Review of CD Measurement And Scatterometry.

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Outline.

- Context for scatterometry introduction
- Demonstration and optical CD-techniques ranking
- Scatterometry user valuation in fab
  - Gate and STI modules
  - Equipment follow-up
- Defect sensitivity
- Future development and perspective

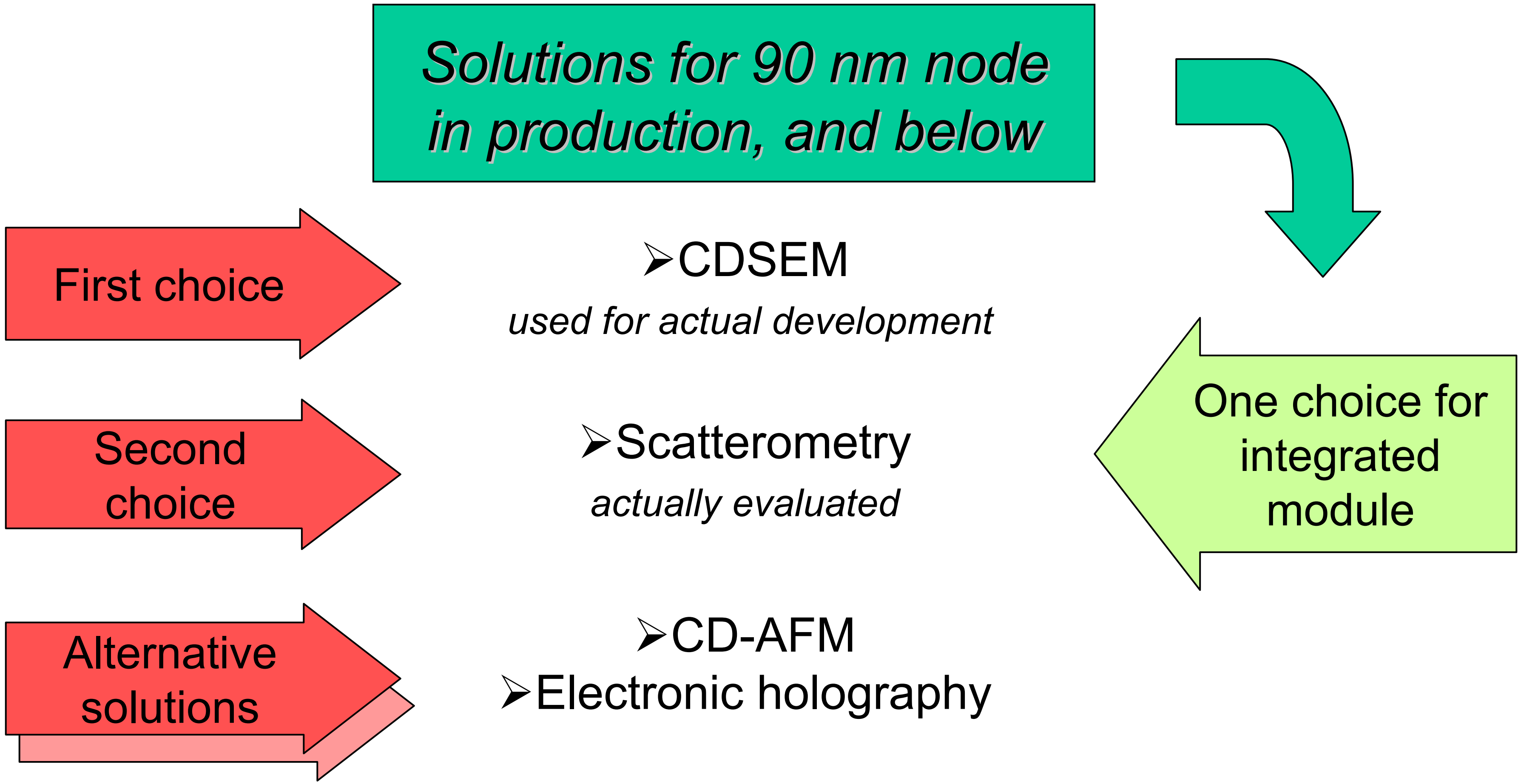
Context and needs for litho and etch.

- New challenges in metrology for patterning processes:
  - Integration in production equipments
  - Multi parameter and cluster tool
  - 300 mm related issues
- ITRS claims: precision performances

node	CD	OVL
90 nm	0.6 nm 3σ	3.5 nm 3σ
65 nm	0.41 nm 3σ	2.3 nm 3σ

- More aggressive challenges for early process development in litho and etch.

Metrology tool offer.



Solutions for 90 nm node in production, and below

First choice

- ➢CDSEM

used for actual development

Second choice

- ➢Scatterometry

actually evaluated

One choice for integrated module

Alternative solutions

- ➢CD-AFM
- ➢Electronic holography

Scatterometry tools.

- Hardware basis:
  - Spectroscopic ellipsometer
  - Spectroscopic polarized or not reflectometer
  - Angle-varying reflectometer
  - Others (extended ellipsometry or goniometry)
- Software for analysis and computation
  - Direct regression
  - Library generation and scan
  - Need for powerful computer in any case
- Target on silicon
  - Grating fully representative of technology
  - Global measurement of line profile
  - Large area required in scribes

Mainly existing (TF)

Main effort on simulation

Users input needed

Optical scatterometry metrology

- Actual evaluation of scatterometry for CD measurement
  - Technique assessment
  - Complement to CD-SEM

BUT…

- No image of the target
  - Defects
  - No X-Y analysis
- Target size
- Lack of universality
  - 2D patterns - holes
  - Isolated pattern

Expectations…

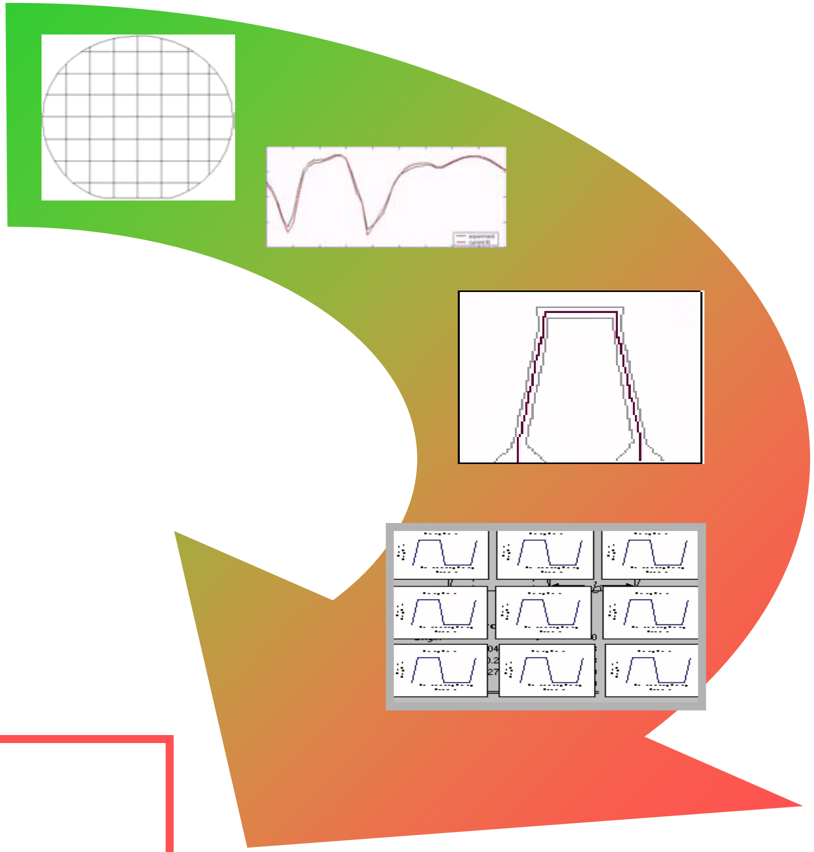
- Profile measurement
- Holes measurement
- Extension to overlay

… or solutions

- Target stacking
- Defect sensitivity study

Independant library approach.

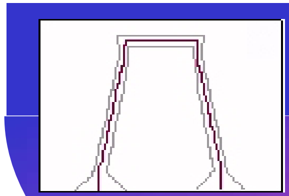
Sample wafer
Grating measurement
Model definition
Library generation
Library optimization and sensitivity evaluation
Library validation



Wafer loading
Target measurement
Library scanning
CD, profile and GOF display

Direct regression approach.

Model definition ?



Wafer loading

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Grating Target measurement

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Direct regression

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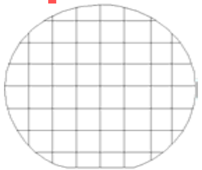
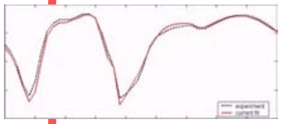
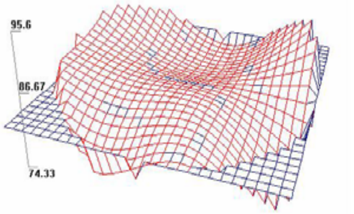
CD, profile and GOF display

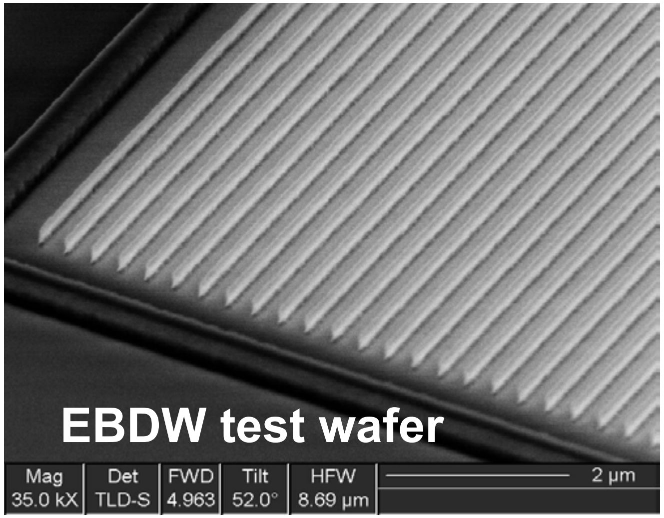






Demo wafers description.

- 193 nm litho wafers
- E-beam written wafers
  - 200 mm wafer
  - Two e-beam technologies
- Reference measurements
  - CD-SEM as standard productoion tool with averaged measurement on scatterometry target
  - FIB SEM for 3D views



CD	pitch
150nm	300nm
100nm	240nm
70nm	280nm
60nm	360nm

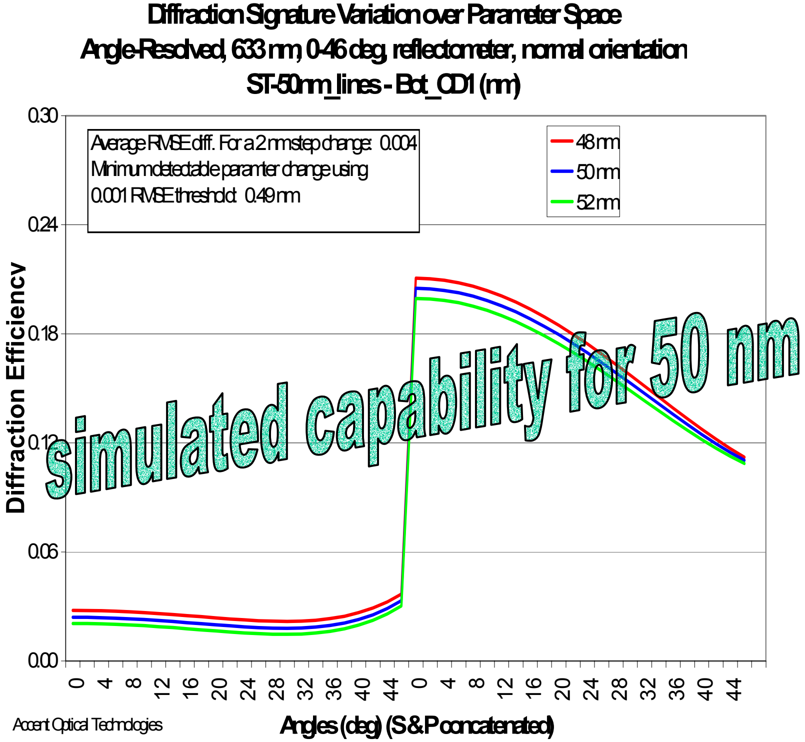
Feasibility simulation.

- Use of suppliers simulation capability

  See graph concerning goniometry

- Use of commercial RCWA model

- Use of local partner simulation engine and first demonstration on spectroscopic ellipsometer



simulated capability for 50 nm

Courtesy of Accent

Demonstration protocol.

- Demonstration with main metrology suppliers
  - 7 HW tools evaluated
  - 6 SW tools used
- Protocol
  1. Blind demonstration
  2. Refinement after cross section profile disclose
  3. Some simulation results for 65 nm technology

Global good results concerning accuracy and precision.

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Some outstanding guess on not disclosed layer stack.

Global difficulties to obtain homogeneous characterisation (HW – precision).

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Refractive index impact

Demonstration results

- 2 runs demonstration for litho application
- Technology ranking and supplier selection
- Drives specifications towards next metrology solution

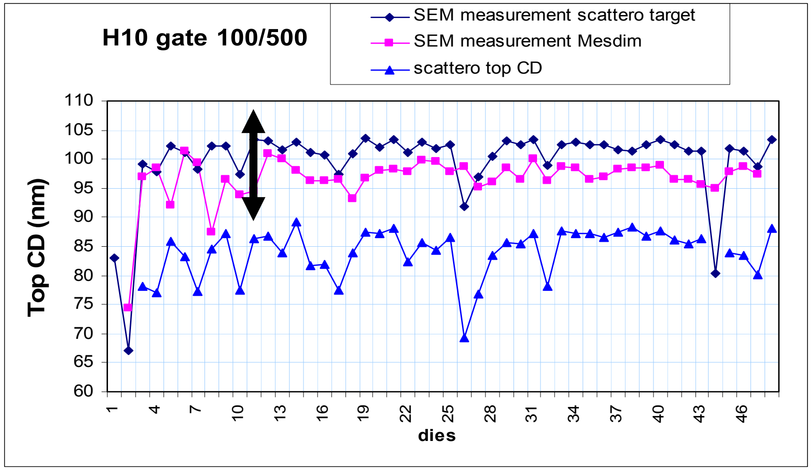
Technique	Shift to reference CD	Dyn. reproducibility (3σ)	Configuration
Spectroscopic ellipsometry	7 nm	0.8 nm	+
Reflectometry	5 nm	NA	++
Polarized reflectometry	8 nm	1.4 nm	++

Mean values over techique and design CD.

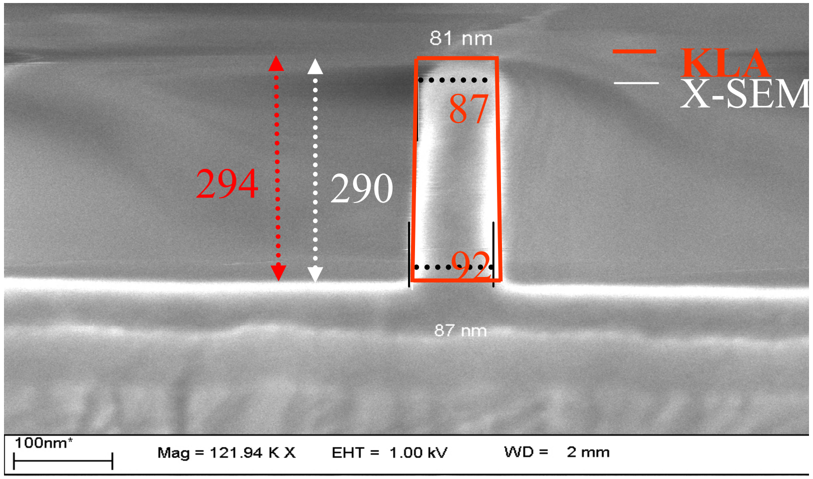
On-site evaluation.

- KLA-Tencor tool operated by ST with local research laboratory support
  - Defined program :
    - Active, gate and metal 1 layers, fab assessment
    - Advanced applications (dual damascene, spacers, …)
    - Process monitor, litho and etch cell qualification
    - Defects sensitivity and fine profiling
- Wishes
  - Other hardware on-site evaluation
  - Further tests of direct regression software solution

Gate for 90nm node

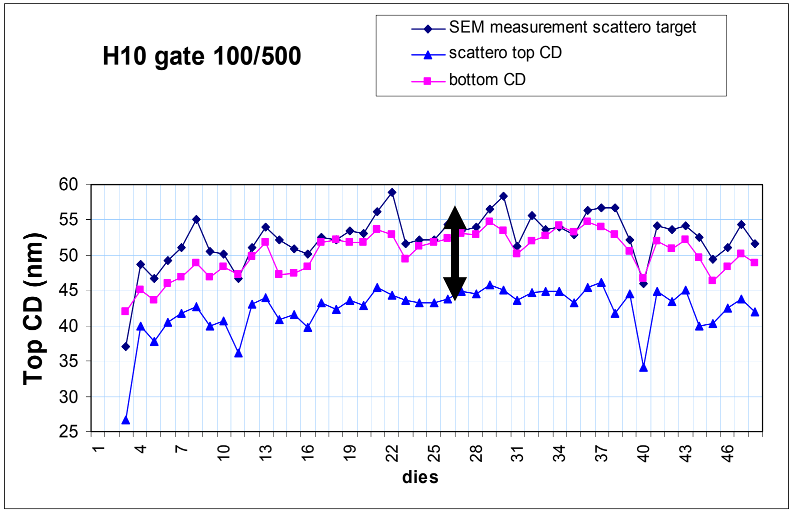


LITHO

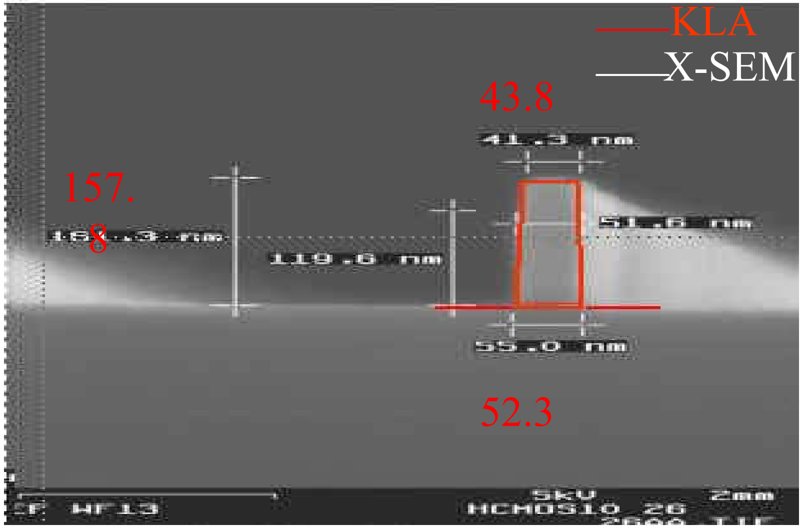


CDSEM correlation

Cross section correlation



ETCH



90nm gate metrology after etch

Library robustness

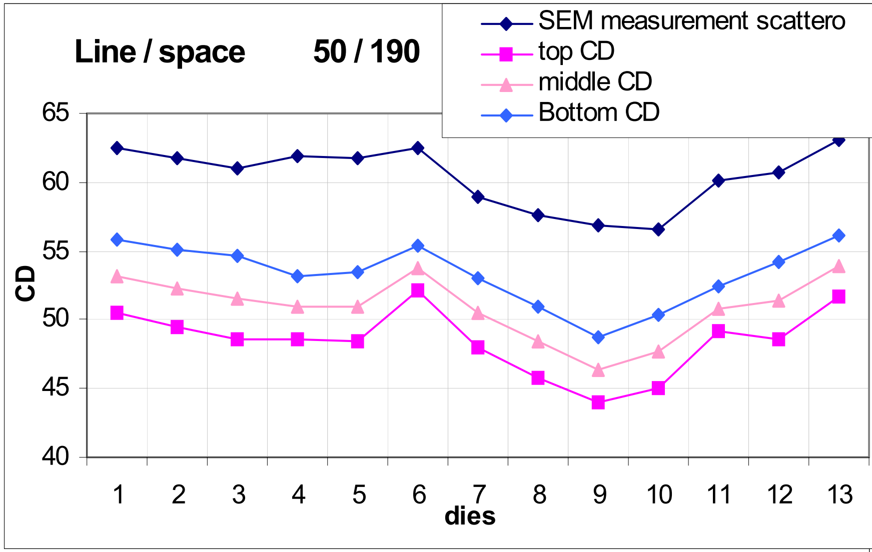
Precision nm 3σ	**TCD**	**MCD**	**BCD**	**SWA**	**HEIGHT**
Static repeatability	0.11 nm	0.04 nm	0.08 nm	0.04 °	0.08 nm
Dynamic reproducibility	0.20 nm	0.10 nm	0.15 nm	0.07 °	0.20 nm
Stability 3 days	1.17 nm	0.14 nm	1.18 nm	0.52 °	0.37 nm

Tool matching (intercontinental)

Precision nm 3σ	**MCD**	**SWA**	**HEIGHT**
Matching	1.03 nm	0.17 °	2.44 nm
Global reproducibility	1.04 nm	0.18 °	2.45 nm

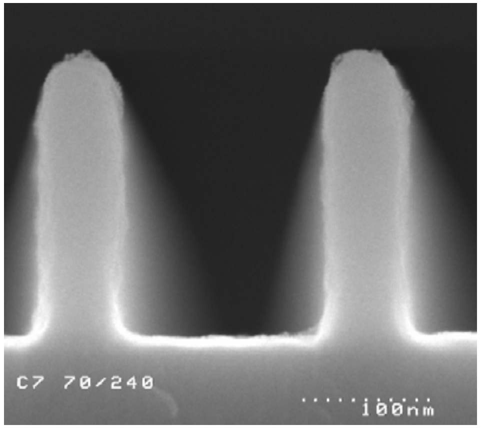
Clear impact

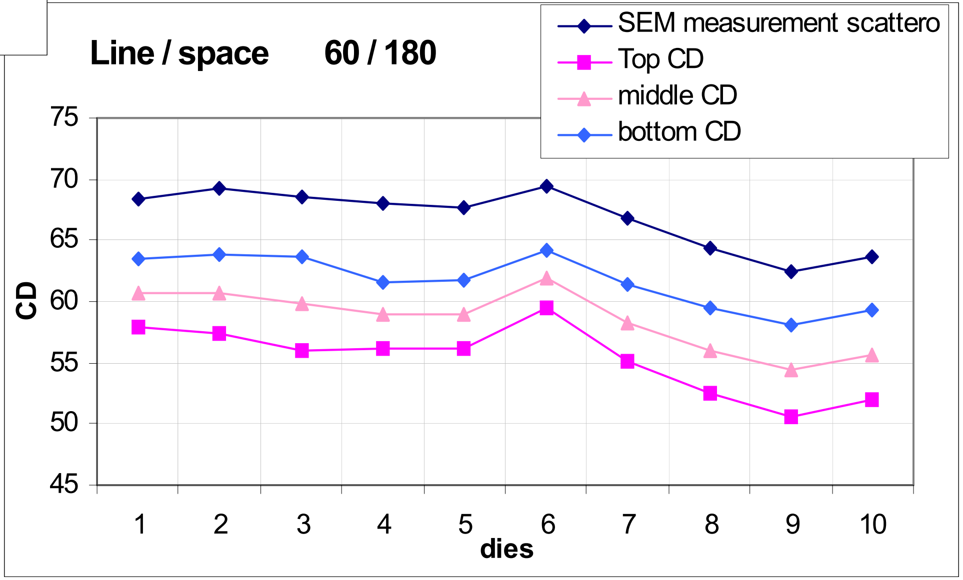
65 nm gate : e-beam lithography



E-beam lithography

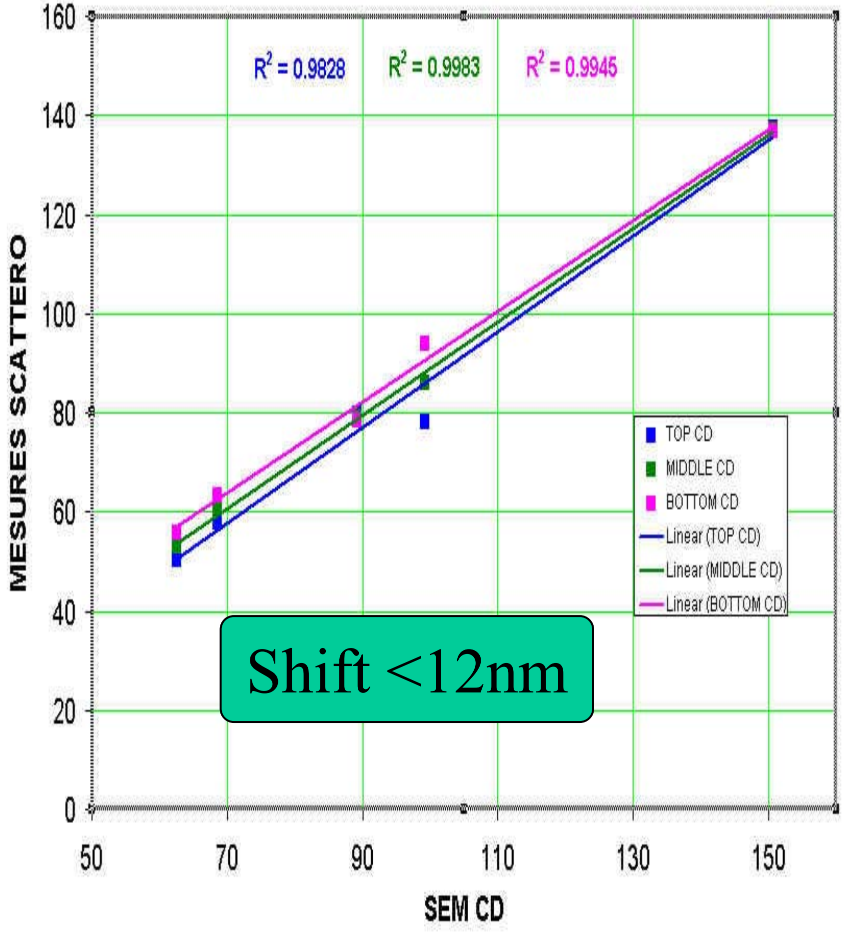
- *Tool follow-up*
- *Negative resist on gate stack*





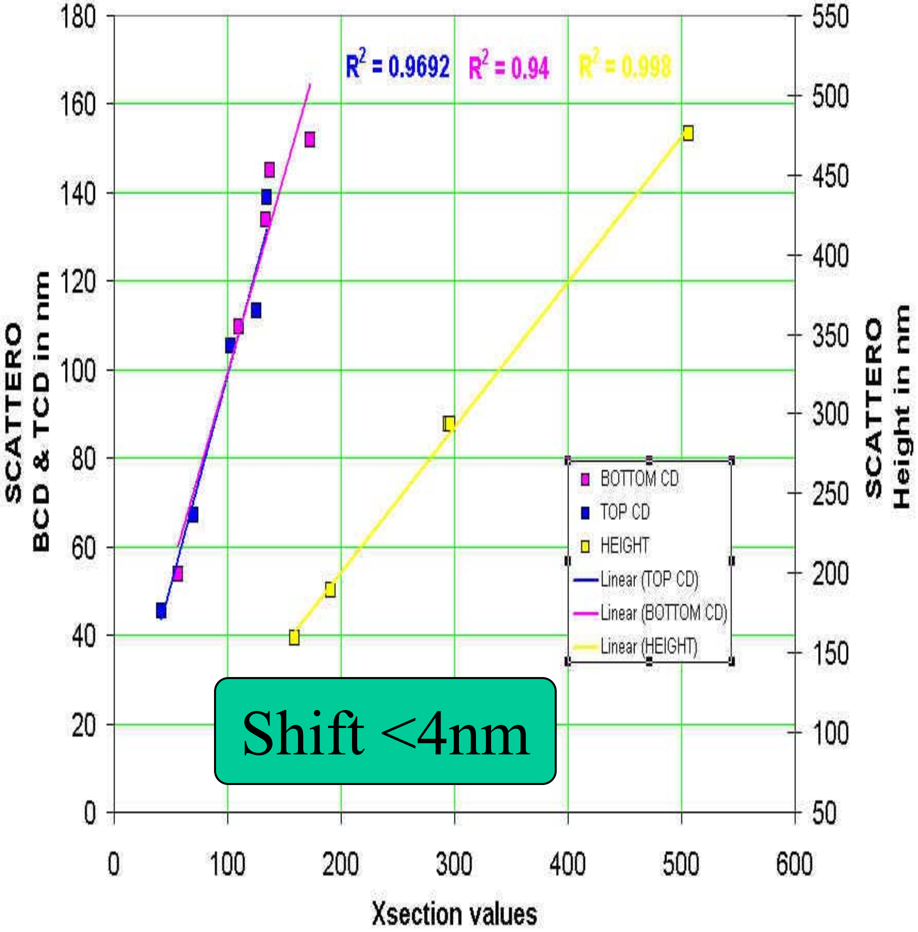
SEM correlations.

CD-SEM



Shift <12nm

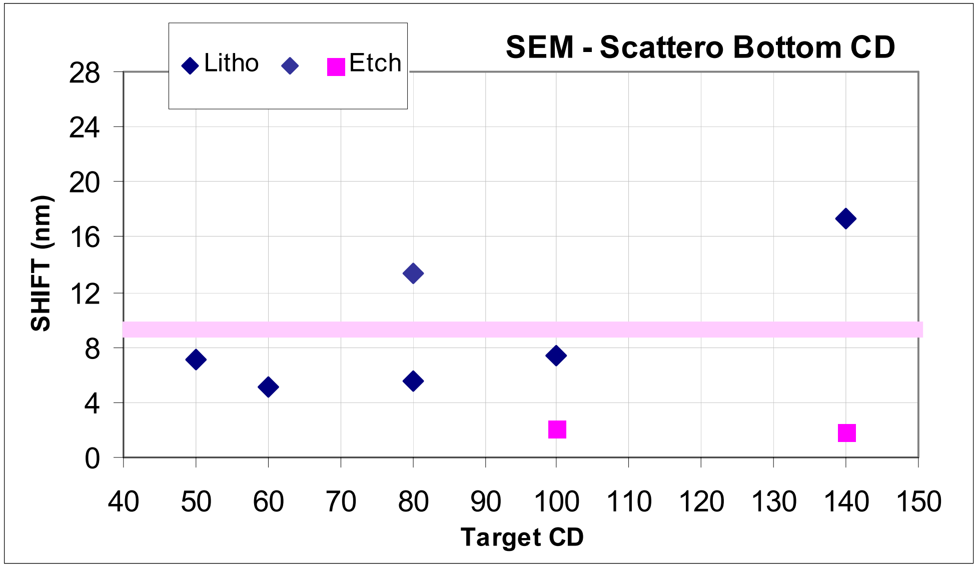
CROSS SECTION



Shift <4nm

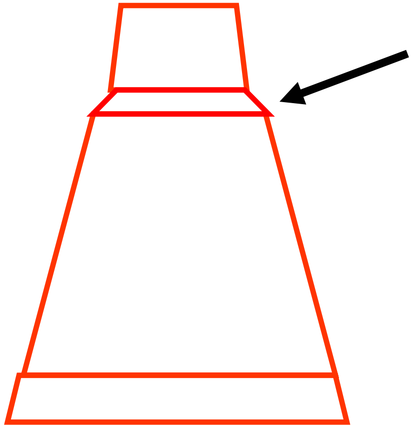
Matching to CD-SEM.

	shift	3σ	linearity
Bottom mean value:	9.3nm	4.2 nm	R^2=0.9945
Middle mean value:	11.3nm	2.4 nm	R^2=0.9983
Top mean value:	13.2nm	2 nm	R^2=0.9828



STI model for scatterometry.

- STI more complex because of line shape and stack after etch.
- Good results with model with four trapezoids (at least)
- Correlation to electric performances ?
- Attempt to address corner rounding effects (top silicon)

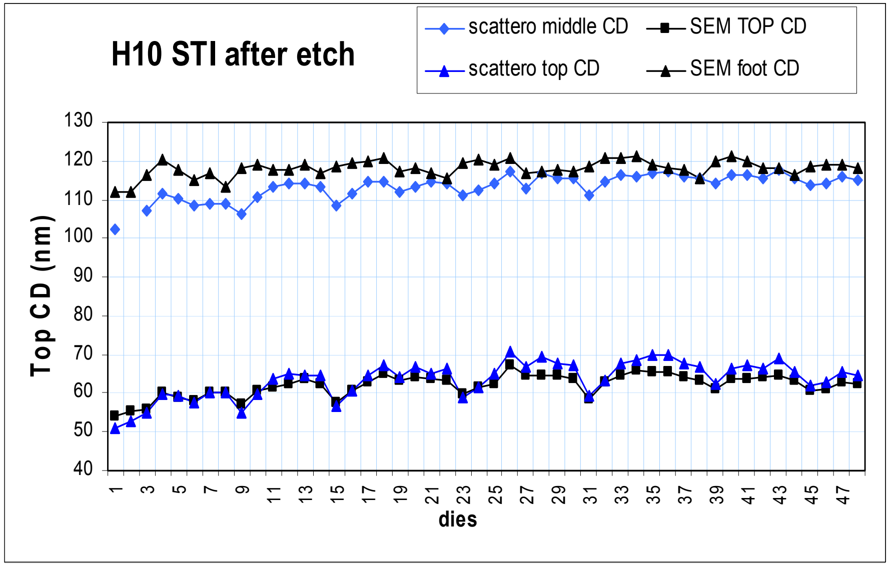


STI 90nm measurement after etch

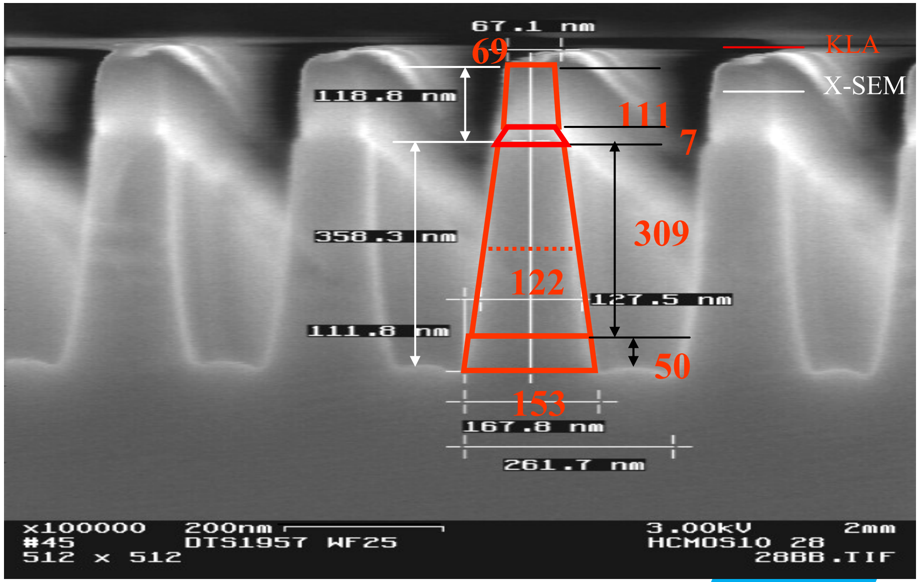
Library robustness

Precision nm 3σ	TCD	MCD	BCD	SWA	HEIGHT	Nitride
Static precision	0.0325	0.034	0.0666	0.006	0.0917	0.033
Dynamic precision	0.1344	0.1233	0.1291	0.0076	0.1273	0.0904
Stability	0.117	0.0785	0.1627	0.0307	0.5997	0.4744

CDSEM matched to SCD™



Cross section correlation



Reliability performance KLA-Tencor tool.

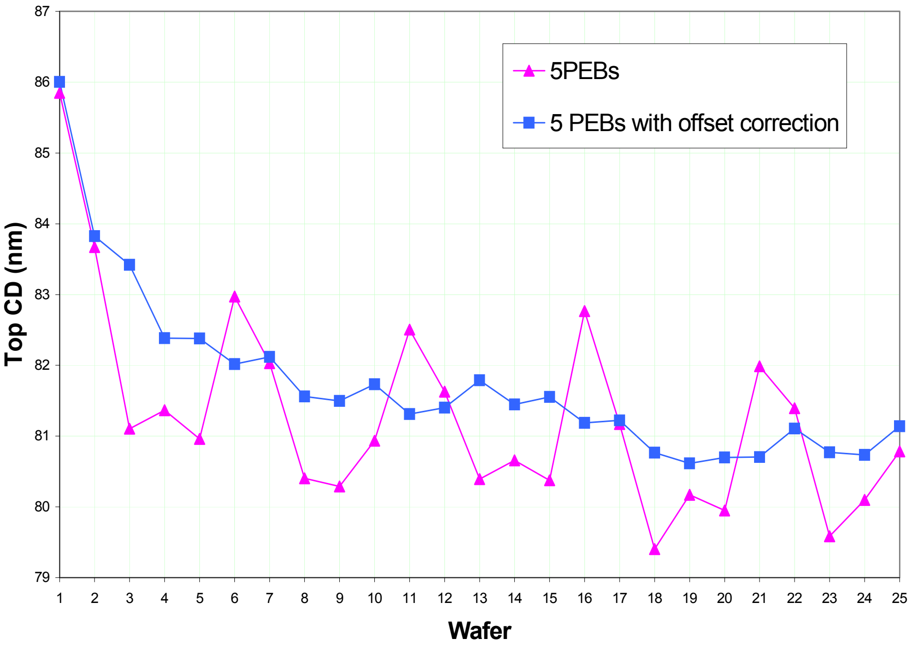
1. Repeatability	< 0.2 nm
2. Reproducibility	< 0.4 nm
3. Stability	< 2 nm
4. Correlation with CDSEM	< 12 nm
5. Correlation on cross section	< 4 nm

3 sigma parameter

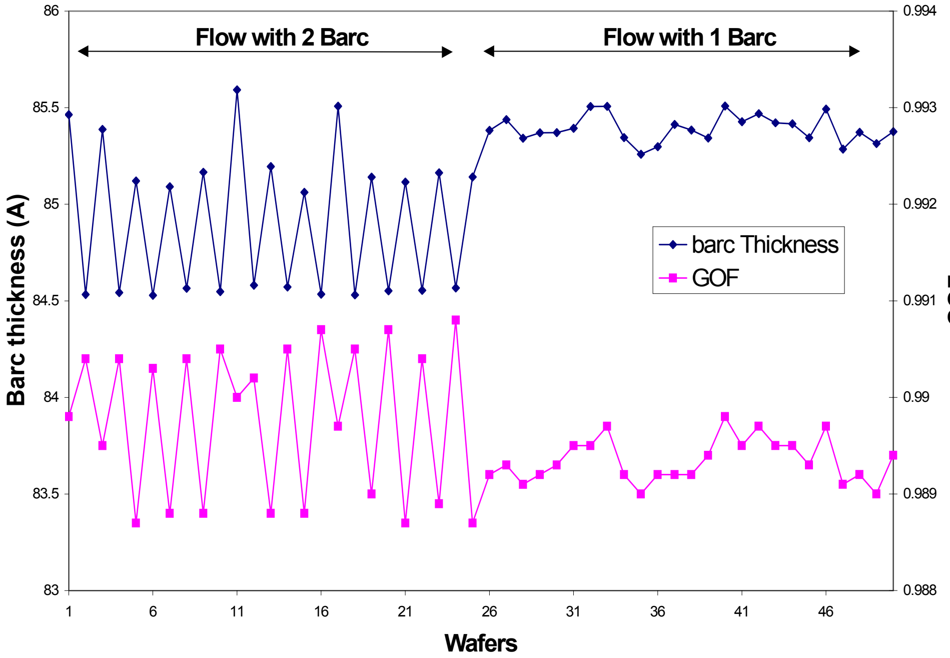
Without matching

Litho cell qualification.

TEL track qualification : resist on silicon, lines 100/700



PEB modules

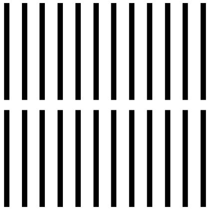


BARC coater module

Thanks to TEL qualification data

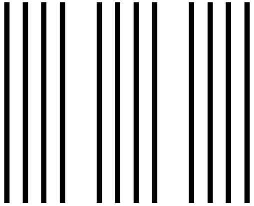
Defect study: raise confidence at 130nm.

Crossed lines



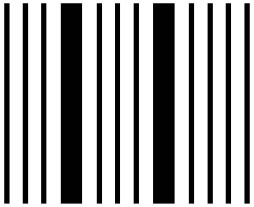
- Simulation of scratch defect in various conditions.
- No influence on GOF and measurement

Missing lines



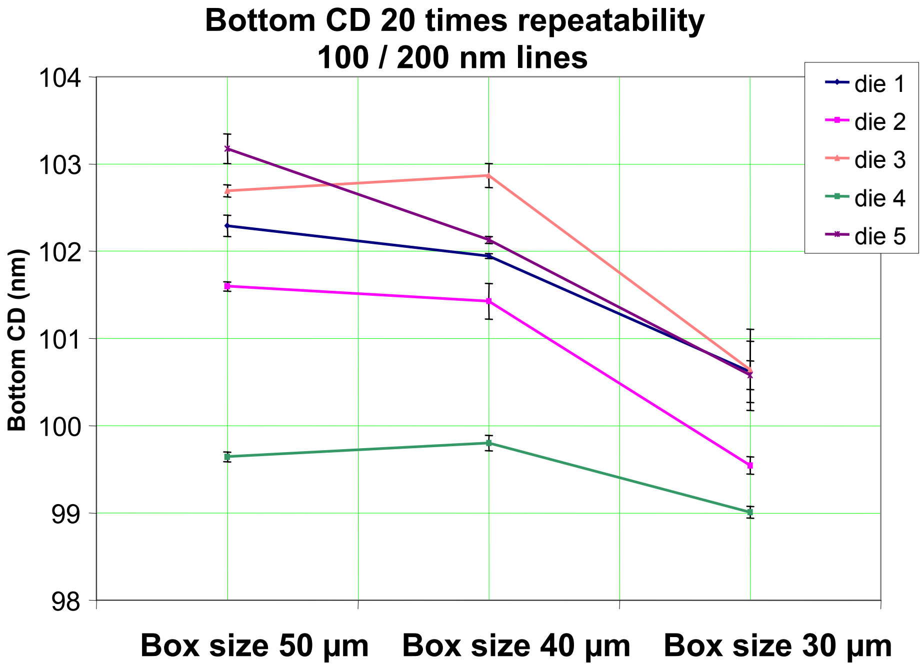
- Weak influence on optical signature.
- Soft converges to an existing signature in the library and displays wrong result.

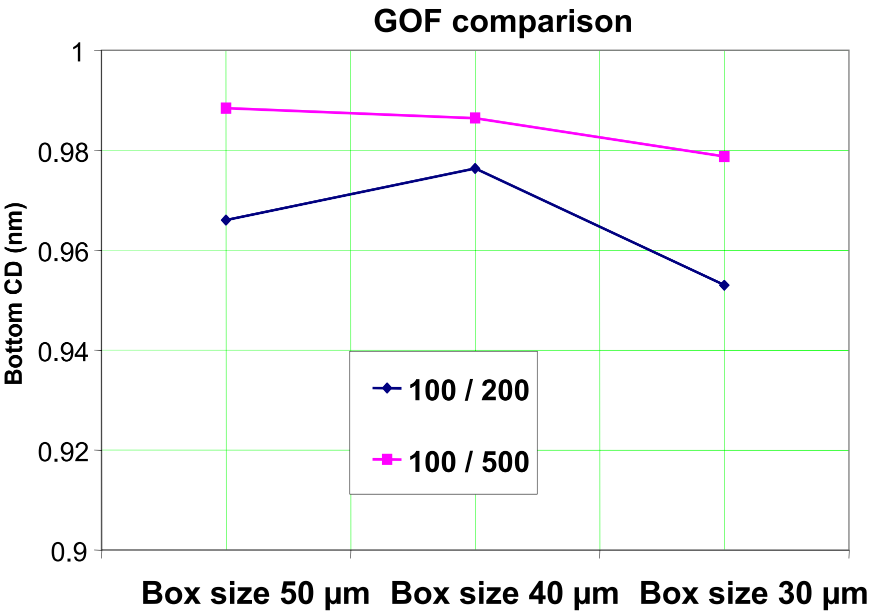
Pat. collapse simulation



- Strong influence on optical signature and GOF even for few defects.
- No signature confusion in this case.

Box size study.





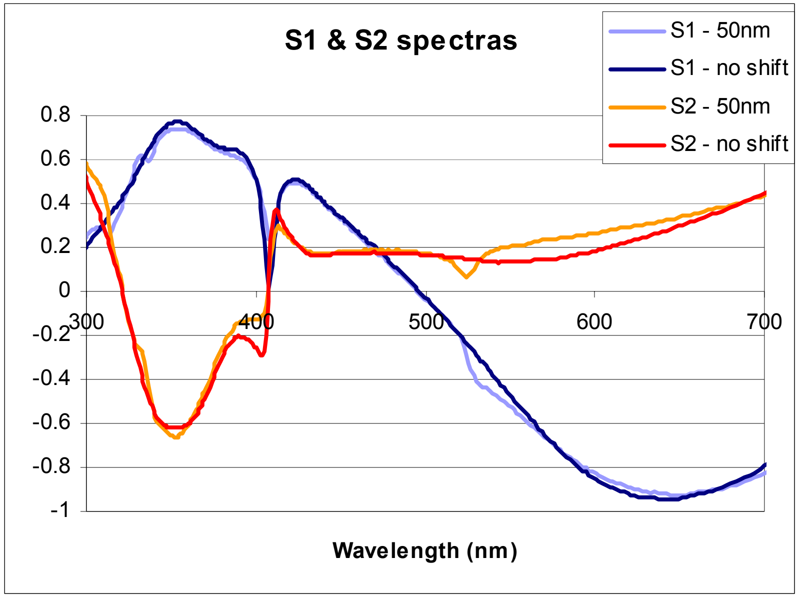
No reliable results below **40 microns** boxes.

Good alignment of target.

Overlay feasibility.

- Lithography of programmed shifted targets
- Spectra's recorded on scatterometry tool
- Reference spectra simulation through RCWA software
- Correlation with reference provides overlay measurement
  - 0 nm shift (simulated)
  - reference shift (simulated/measured)

Other solution with direct regression using multiple target design, avoiding RCAW calculations.



Conclusions

- Scatterometry capability evaluation
  - Usability of scatterometry demonstrated in the fab for several CD application

Litho and etch	90 and 65 nm

  - Capability for profiling proven on particular cases.
  - Extension to overlay, holes… pending.
  - Secured use with respect to main defects.
- Assessment of spectroscopic ellipsometry and library approach for manufacturing, one layer.

Perpectives.

- Integration
  - Target size
  - Muliple layer
  - Library/run-time regression user compromise
- New applications assessment
  - Pending demo on holes measurement
  - Feasibility of overlay by suppliers
  - Full patterns measurements
- Still extensions
  - New optical hardware development
  - Isolated features

Aknowledgement.

- CEA/LETI (P. Chaton, J. Hazart, G. Grand) and with CNRS/LPICM (B. Drevillon and A. de Martino).
- Many thanks to suppliers for their work for scatterometry demonstration and active contacts: Accent, Nanometrics, Nova, TEL and TEL/Timber, ThermaWave and Sensys, SOPRA, and in particular KLA-Tencor (S. Kremer, M. Polli) that allow us to gather major part of these results.