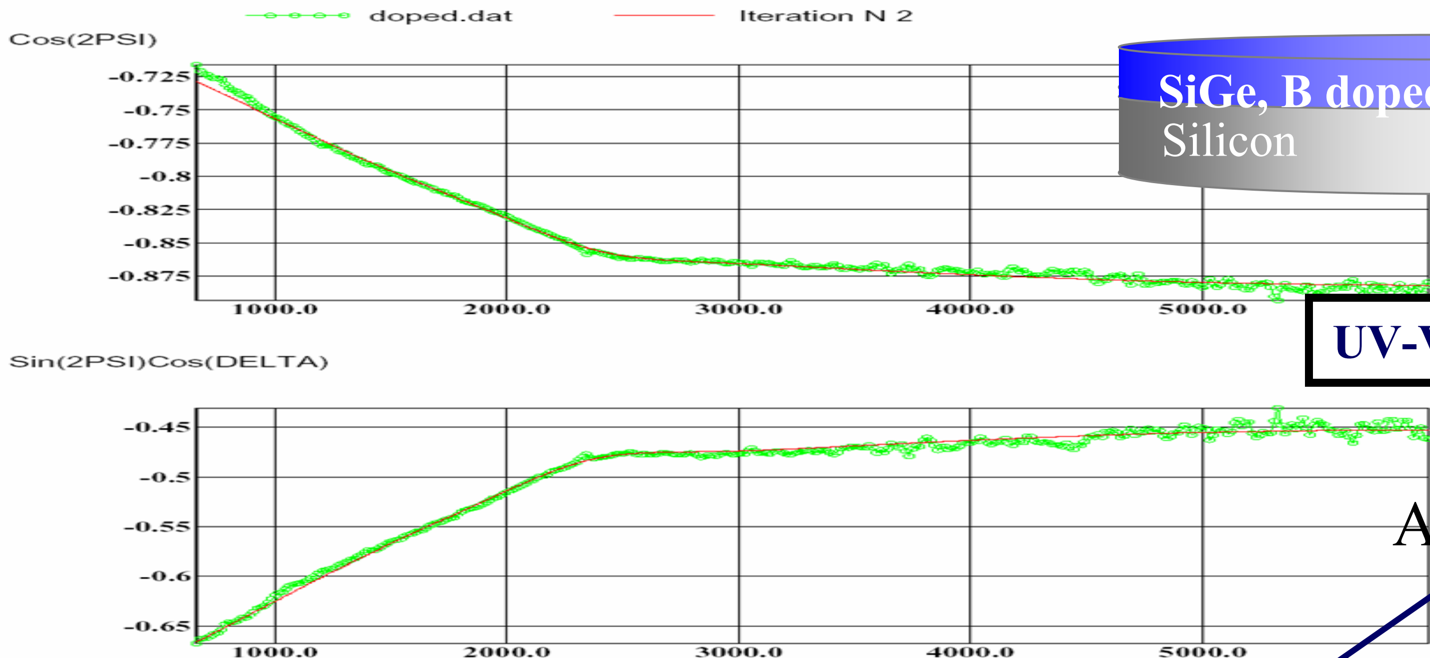
Free carrier density N through

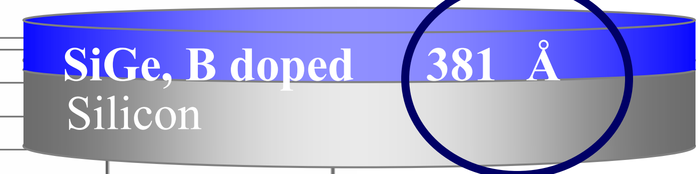
$$N = m^* \frac{\varepsilon_0 \omega_p^2}{e^2}$$

Free carrier mobility μ

$$\mu = \frac{e}{m^* \omega_\tau}$$

B doped SiGe





UV-VIS SE gives 385 Å !

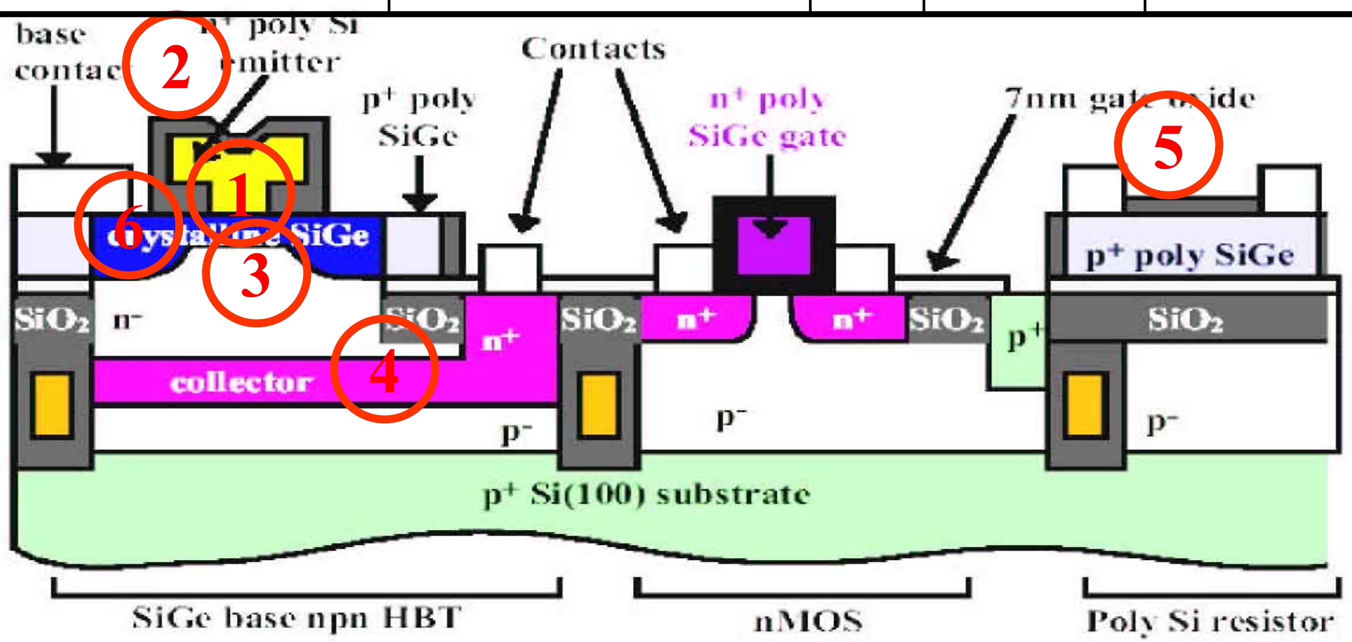
Analysis gives

Enter Drude parameters				Enter the Thickness (Å)	
Lo^{-1} (µm-1)	dLo^{-1} (μm^{-1})	$taux^{-1}$ (μm^{-1})	$dTaux^{-1}$(μm^{-1})	T	dT
0.8375	0.0070	**0.1109**	0.0010	381	8

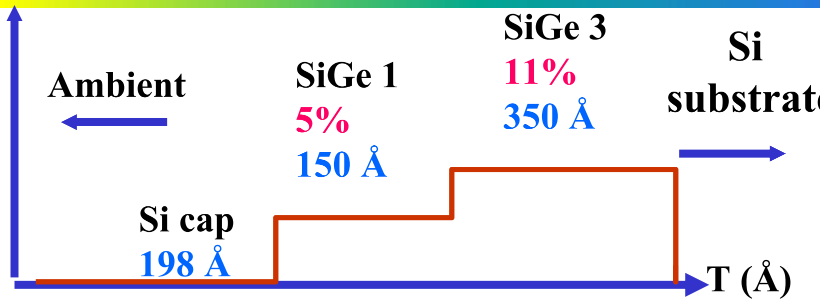
The results (and their uncertainties) are automatically calculated on the following table :

Electrical properties						Dopant		
cond (S/m)	dcond (S/m)	ρ (mOhm.cm)	dρ (mOhm.cm)	R1(Ohm/◊)	dR1(Ohm/◊)	effective mass	N (at/cm3)	dN (at/cm3)
1.06E+05	3.E+03	**0.95**	0.02	**248.8**	11.6	0.37	**2.90E+20**	5.E+18

		Tool/ product wafer		Enabling technology	
1)	SiGe Emitter	XRD, SIMS, XRR	No	IRSE300	Yes
2)	N+ Poly Emitter	4PP, SIMS	No	IRSE300	Yes
3)	Thin P/P+ Epi	FTIR, SIMS, 4PP	No	IRSE300	Yes
4)	N+ Buried collector	FTIR, SIMS	No	IRSE300	Yes
5)	Poly SiGe	XRR, XRD	No	IRSE300	Yes
6)	B doped SiGe	SIMS, 4PP	No	IRSE300	Yes



Bipolar: Graded SiGe



Total epi thickness 685 Å

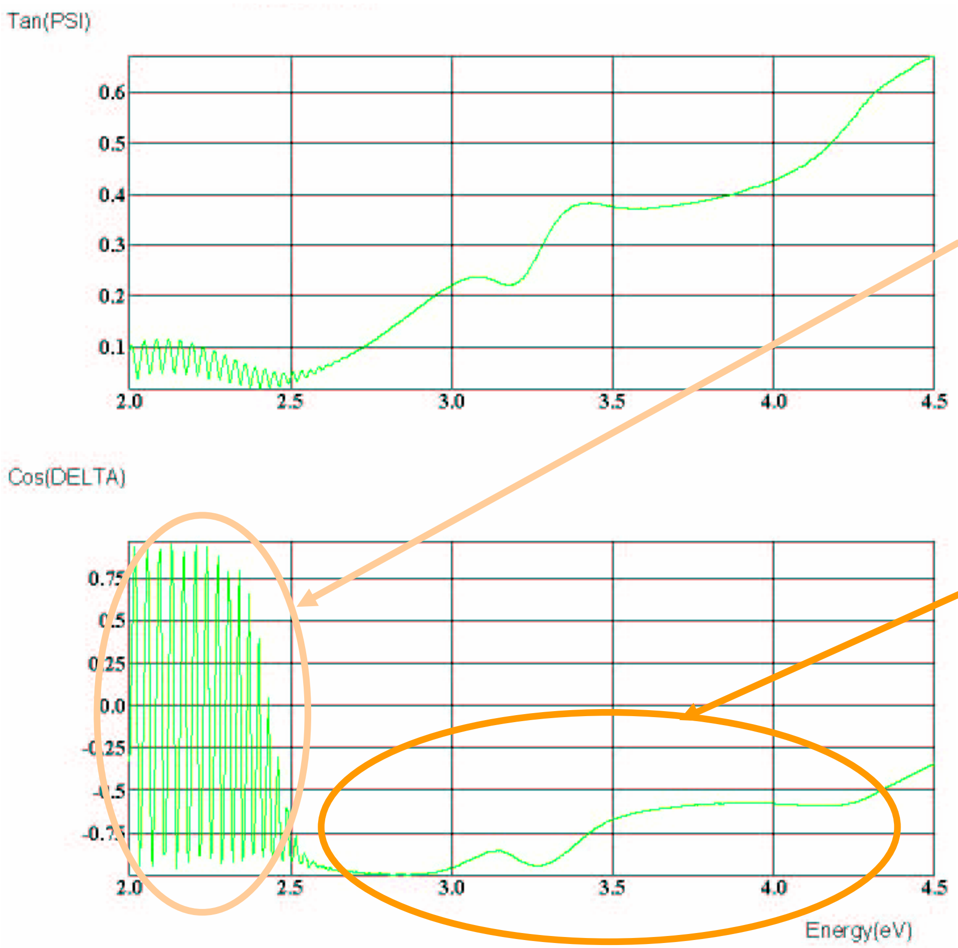
Dynamic repeatability:

1. Graded structure with cap
2. Product wafer
3. measurement time: 1 second per site
4. Pattern of 100x150 um
5. 15 load /unload with pattern recognition

100x150um box / dynamic repeatabiltiy							
	sio2 T(A)	sicap T (A)	sige 1 T(A)	sige1 %	sige2 T(A)	sige2 %	total T(A)
m1	29	195	143	5.1	348.5	11.1	686.5
m2	30	201	138	5.2	348.5	10.8	687.5
m3	29.8	199	145	5.1	344.5	10.9	688.5
m4	29.5	198	146	5.2	343.5	11	687.5
m5	30	197	143	5.1	346.5	11	686.5
m6	30.8	199	138	5	349.5	11	686.5
m7	29.8	198	146	5.1	342.5	10.9	686.5
m8	31.3	200	147	4.9	341.5	10.8	688.5
m9	31.3	192	141	4.8	354.5	11	687.5
m10	30.1	200	143	5.2	344.5	10.9	687.5
m11	30.4	193	140	5	353.5	10.9	686.5
m12	31.3	200	141	5	347.5	10.9	688.5
m13	30.6	199	148	5.1	342.5	10.8	689.5
m14	31.1	199	149	5	341.5	10.8	689.5
m15	31.1	204	150	5.4	332.5	10.9	686.5
mean	**30.41**	**198.27**	**143.87**	**5.08**	**345.43**	**10.91**	**687.57**
max	31.30	204.00	150.00	5.40	354.50	11.10	689.50
min	29.00	192.00	138.00	4.80	332.50	10.80	686.50
sigma	0.73	3.06	3.81	0.14	5.40	0.09	1.10
% sigma	**2.41**	**1.54**	**2.65**	**2.80**	**1.56**	**0.84**	**0.16**

0.16% repeatability On Total thickness of the epi stack

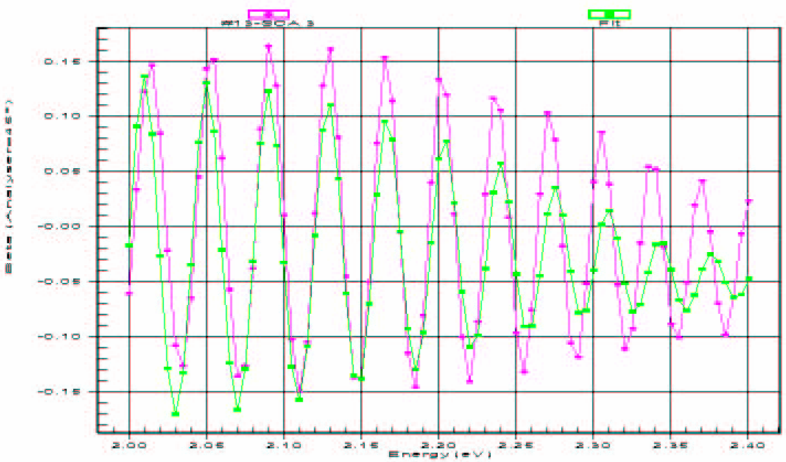
Si / SiGe / SiGe graded / SiGe on SOI on Si



By looking at the spectrum
we are able to see two areas.
The range 2 to 2.6eV represents
interference from the SOI layers.
The information regarding the cap and
the SiGe layers are in the range 2.5-4.5eV.

So, to analyze this sample we have
decided to make **two pass** in the
regression.
The first one will give use SOI thicknesses,
while the second one with give us other
layers informations.

Si / SiGe / SiGe graded / SiGe on SOI on Si
SOI Analysis



LAYER 7	Mixed	Bruggeman	2.7323	Polarization Coeff. = 0.3333 Component n°1 : Sicr Conc. = 1.062 Component n°2 : Void Conc. = -6.2124E-02
LAYER 8	Single		0.316640	Sio2.nk
SUBSTRAT	Single		-	sicr.nk

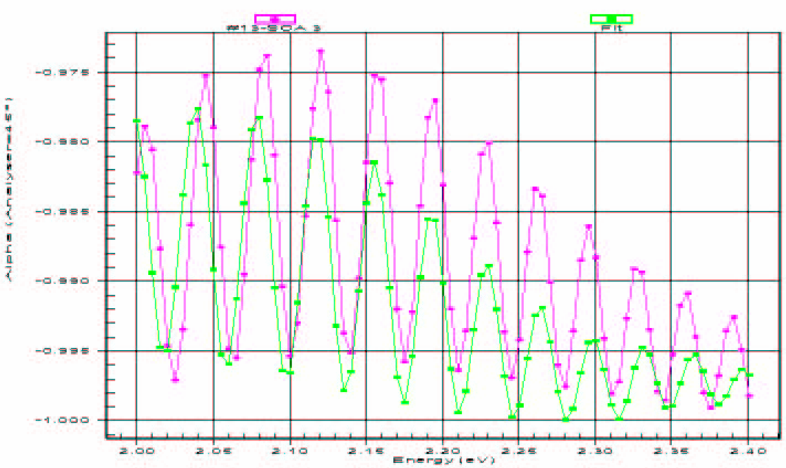
Measurement File n°1 : #13-SCA 3 - Ellipsometric Data, Fit on Alpha & Beta for Analyzer angle = 45°

RESULTS :

Regression Spectral Range (eV) : From 2.000 To 2.400
Confidence interval = 2Sigma
Statistical measure of goodness of fit (sigma) : 3.9880E-03 Number of iterations : 2

Fit on Parameters :

Parameter 1 : Thickness (um) = 2.7323 ± 4.1496E-02
Parameter 2 : Conc. file 2 = -6.2124E-02 ± 2.2833E-02
Parameter 3 : Thickness (um) = 0.316640 ± 6.0807E-03



By modeling the full structure with the target values of each layer and by fitting only on SOI layers thicknesses between 2 and 2.6eV, we obtained the following results :

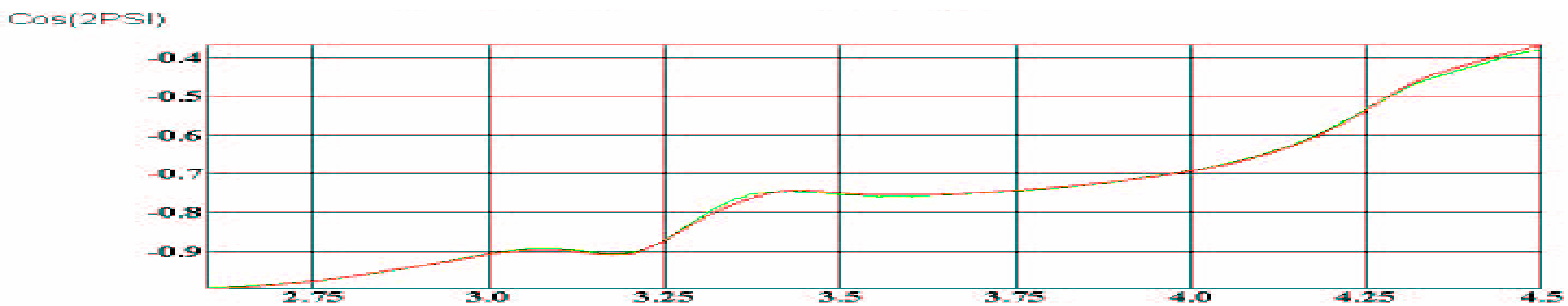
	Target	Result
Si	2.5 um	2.73 um
SiO2	300 nm	316 nm

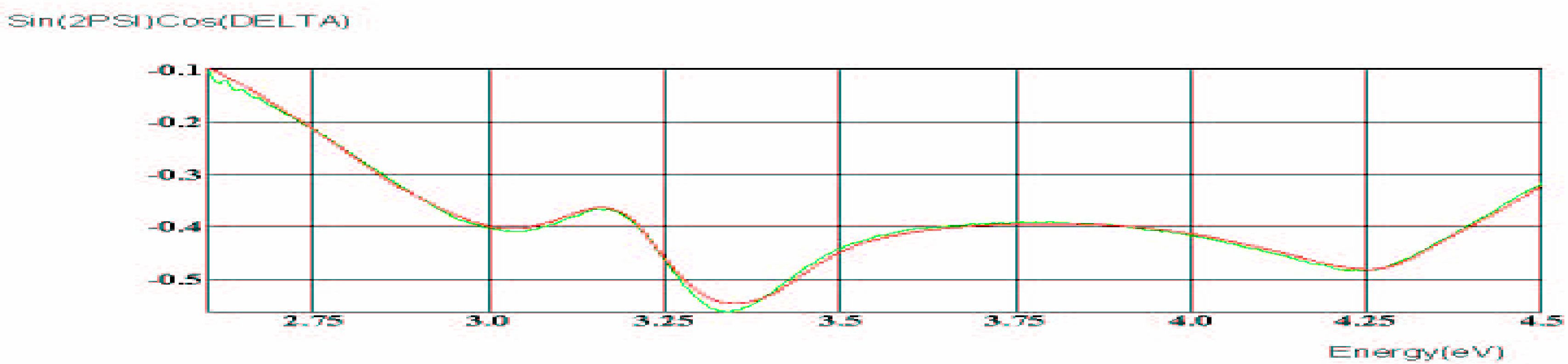
Si / SiGe / SiGe graded / SiGe on SOI on Si

SAMPLE STRUCTURE

LEVEL	TYPE	MIX/LAW	THICKNESS		
AMBIENT	SINGLE		0	VOID.nk	
LAYER 1	SINGLE		1.406487	Sio2.nk	
LAYER 2	SINGLE		24.74058	sicr.NK	
LAYER 3	SINGLE		12.23043	3tsg.all	Alloy Conc. = 4.221%
LAYER 4	SINGLE		20.58502	3tsg.all	Alloy Conc. = 18.916%
LAYER 5	SINGLE		2722.2	sicr.NK	
LAYER 6	SINGLE		216.6	sio2.NK	
SUBSTRATE	SINGLE		0	SICR.nk	

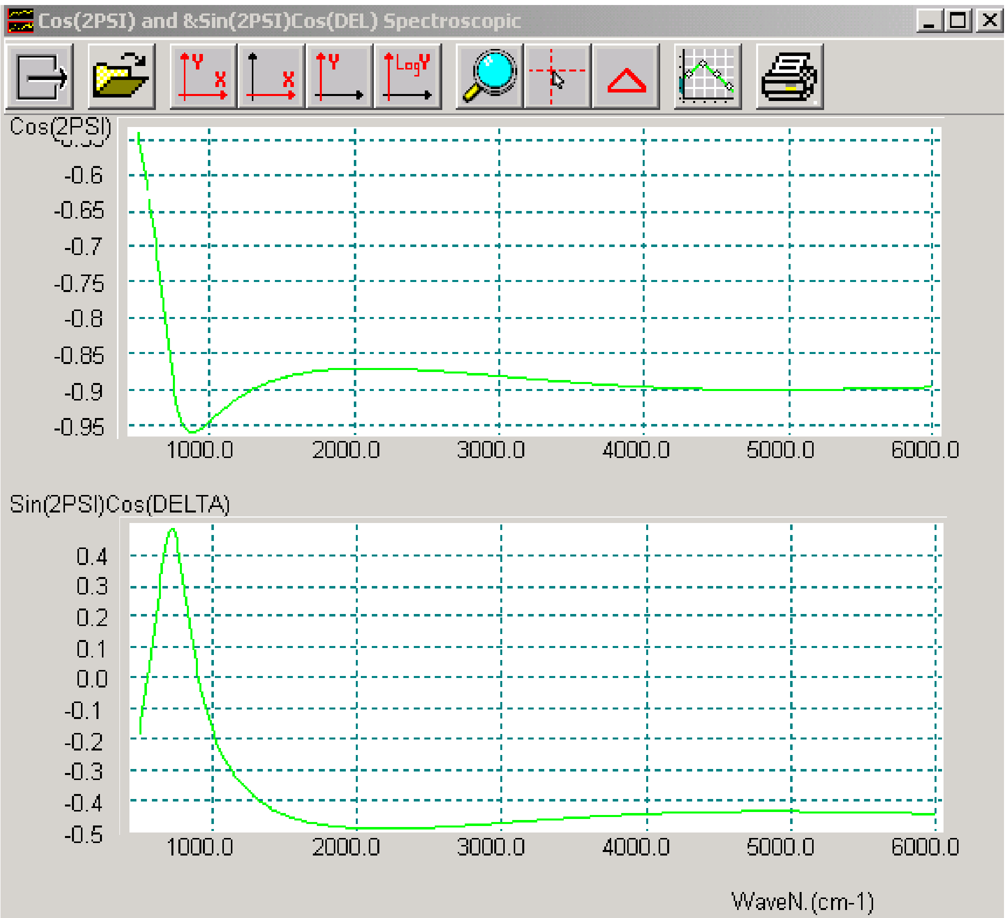
- **Thickness and Ge% within a tight range**
- **Total thickness accurately and repeatably**
- **Average Ge% of the ramp + thin box**
- **Ge% of the box below**
- **Thickness of the SOI (inhomogeneity of SOI don't affect SiGe accuracy)**
- **Measurement done on product wafer with small spot**





Thin P / P+ Epi layers

Thin P/P+ epi layers



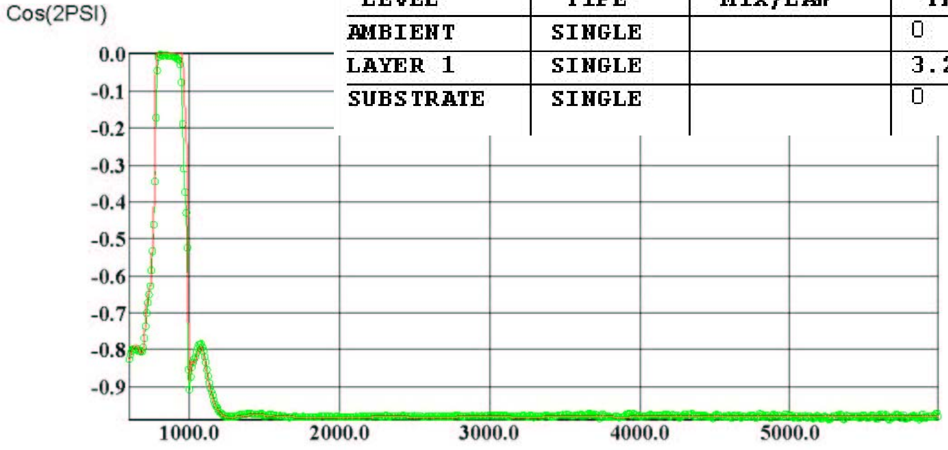
10 static measurements in the center of the wafer.

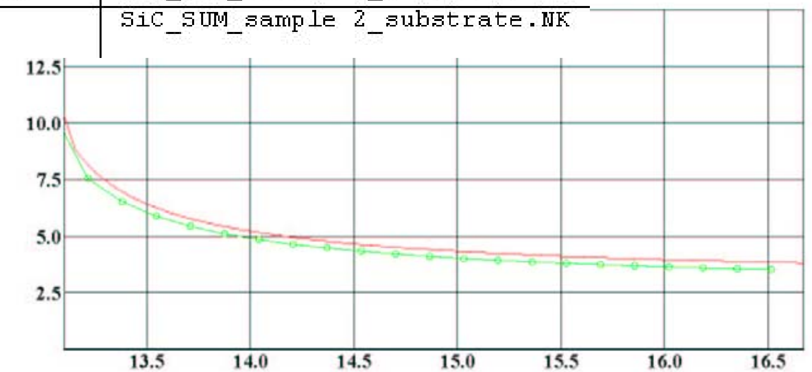
Meas n°	T(µm)	N (at/cm^3)
1	0.3235	3.23E+19
2	0.3233	3.22E+19
3	0.3225	3.20E+19
4	0.3223	3.21E+19
5	0.3238	3.21E+19
6	0.3220	3.21E+19
7	0.3237	3.21E+19
8	0.3220	3.21E+19
9	0.3231	3.21E+19
10	0.3227	3.21E+19

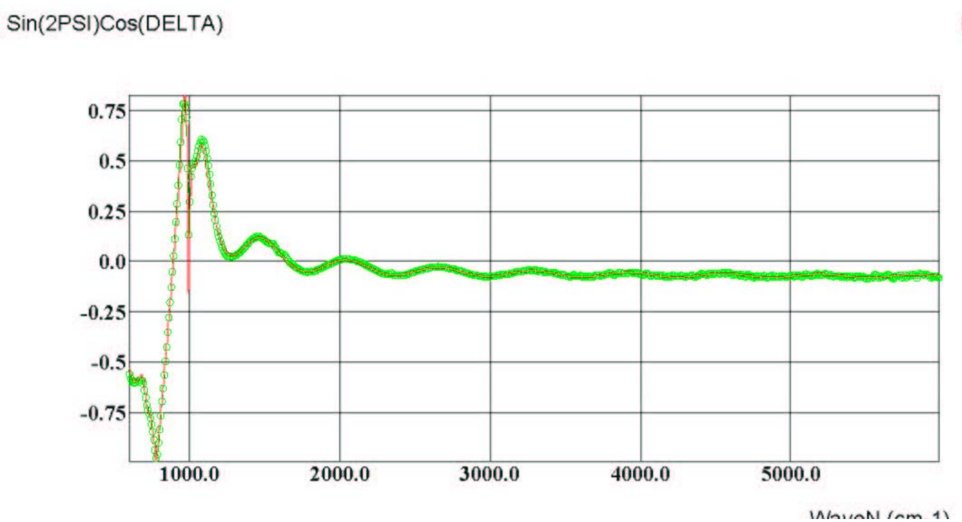
Max	0.3238	3.23E+19
Min	0.3220	3.20E+19
Mean	0.3229	3.21E+19
Std Dev.	0.001	6.3E+16
Std Dev.(%)	0.2%	0.2%

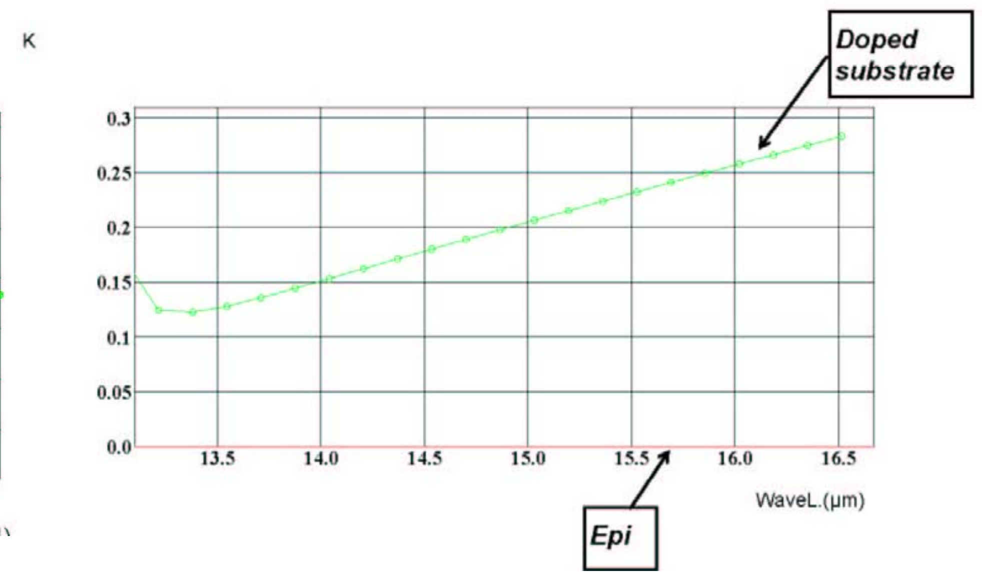
SiC epilayers

LEVEL	TYPE	MIX/LAW	THICKNESS	
AMBIENT	SINGLE		0	VOID.nk
LAYER 1	SINGLE		3.255657	SiC_SUM_sample 2_P Epi.NK
SUBSTRATE	SINGLE		0	SiC_SUM_sample 2_substrate.NK



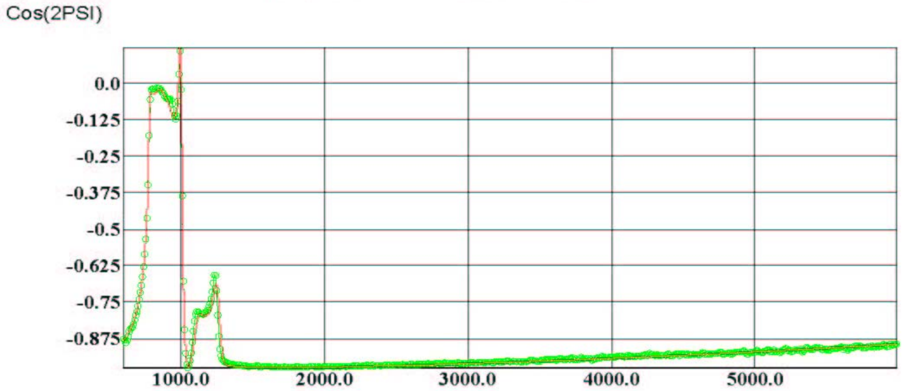


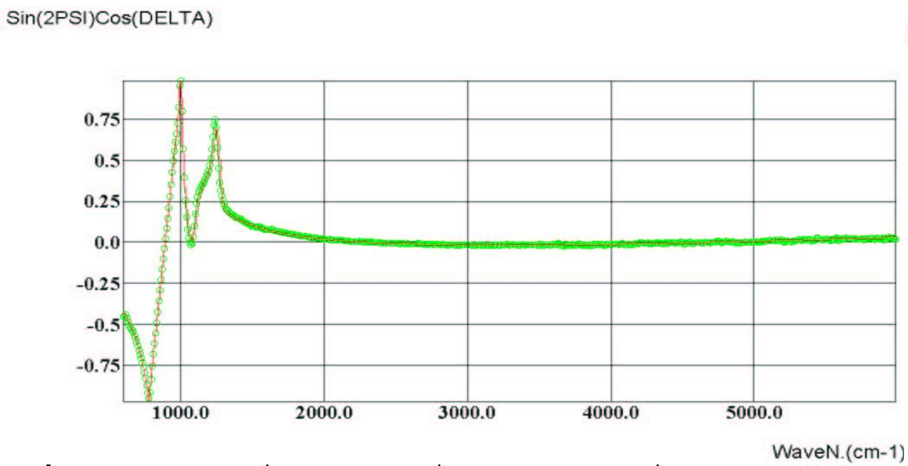




SiC epilayers

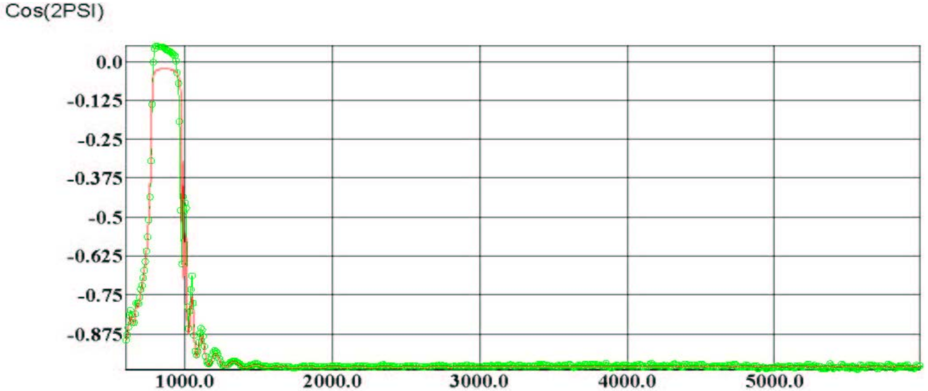
Thin Epi layer: 1000A

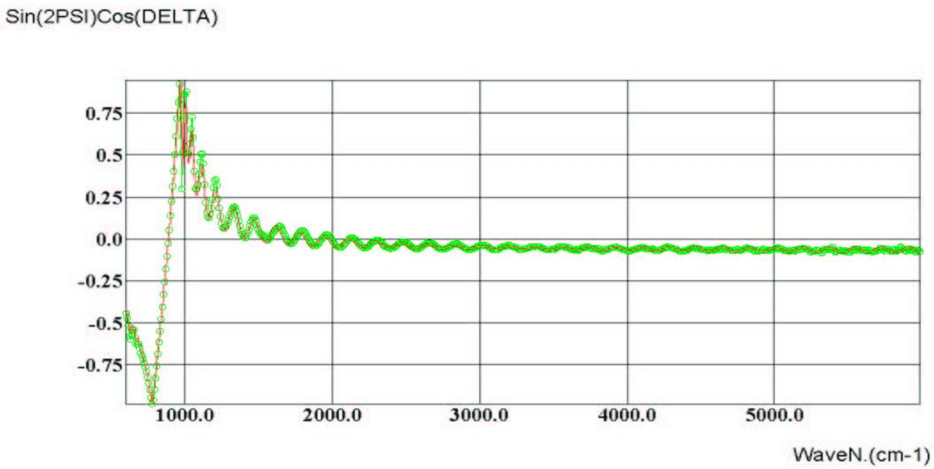




LEVEL	TYPE	MIX/LAW	THICKNESS
AMBIENT	SINGLE		0
LAYER 1	SINGLE		0.105109
SUBSTRATE	SINGLE		0

Thick Epi layer: 11.7 microns





LEVEL	TYPE	MIX/LAW	THICKNESS
AMBIENT	SINGLE		0
LAYER 1	SINGLE		11.706799
SUBSTRATE	SINGLE		0

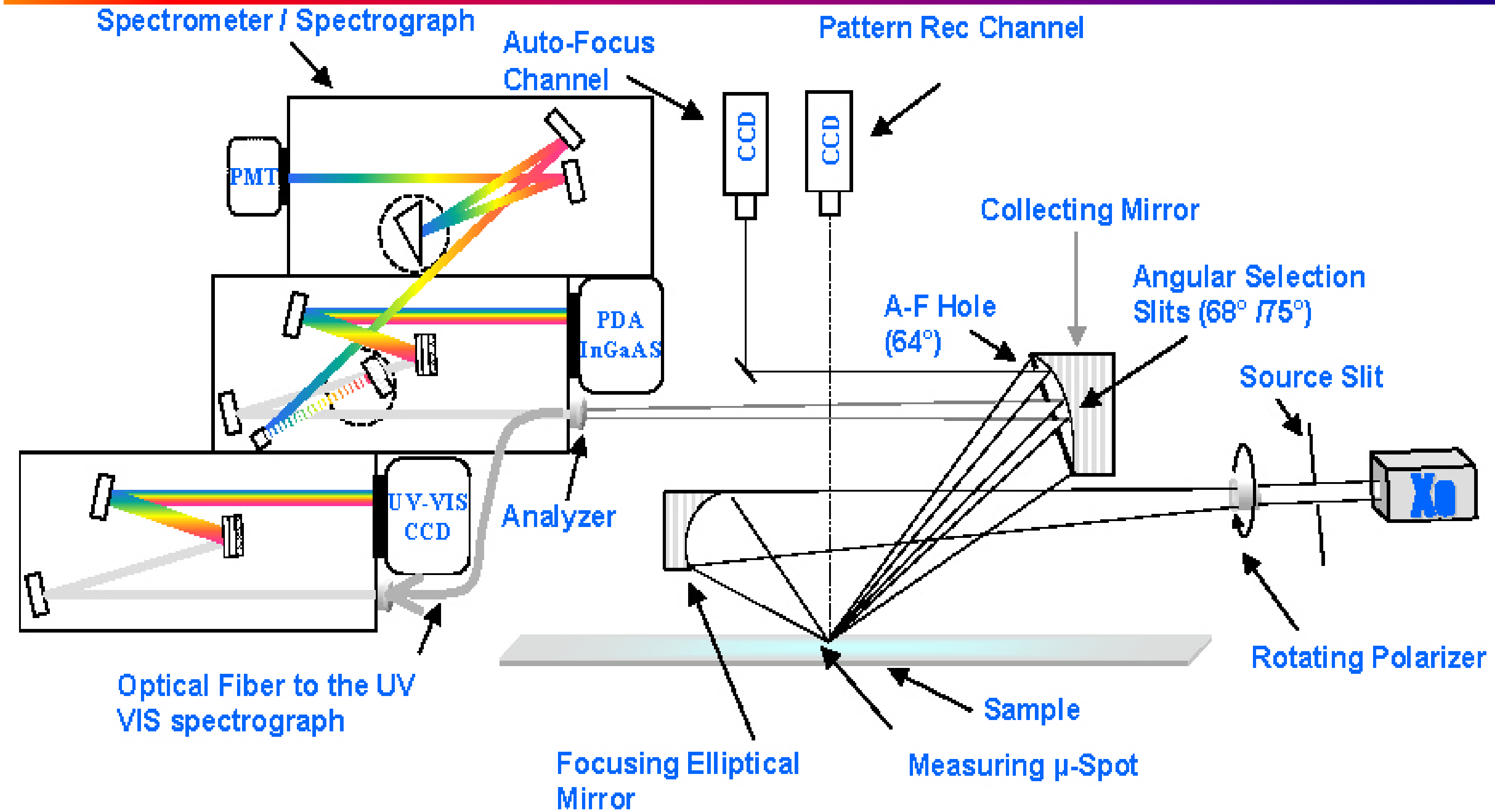
200 mm / 300 mm with FOUP or SMIF interface

Full Automation

Pattern Recognition and Autofocus

User-friendly interface

4 channels: UV-Visible
OMA CCD
OMA NIR
IR Ellipsometer

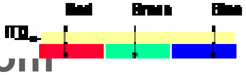


UV-VIS CCD SE is:

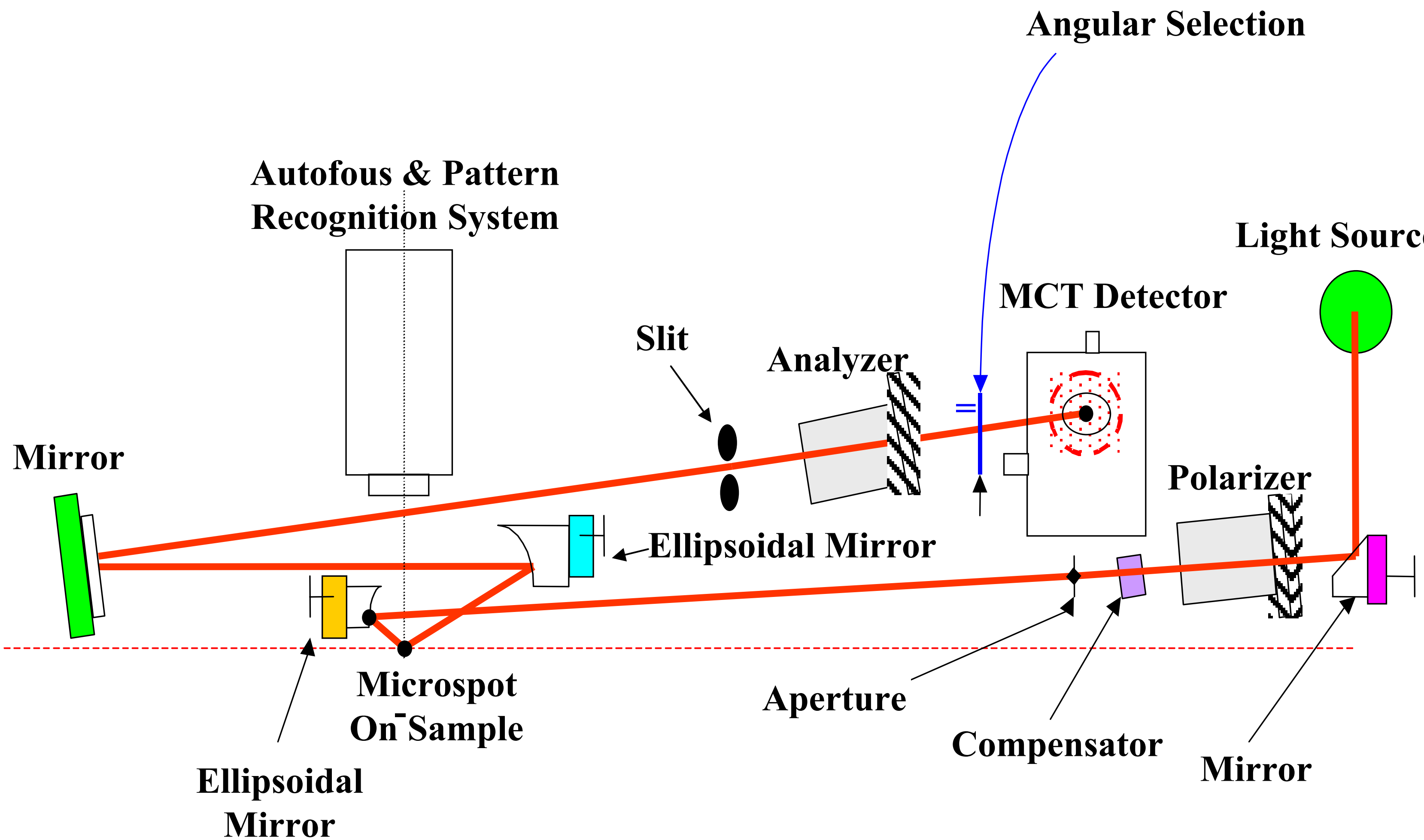
1. High speed measurement.
2. Single grating monochromator.
3. CCD detector based.

OMA-NIR SE is:

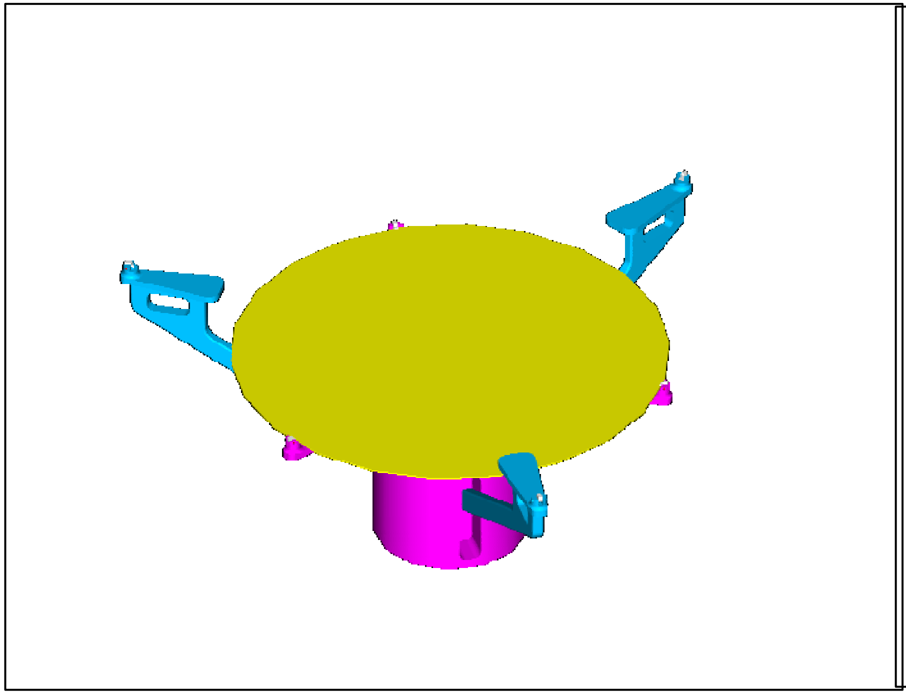
1. High speed measurement.
2. Single grating monochromator.
3. InGaAs PDA based detector
4. Near IR enhanced (1.7µm)



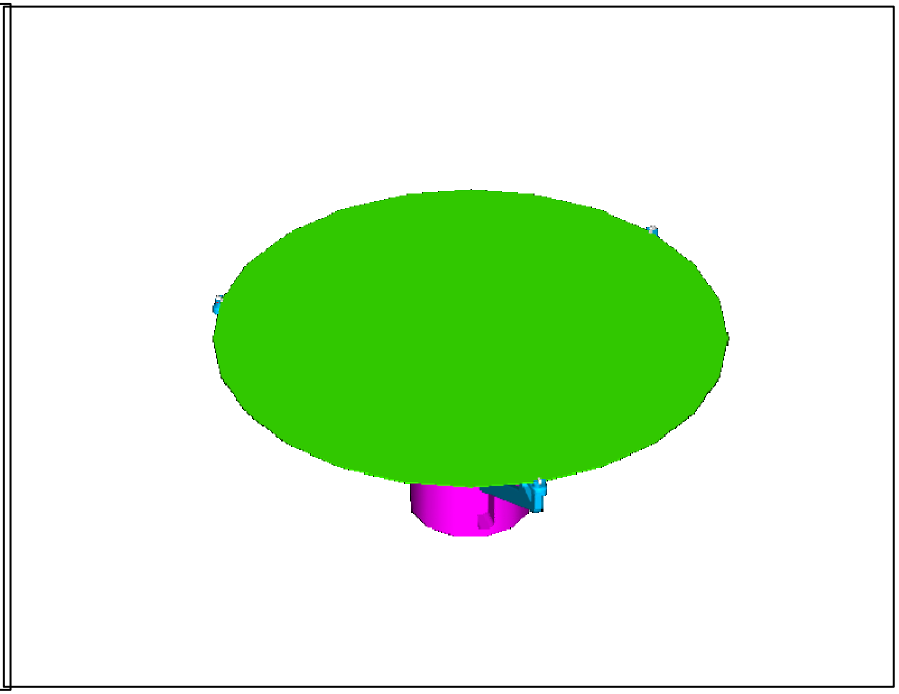
Fixed polarizer, rotating analyzer ellipsometer coupled to a Fourier Transform Spectrometer



Edge Grip Sample holder



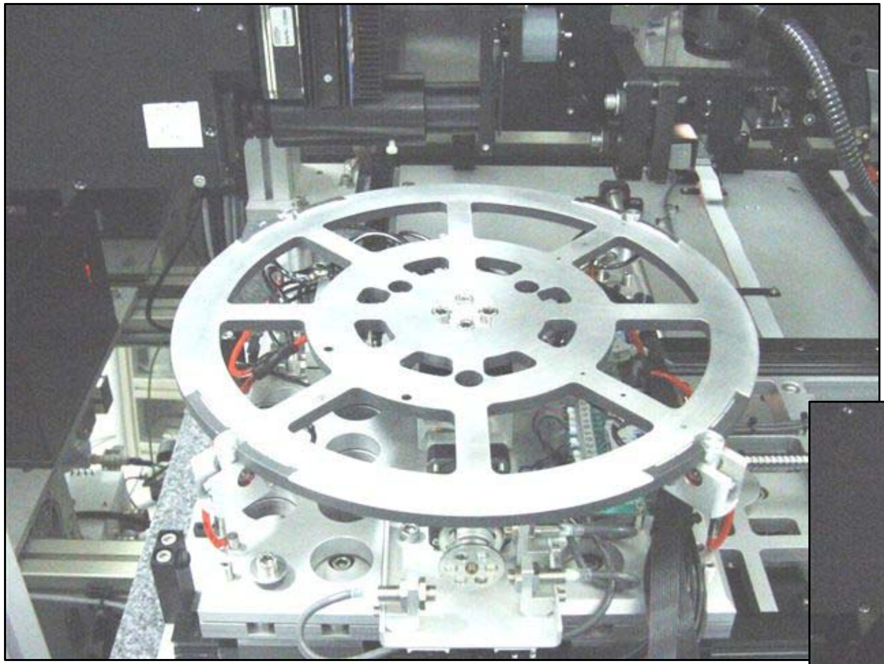
200 mm (without Edge Grip)



300 mm

- ✓ PEEK material in contact with the wafer
- ✓ Contamination specs: 1E10Atm/cm2

Edge Grip Sample holder



- Thank you !!!

- Contact: Laurent Kitzinger

  Lkitzinger@soprainc.com