Development of X-ray Tool For Critical-Dimension Metrology

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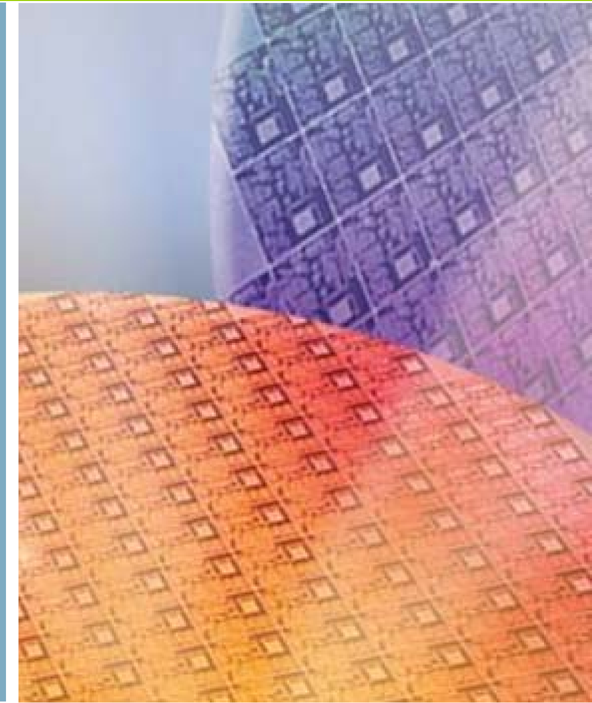

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Overview

- Introduction
- Pilot set-up
- Software package
- Sample and alignment
- Experimental results
- XRR measurement for height
- Conclusions

Why X-rays?

- OCD and CD-SEM limitations
- Nodes 32 nm and below
- Negative slopes existing in some structures
- First principle method (no libraries required)

Current status of CD-SAXS:

Based on NIST publications, the technology delivers a promising capabilities for current and future design nodes, while using synchrotron radiation as a source

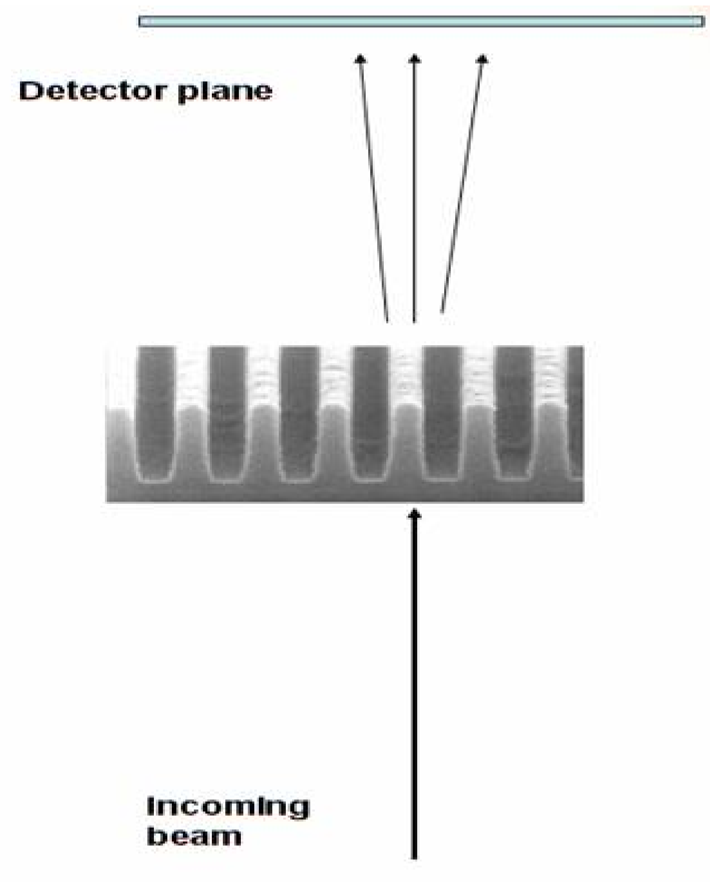
Goal of this research:

assessing feasibility of making an X-ray tool of laboratory scale, allowing characterization of CD-structures with measurement times suitable for production control

Small Angle X-ray Scattering (CD-SAXS, or XCD™)

- Diffraction of highly collimated monochromatic X-ray beam on a periodic structure
- Intensity as a function of angle
- Transmission mode vs reflection mode
- Why 17.4 keV
- Spot size 100 µ
- Physical dimensions of the set-up
- Vertical beam
- No-vacuum X-ray path

~1,300 mm



Pilot set-up – major physical components

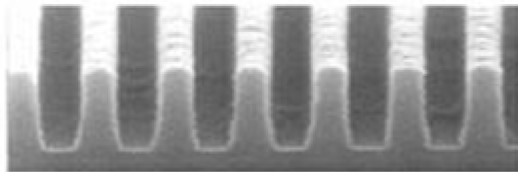
- μ-focus X-ray tube (Mo anode, operated at 50 kV, 50 W)
- focusing monochromator (doubly bent graded multilayer mirror with 100 μ spot size)
- deep depletion CCD operated in the direct detection mode
- additional very important gadgets: set of slits, beam stopper

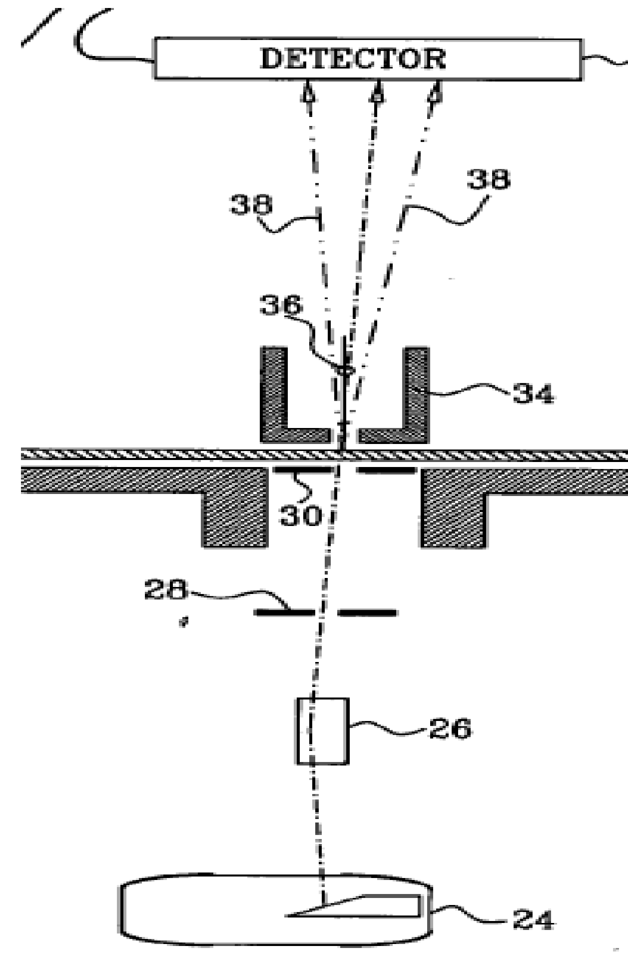
Software package

- Simulation of the XCD signal takes into account all the components contributing to the instrumental function of the system
- Beam divergence, beam cross-section, detector pixel size
- Background modeling based on experimental spectra
- Statistical fluctuations on/off
- Normalization to experimentally measured intensities
- Selection of various shapes (rectangular, trapezoid, etc.)
- Processing of experimental spectra by fitting based on Genetic Algorithms

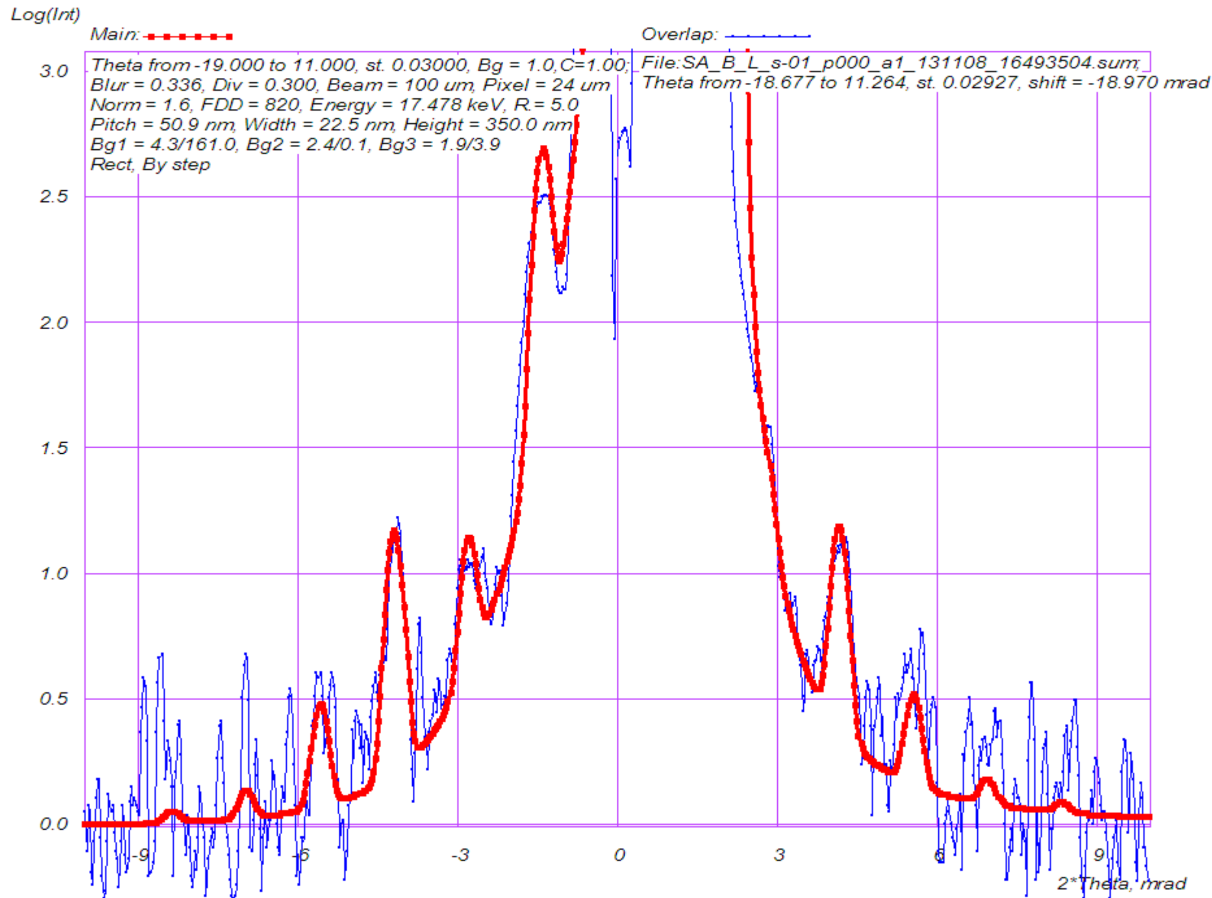
Sample and alignment

- Special sample for initial evaluation
- Si lines 50 nm pitch, aspect ratio 6
- High density contrast
- Features few mm² area - simplified navigation
- Special technique to align CD-lines direction on the sample with the detector CCD pixels direction





Experimental XCD spectrum



X-ray Critical Dimensions and OverLay | Ready

Show: ☑ Main ☑ Over ☐ Main 2D ☐ Over 2D | 2*Theta, mrad

2*Theta, mrad: Start -10 | End 10 | Step 0.03 | Rot., deg 0.00 | Shape Rect | Calc. Type By step | ☐ Step ☐ Pic

Param	Nom	Best	Min	Max	Fit
Pitch,nm	50.93	50.93	25	102	☒
Width,nm	22.50	22.50	11	45	☒
TWidth,nm	31.67	31.67	16	63	☐
Height,nm	350.00	350.00	175	700	☐
Slope,deg	0.29	0.29	0.14	0.58	☐
Norm.	1.6	1.6	0.79	3.2	☒
Rough,nm	2.9	2.9	1.4	5.7	☒
BG	0.98	0.98	0.49	2.0	☒
Bg1 Right	4.3	4.3	2.2	8.6	☒
Bg2 Right	2.4	2.4	1.2	4.9	☒
Bg3 Right	1.9	1.9	0.96	3.9	☒
Bg1 Left	161	161	81	322	☒
Bg2 Left	0.05	0.05	0.02	0.10	☒
Bg3 Left	3.9	3.9	1.9	7.7	☒
Width2,nm	10	10	5.0	20	☐
Height2,nm	100	100	50	200	☐
Shift,nm	20	20	10	40	☐

Control: Build As Main | Build As Overlap | Swap | O-M On | ☐ Noise ☐ Quant

GA Fit — Range, mrad: Start Fit -9.0 | End Fit 9.0 | Skip Start -2.5 | Skip End 2.7 | Run | Mark... | Best To Nom | Refr. Min/Max

Gen. Max 500 | Cur.Gen | FOM | ☑ Spike.Cor.

M + O | -->M | Auto Angle Range

Rotation | Height | Pitch | Width

Extracted absolute values: XCD vs other methods

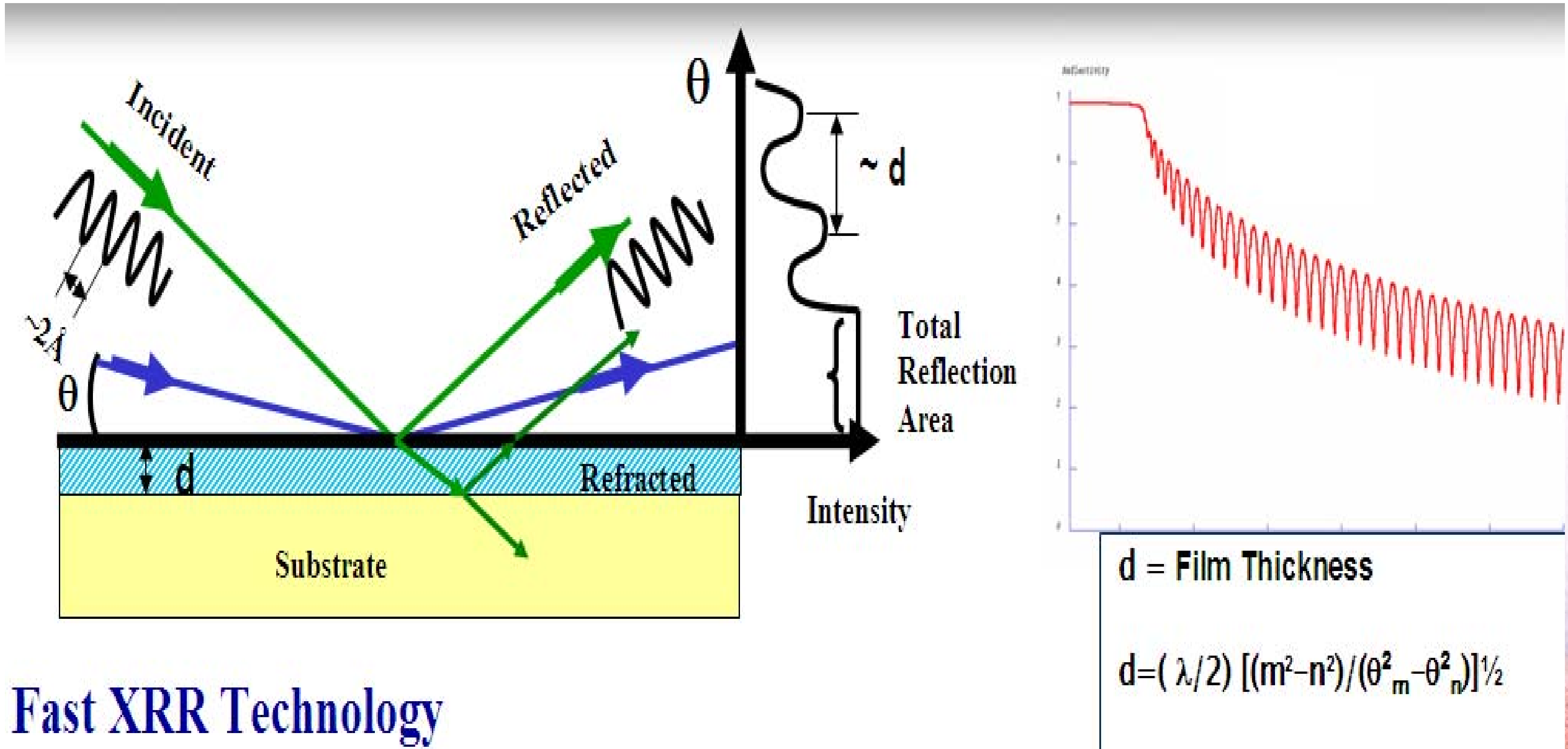
TABLE 1. Pitch and width values.

	Pitch, nm	Width, nm
XCD value found on feature 11L1	50.8	22.6
XCD value found on feature 11R1	50.4	22.6
values known from SEM and OCD measurements	50.0	22.4 (OCD) 23.9 (SEM)

XCD results – static repeatability

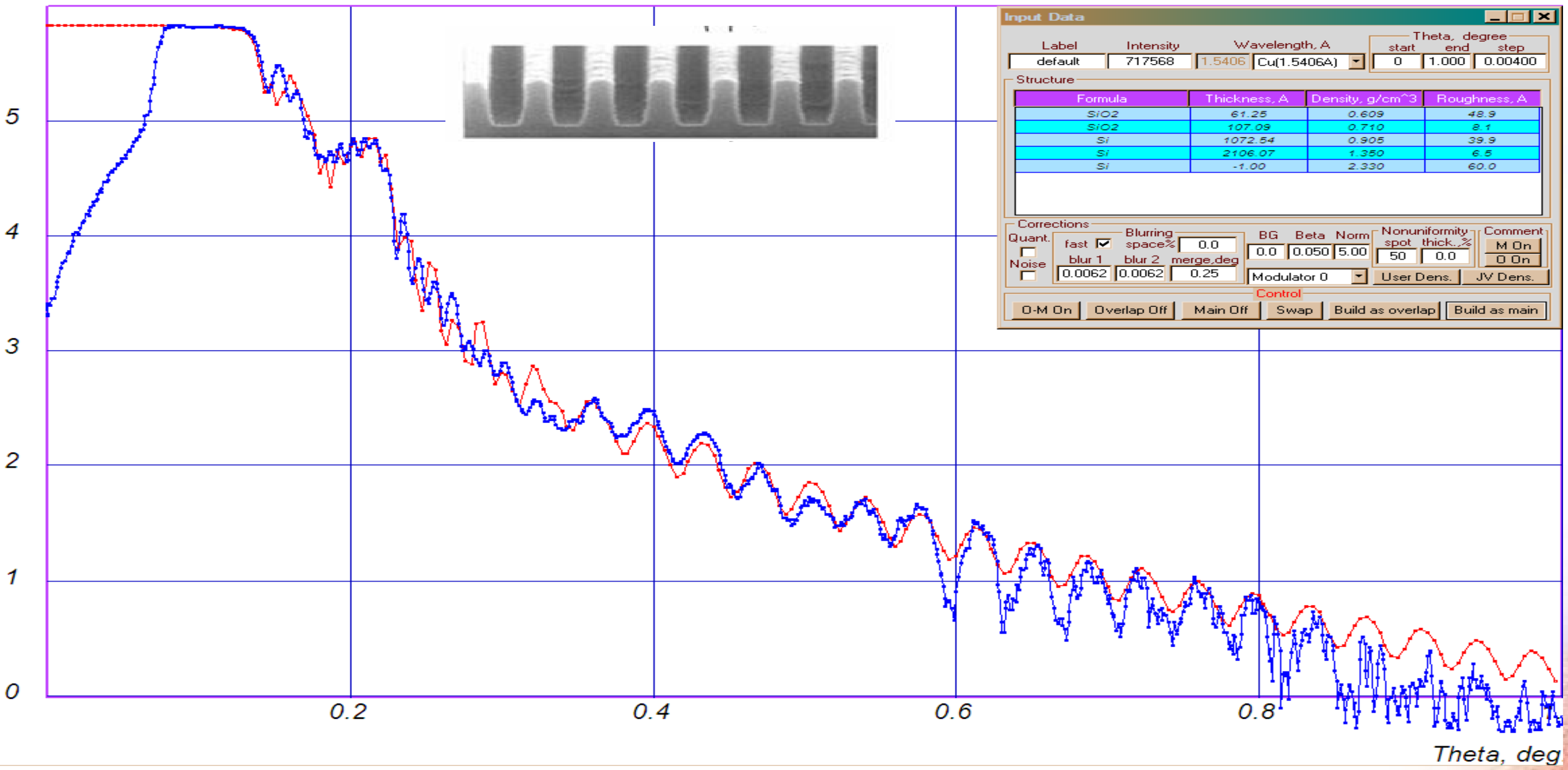
location	#	pitch, nm	width, nm
11L1	1	51.0	22.9
11L1	2	50.4	22.8
11L1	3	51.1	22.1
11L1	4	51.1	23.2
11L1	5	50.9	22.1
11L1	6	50.6	22.3
11L1	7	50.9	23.5
11L1	8	50.8	22.2
11L1	9	50.7	22.4
average		50.8	22.6
RSD, %		0.5	2.2

Height measurement with the fast XRR channel



Fast: simultaneous irradiation in the entire angle range;
simultaneous detection of reflections in the entire angle range

Experimental fast XRR spectrum from the CD structure



Height obtained from XRR fringes: 316 nm;

Height as measured by SEM: 310 nm

XCD channel - potential luminosity increase

- Mirror-monochromator efficiency: 10-15 times
- Detector efficiency: 10-15 times
- Tube power: 5-6 times
- Overall: ~ 1,000 times
- Acquisition time for Si lines: ~ 7 s
- Acquisition time for photo resist lines:
  in the range 10 - 100 s

Discussion and conclusions

- Development of a production control worthy XCD tool is feasible
- Another important application for such tool might be the overlay metrology
- Further R&D is required for selection and combining major physical components
- A substantial engineering challenge in the project will be mechanical design for sample inclination and navigation on such wafer

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