Development of X-ray Tool For Critical-Dimension Metrology

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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
# Extracted absolute values: XCD vs other methods

## TABLE 1. Pitch and width values.

<table>
<thead>
<tr>
<th></th>
<th>Pitch, nm</th>
<th>Width, nm</th>
</tr>
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<tbody>
<tr>
<td>XCD value found on feature 11L1</td>
<td>50.8</td>
<td>22.6</td>
</tr>
<tr>
<td>XCD value found on feature 11R1</td>
<td>50.4</td>
<td>22.6</td>
</tr>
<tr>
<td>values known from SEM and OCD measurements</td>
<td>50.0</td>
<td>22.4 (OCD) 23.9 (SEM)</td>
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</tbody>
</table>
XCD results – static repeatability

<table>
<thead>
<tr>
<th>location</th>
<th>#</th>
<th>pitch, nm</th>
<th>width, nm</th>
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<td>51.0</td>
<td>22.9</td>
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<td>22.1</td>
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<td>51.1</td>
<td>23.2</td>
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<tr>
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<td>50.9</td>
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<td>50.6</td>
<td>22.3</td>
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<tr>
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<td>50.8</td>
<td>22.2</td>
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<tr>
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<td>22.4</td>
</tr>
<tr>
<td>average</td>
<td></td>
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<td>22.6</td>
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<tr>
<td>RSD, %</td>
<td></td>
<td>0.5</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Height measurement with the fast XRR channel

Fast XRR Technology

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

\[ d = \frac{\lambda}{2} \left\{ \left( m^2 - n^2 \right) / \left( \theta_m^2 - \theta_n^2 \right) \right\}^{1/2} \]
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
THANK YOU FOR YOUR ATTENTION

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