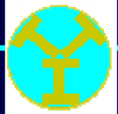
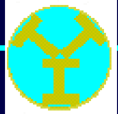


Phase Profilometry

WISE 2000

Junwei Bao, Costas Spanos
EECS, University of California, Berkeley
Xinhui Niu, Nickhil Jakatdar
Timbre Technology, Inc.



Outline

- Motivation of Phase Profilometry
- Electromagnetic simulation of ellipsometric response of periodical structures
- A library-based profile extraction method
- Sensitivity study and comparison with 2-θ scatterometry
- Recent experimental results
- Conclusion

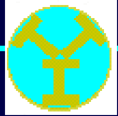


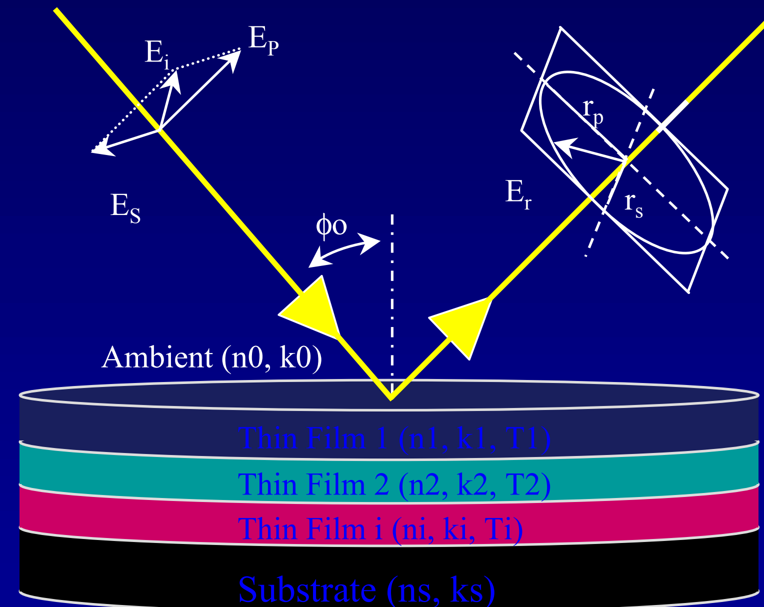
Illustration of Spectroscopic Ellipsometry

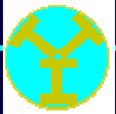
Thin Film Characterization

$$\rho = \frac{r_p}{r_s} = \mathrm{Tan}(\Psi).e^{j(\Delta)}$$

Measured Parameters

$\mathrm{Tan}\Psi$ and $\mathrm{Cos}\Delta$





Film Stack Analysis

TanΨ
Experimental
Measurement
CosΔ

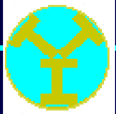
Physical Model
- Film Stack and structure
- Material n, k, dispersion
- Composition Fraction

Measurement
=
Model
Simulation ?

No

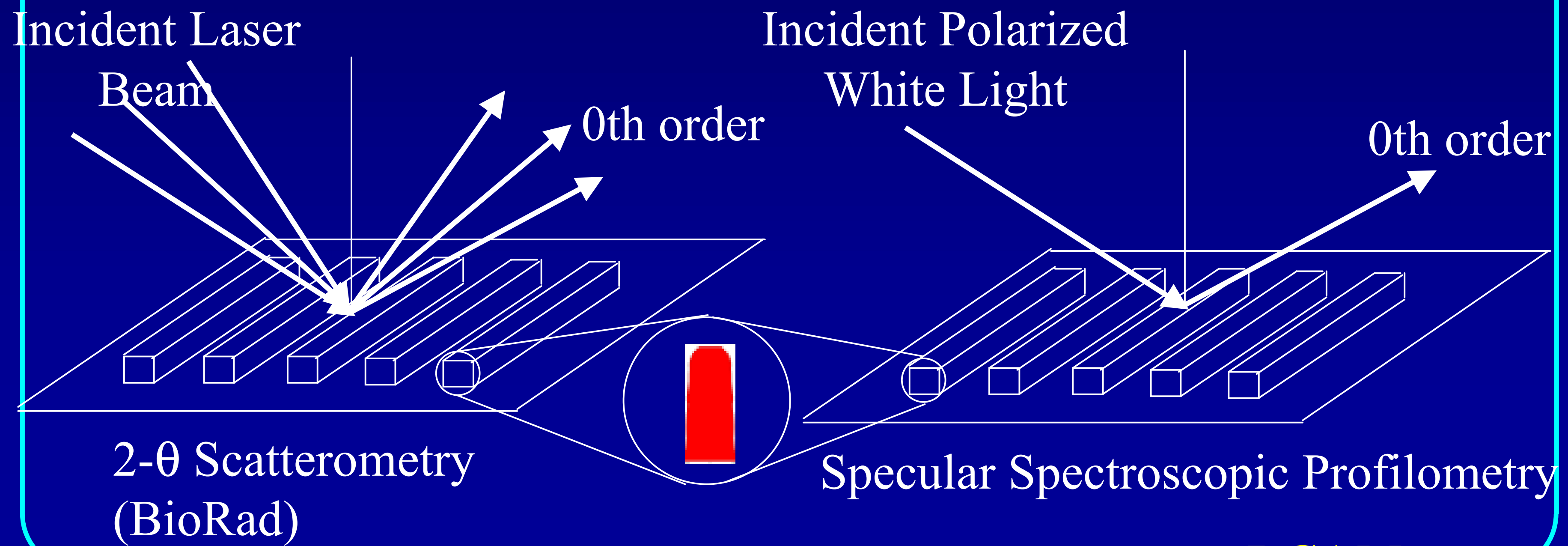
Yes

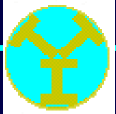
T_i , n_i , k_i



Concept of Optical Profile Metrology

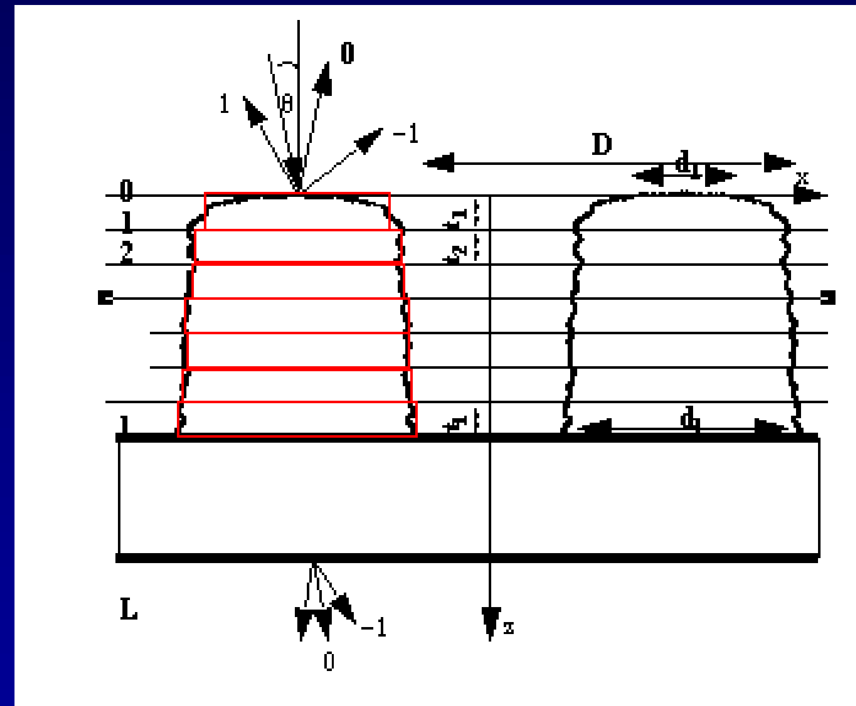
- Scattering (diffraction) of light from features produces strong spectral structure in reflected optical field
- Analyze structure to obtain topography information
- Periodic structures (gratings) can be numerically modeled "exactly"

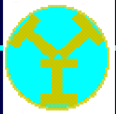




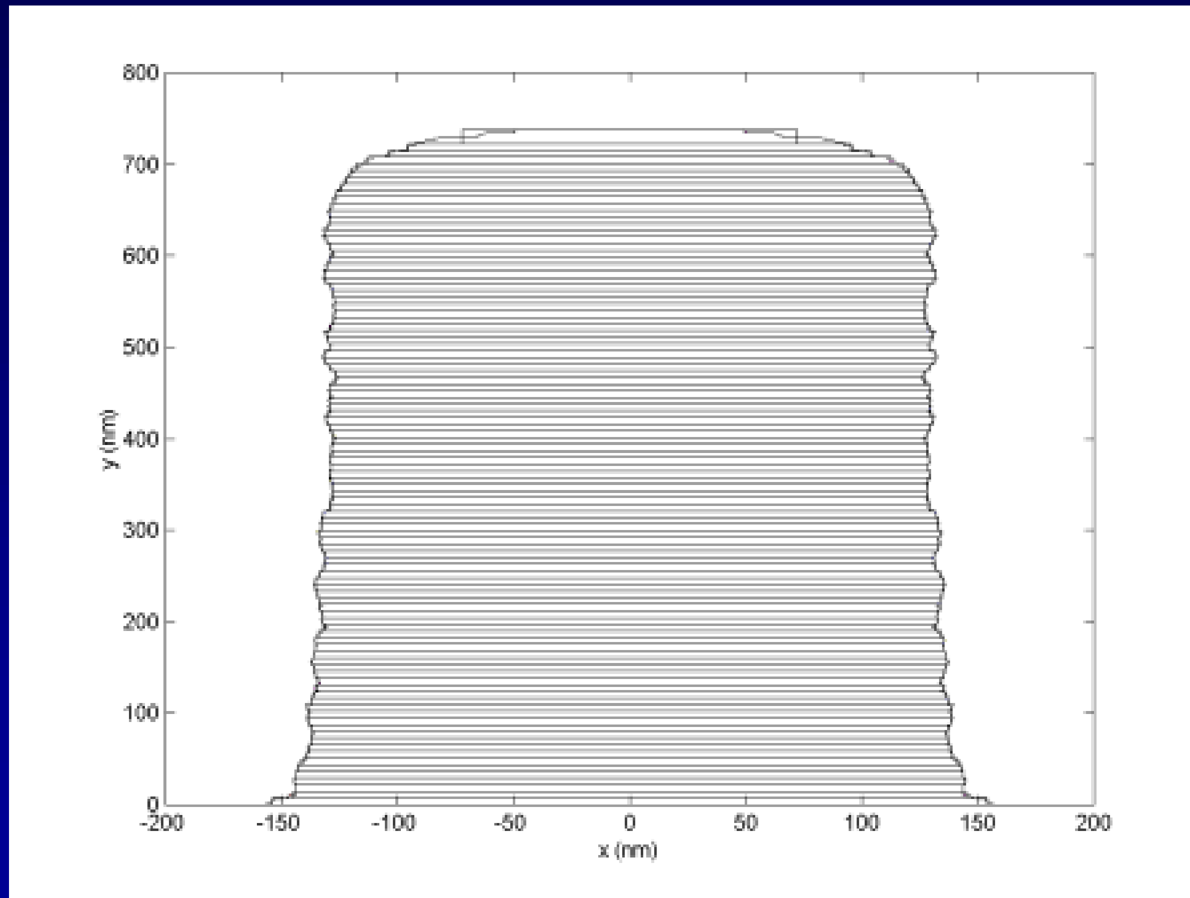
Electromagnetic Simulator

- Fourier expansion of the grating profile
- Eigensystem formulation
- Linear system solution of E&M field
- In theory, this approach is “rigorous”





CD-AFM Profile Segmentation



UV5:

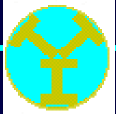
100 layers

739.75nm

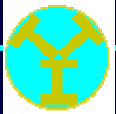
ARC:

1 layer

162.9nm



Simulator Convergence (TE)



Simulator Convergence (TM)

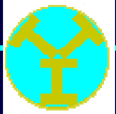
0th DE

0.05
0.045
0.04
0.035
0.03
0.025
0.02

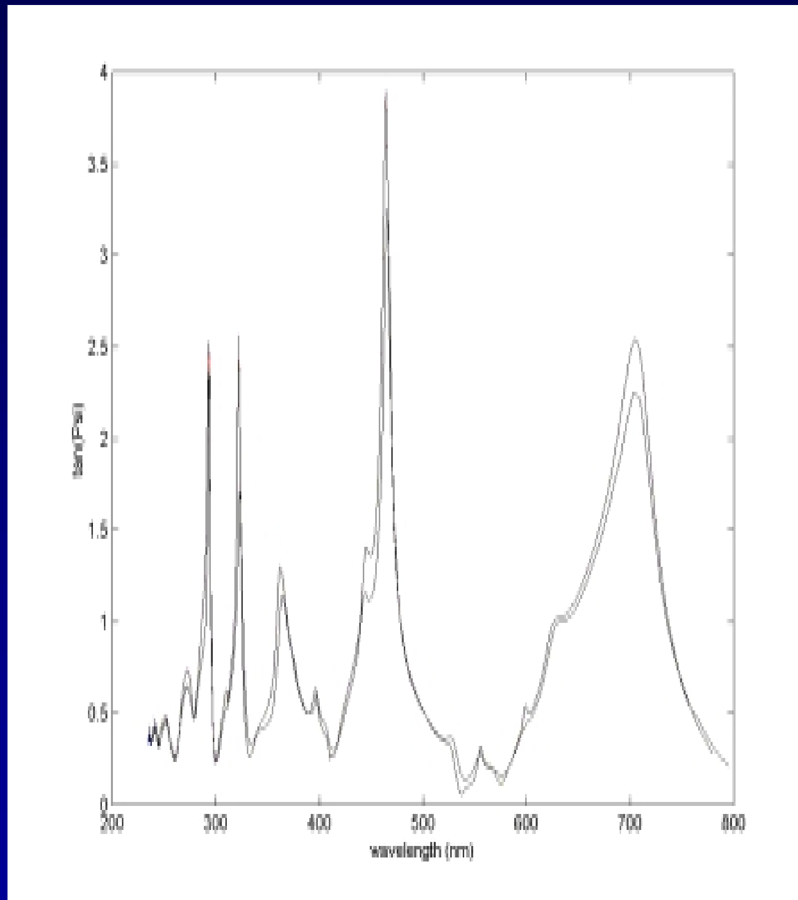
0 10 20 30 40 50 60

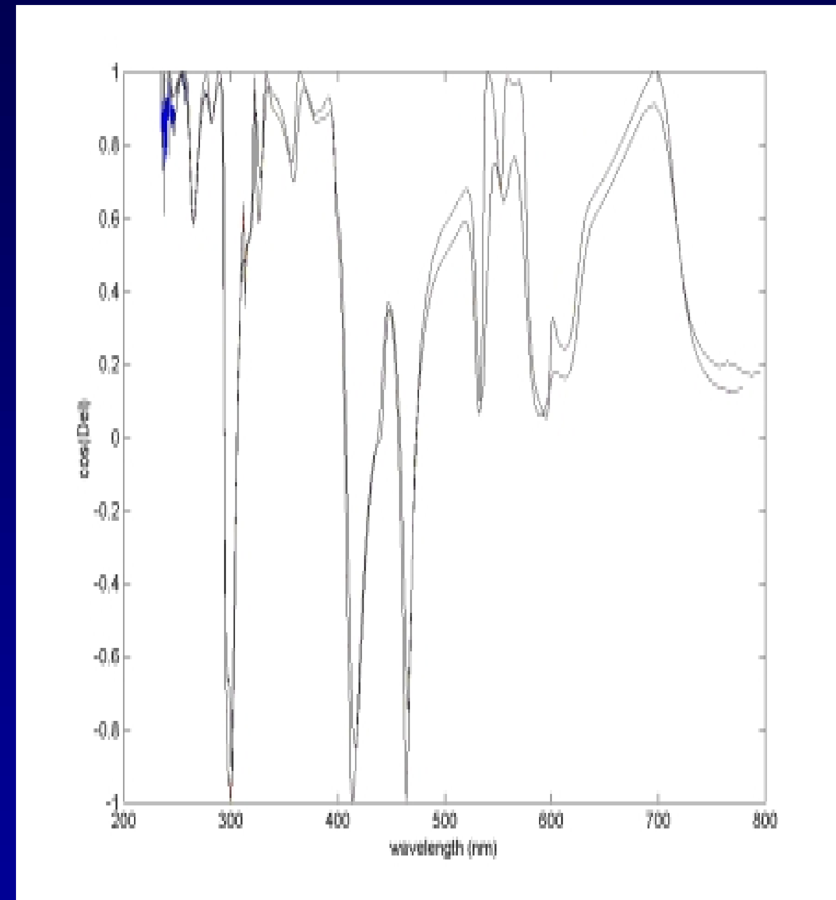
order

Transverse Magnetic
# of retained order = 41

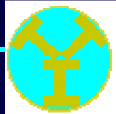


Comparison of Measured and Simulated Signal





blue – measured red – simulated



GTK online Interface at the SFR Website

Save | Open | Run Analysis | Help | About | Refresh

Period, nm: 660.0 Order retained: 2

BUILDER

Layer Select

Layer #: 21 Add Delete Insert

TopWidth, nm: 130.4

BottomWidth, nm: 130.4

Height, nm: 32.9 (Enter -1 for substrate)

Slices 1

Material: Titanium oxide 1 / UV5 / Ytrium oxide / Zirconium oxide

Load

Database URL: http://radon.eecs.berkeley.edu/~tduncan/cgi-

ANALYSIS Method: FTE

Independent	Constant	Min	Max	Step
Theta, deg	0	0	38	1
Phi, deg	0	0	0	0
Psi, deg	90	0	0	0
Lambda, nm	632.8	0	0	0

E-mail Address: tduncan@eecs.berkeley.edu

Current File: grating

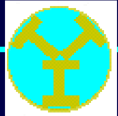
Status

Example layer: top width, bottom width, n-slices, height, theta, period width

layer: 21, layer: 20, layer: 19, layer: 18, layer: 17, layer: 16, layer: 15, layer: 14, layer: 13, layer: 12, layer: 11, layer: 10, layer: 9, layer: 8, layer: 7, layer: 6, layer: 5, layer: 4, layer: 3, layer: 2, layer: 1, layer: 0

http://radon.eecs.berkeley.edu/~tduncan/gtk2.html

BCAM



A Library Based Methodology for Profile Extraction

1

Profiles

gtk

Diffraction Grating Response

2

Pre-computed, off-line library build

Compiled Library

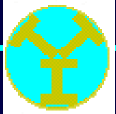
3

Real-time, in-line measurement

Measured

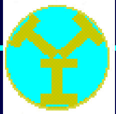
Extracted

BCAM



FEM Experiment for 1D Grating

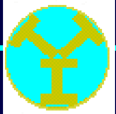
center: 13.5mj/cm^2
0µm
dose step: 0.5mj/cm^2
focus step: 0.1 µm
area: 200µmX200µm
KLA-Tencor UV-1280 SE



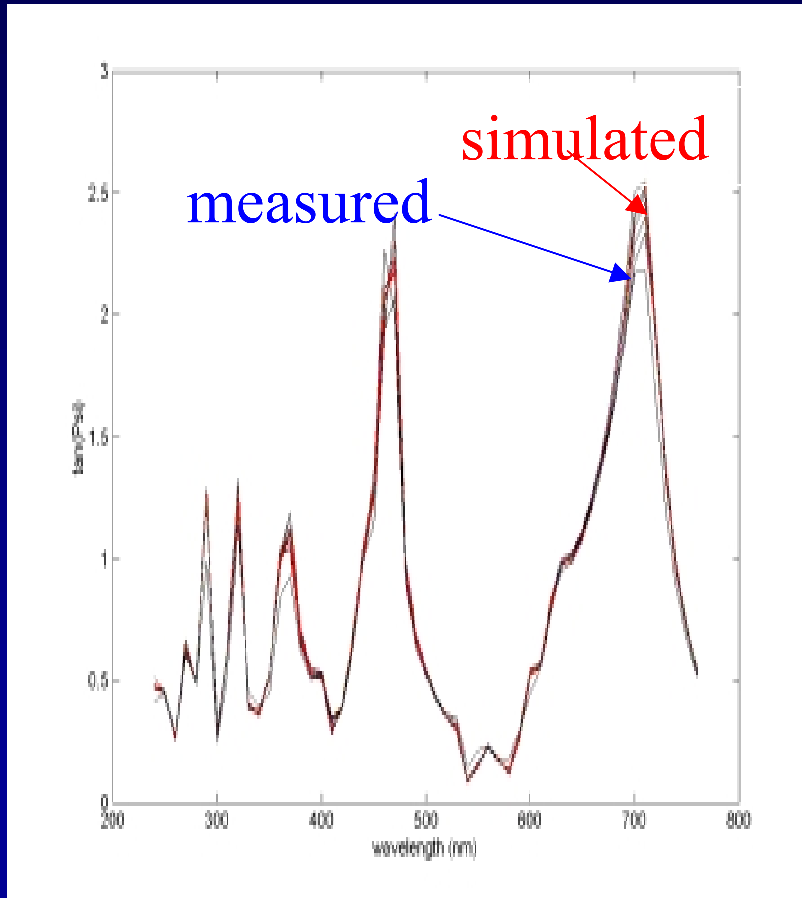
TanΨ of the Entire FEM

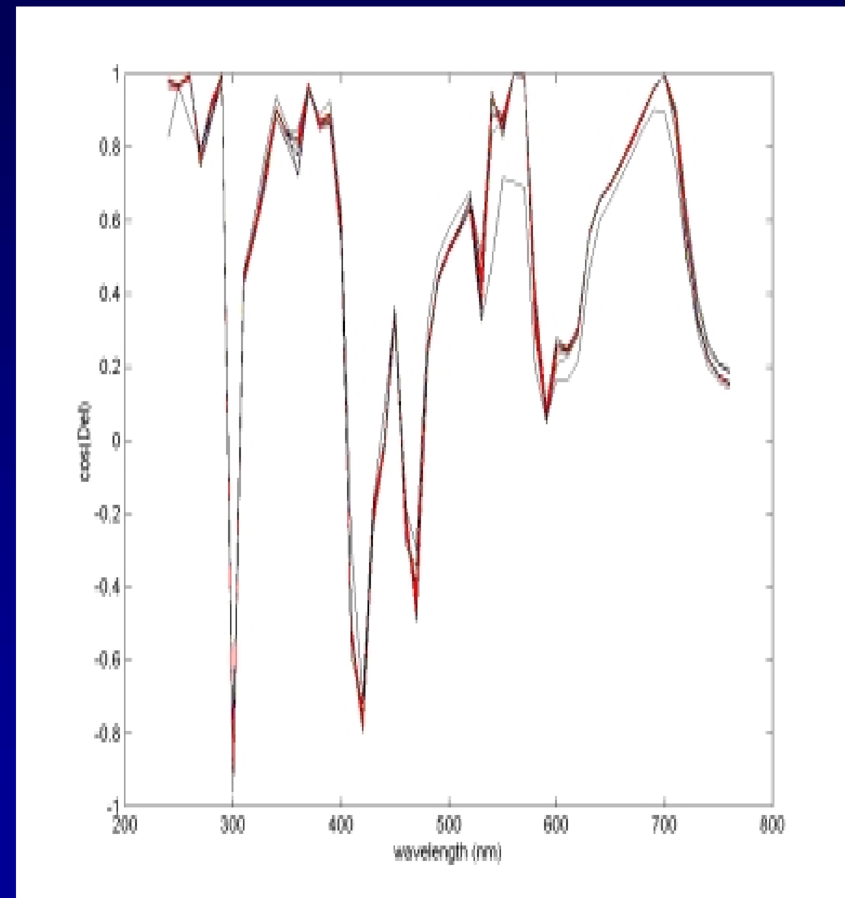
Dose: -3 -2 -1 0 1 2 3

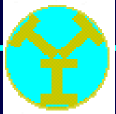
Focus: 2 1 0 -1 -2



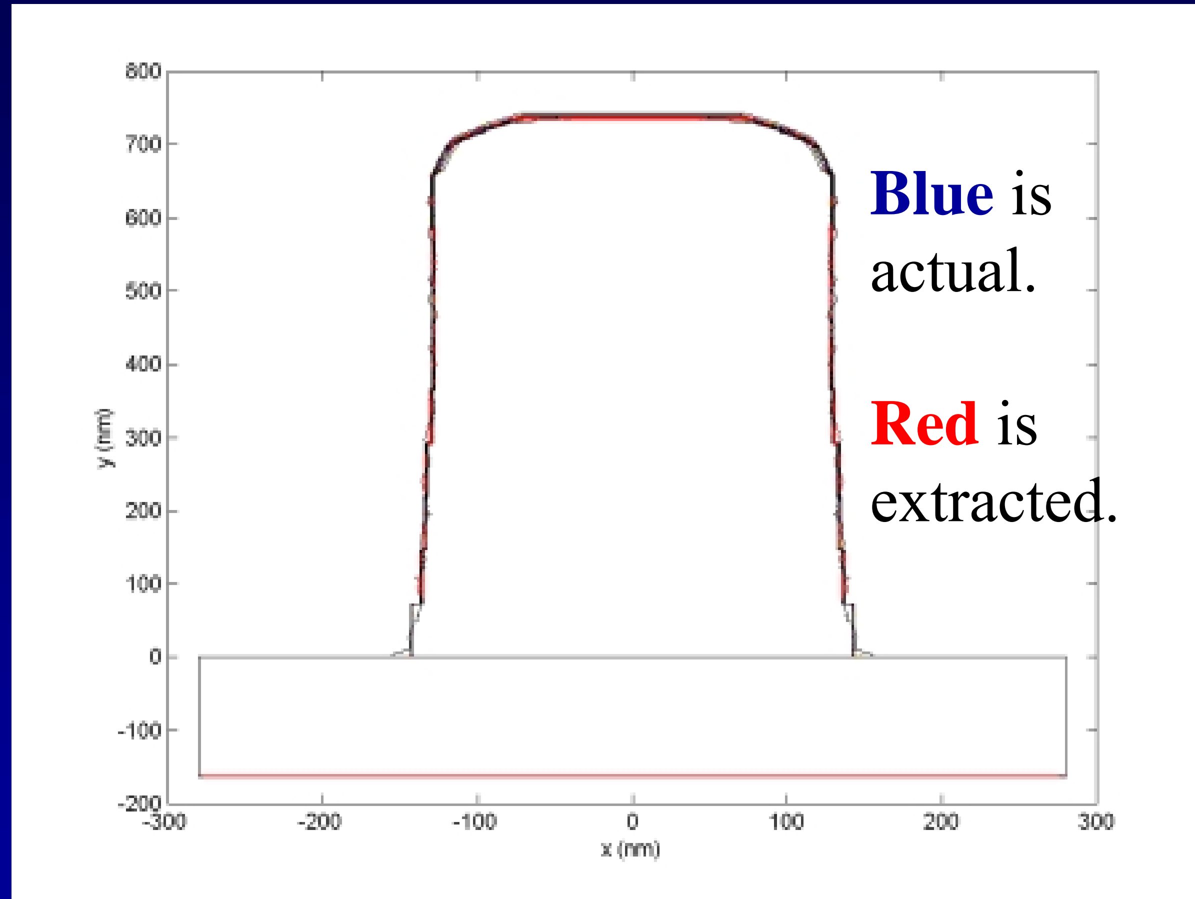
Matching on TanΨ and CosΔ





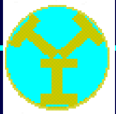


Example of Profile Extraction

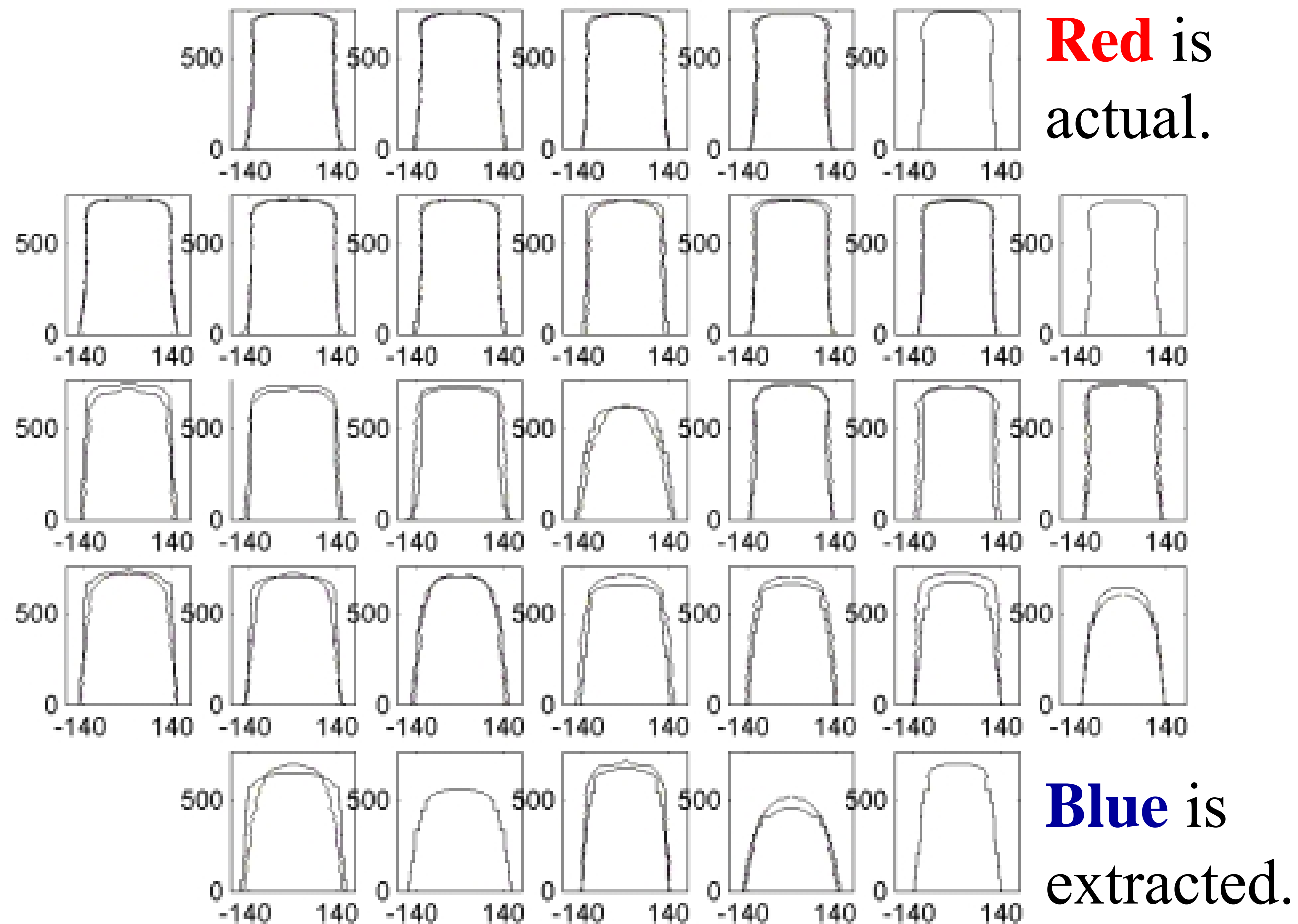


Blue is actual.

Red is extracted.

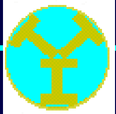


Profile Extraction over the Entire FEM

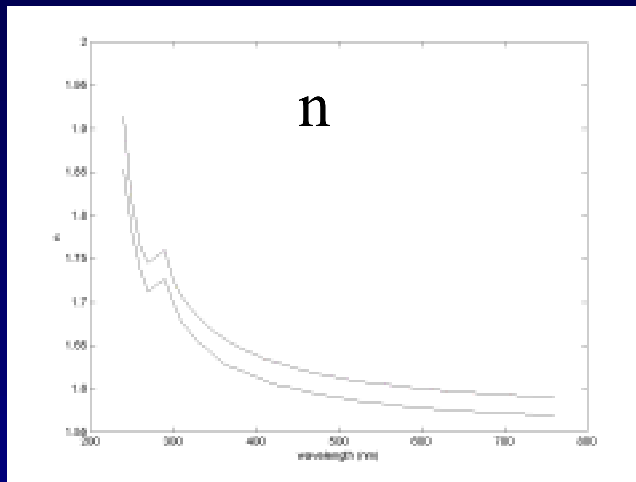


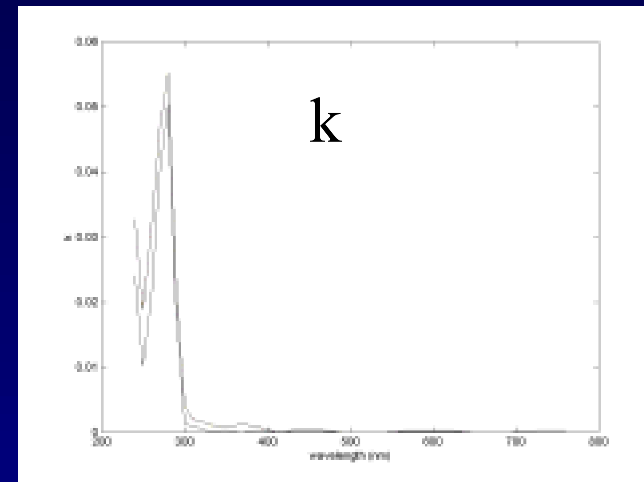
Red is actual.

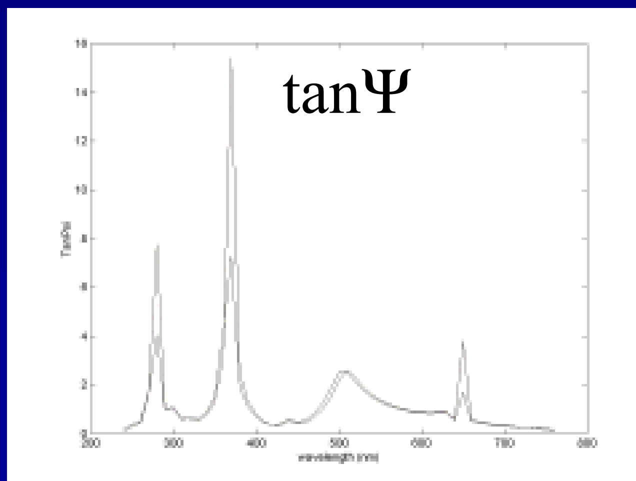
Blue is extracted.

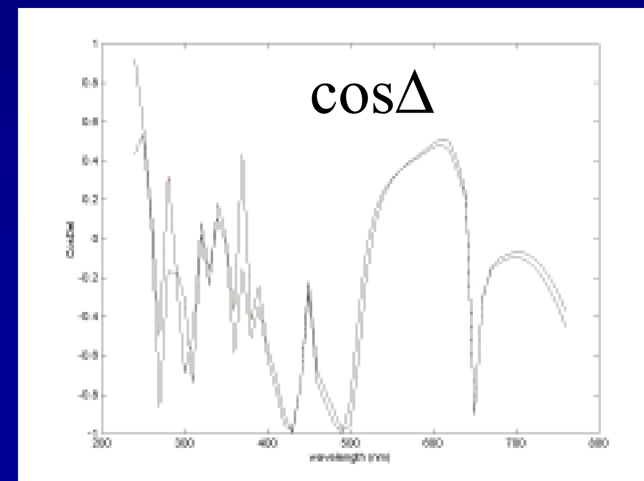


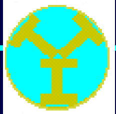
The Effect of Material Index Variation (UV5)



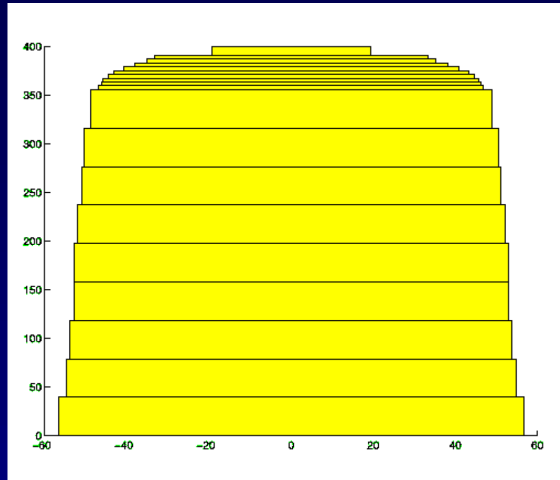


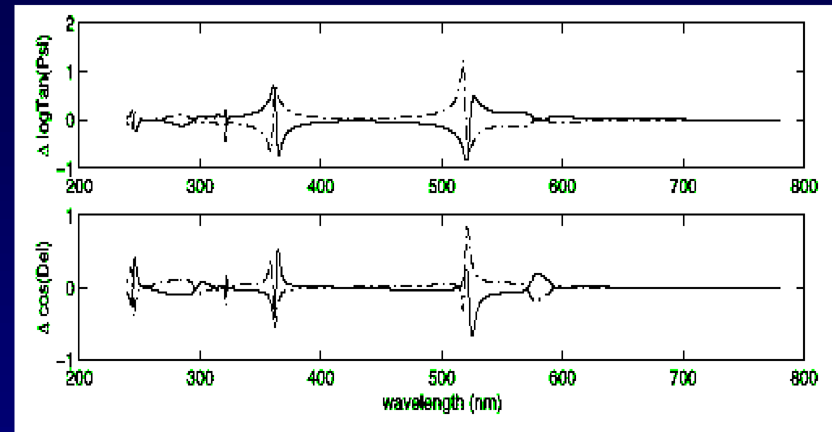




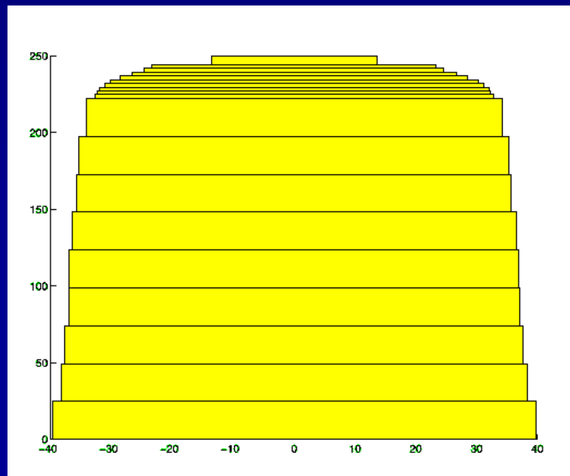


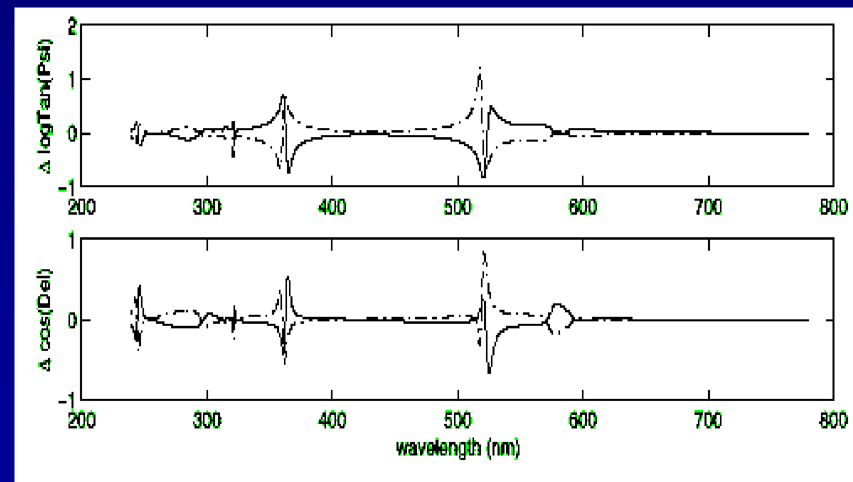
Sensitivity Analysis – Phase Profilometry



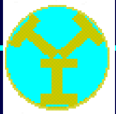


1.5nm Sensitivity



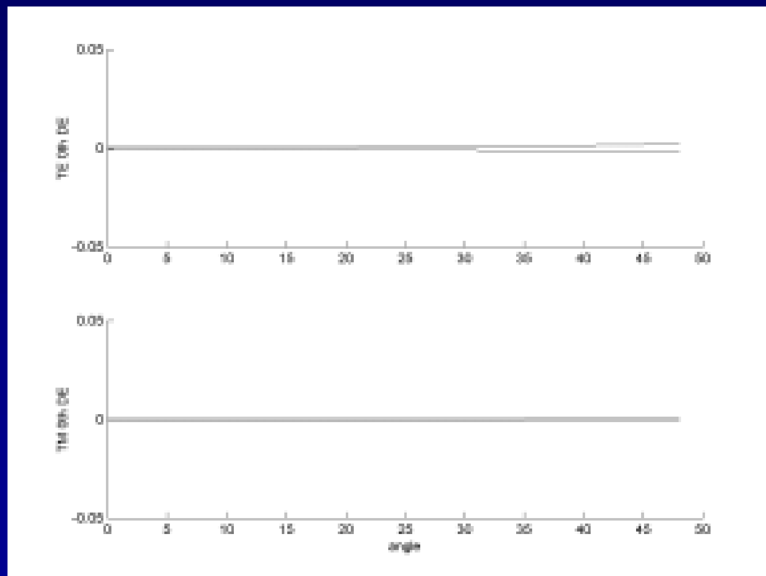


1nm Sensitivity

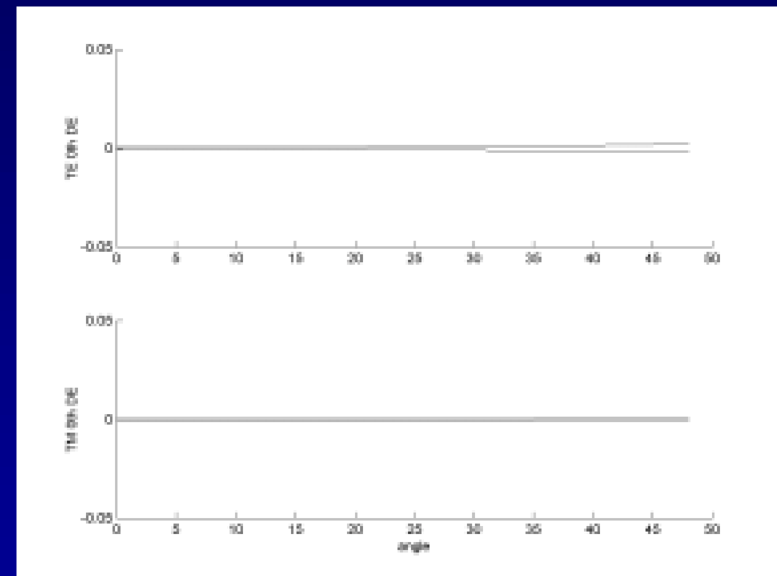


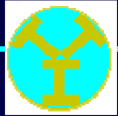
Sensitivity Analysis -- 2θ Scatterometry

1.5 nm Sensitivity



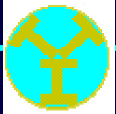
1 nm Sensitivity





Comparison between Phase Profilometry and 2θ Scatterometry

Phase Profilometry	2θ Scatterometry
• Multi wavelength, fixed angle	• Multi angle, single wavelength
• Uses existing Spectroscopic Ellipsometer	• Requires specialized hardware
• Both magnitude and phase info	• Magnitude reflectivity only
• More sensitive to profile variation	• Less sensitive to profile variation
• Utilizes full spectrum material property, less prone to uniqueness problem	• Uses material property at single wavelength, unable to distinguish films with similar optical properties at measurement wavelength

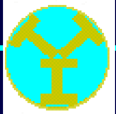


Gate Stack with 193 nm Lithography

120/120 Line/Space

Focus-Exposure Matrix

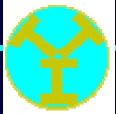
Measurement Area: 120 µm * 80 µm



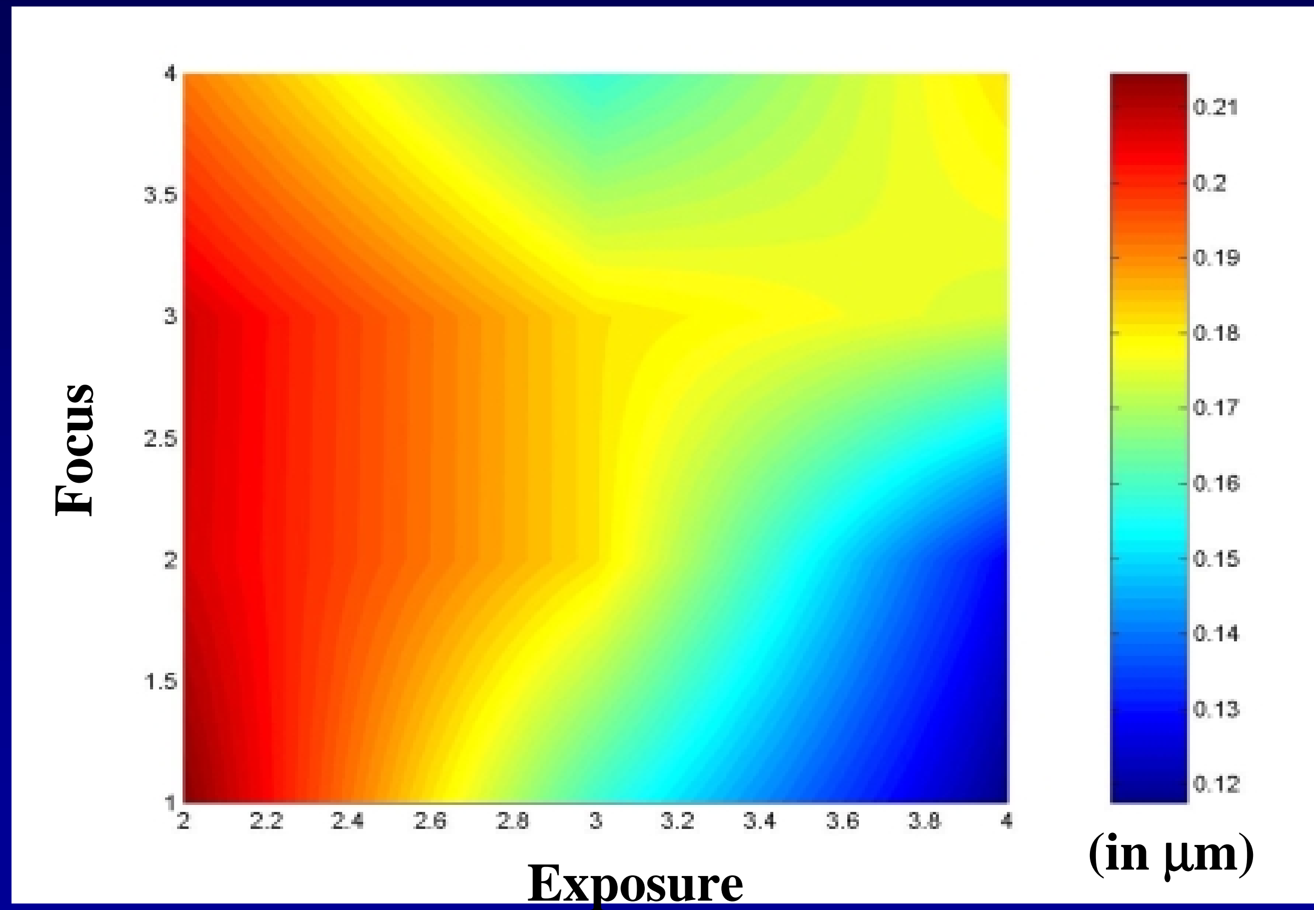
Extracted Profile

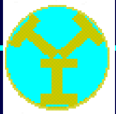
Focus (in µm)	18.0	16.5	15.0	13.5
-0.5				
-0.2				
+0.1				
+0.4				

Exposure (in mJ/cm²)

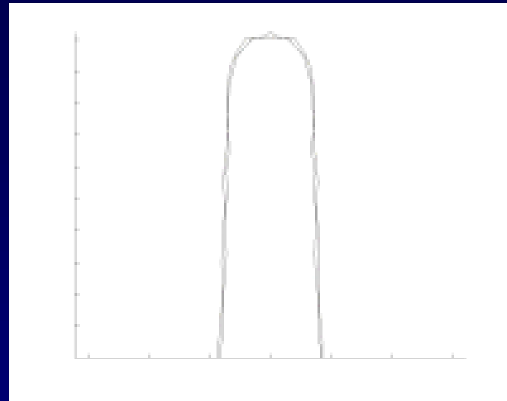


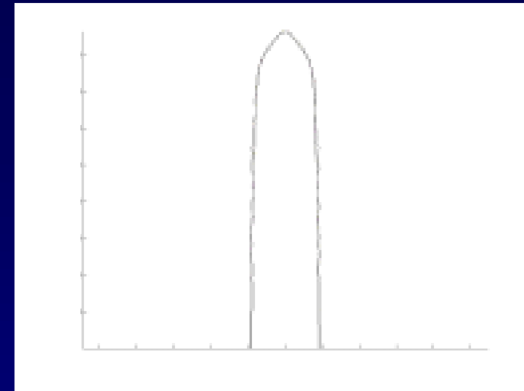
CD Contour Map





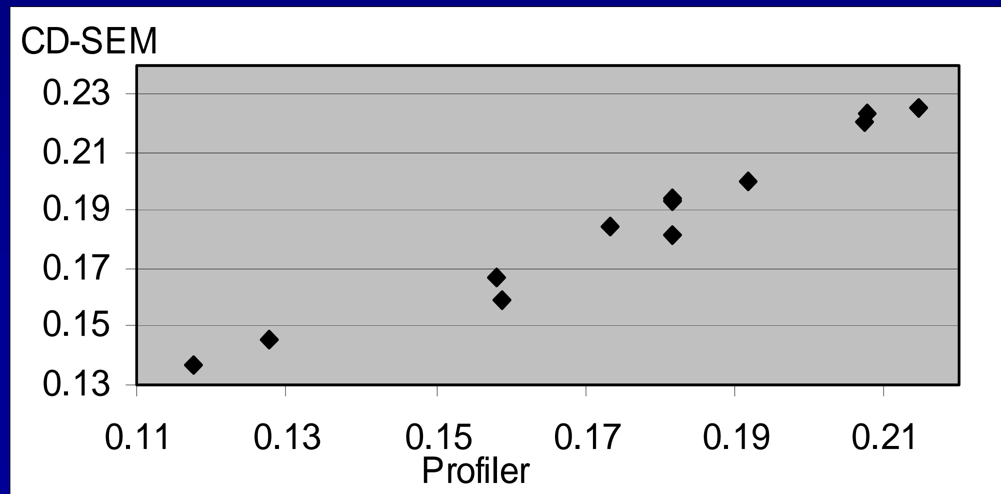
Comparison with AFM and CD-SEM

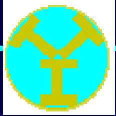




Phase profilometry in Red   AFM in Blue

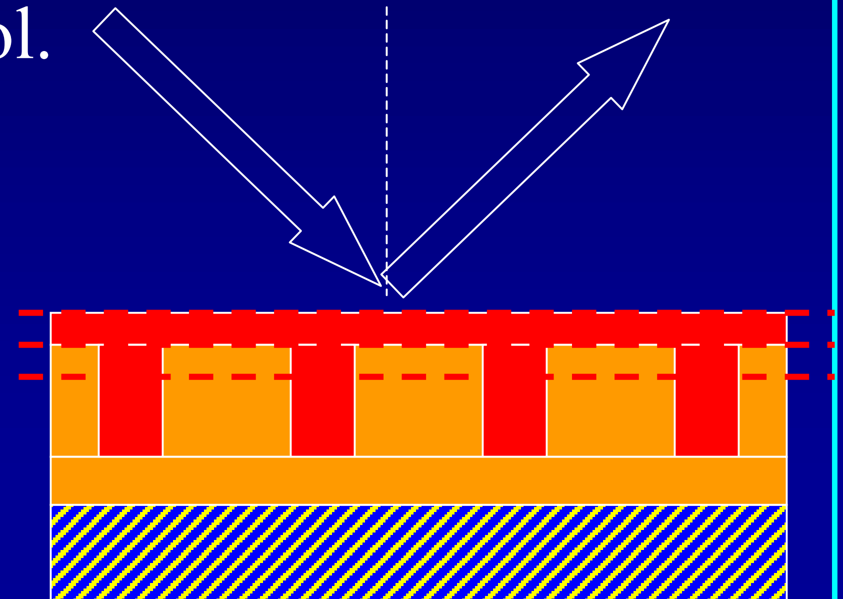
Correlation = 0.98

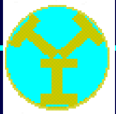




Proposed Application for Damascene Process In-line Metrology

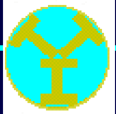
- Damascene Processes bring a new, difficult challenge to critical dimension measurement.
- Metal line metrology and endpoint detection is important for process control.
- Both film thickness and metal line profile can be measured and used for process control.





Advantages of Phase Profilometry

- Accurate and full profile information
- Uses software plus cheaper hardware (compare to CD SEM) already existing in fabs
- Throughput comparable to CD-SEM
- Scalable for future technologies
- Non-destructive
- Inline/in-situ capable
- Does not require "golden" wafer to calibrate
- Capable to measure both profile and film stacks



Conclusion

- Phase profilometry shows high sensitivity to profiles of gratings.
- Profiles of FEMs have been extracted for resist, poly and metal features.
- Good correlation with CD-SEM and AFM was achieved.
- Phase profilometry is a promising in-line CD and profile metrology for the sub 180nm pattern transfer process.
- The rich information obtained from phase profilometry can be further used for process optimization and control.