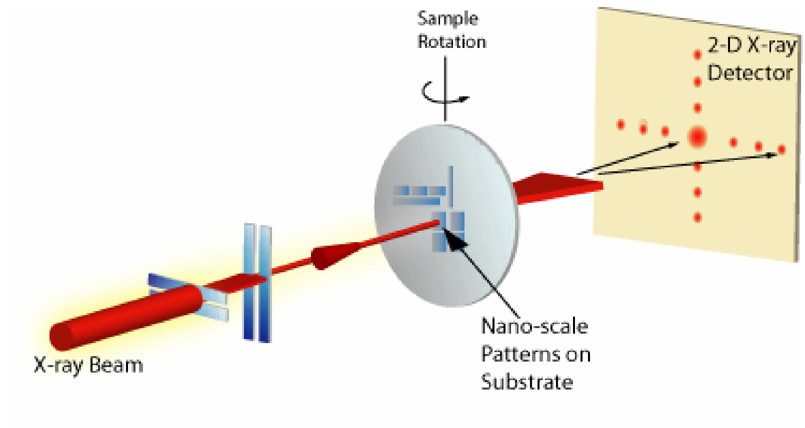
Cross Section and Line Edge Roughness Metrology for EUV Lithography using Critical Dimension Small Angle X-ray Scattering



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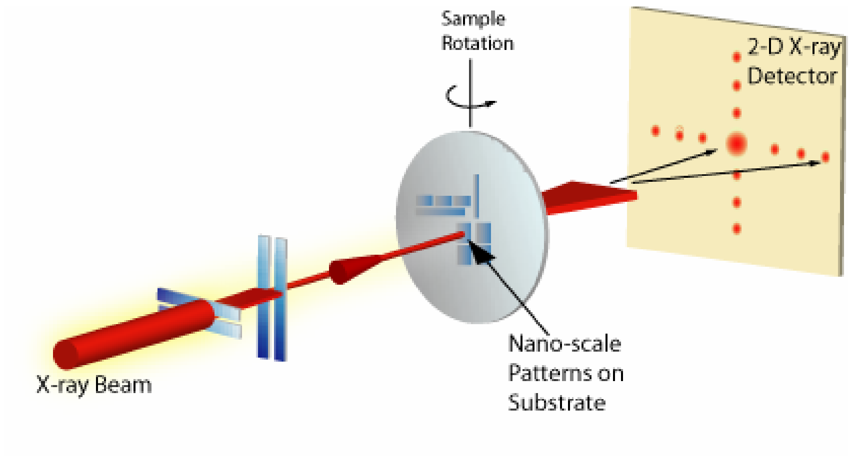
Intel, Hillsboro, OR

Critical Dimension Small Angle X-ray Scattering (CD-SAXS)



Transmission SAXS

- Silicon transparent for E > 13 keV
- Non-destructive / No sample prep

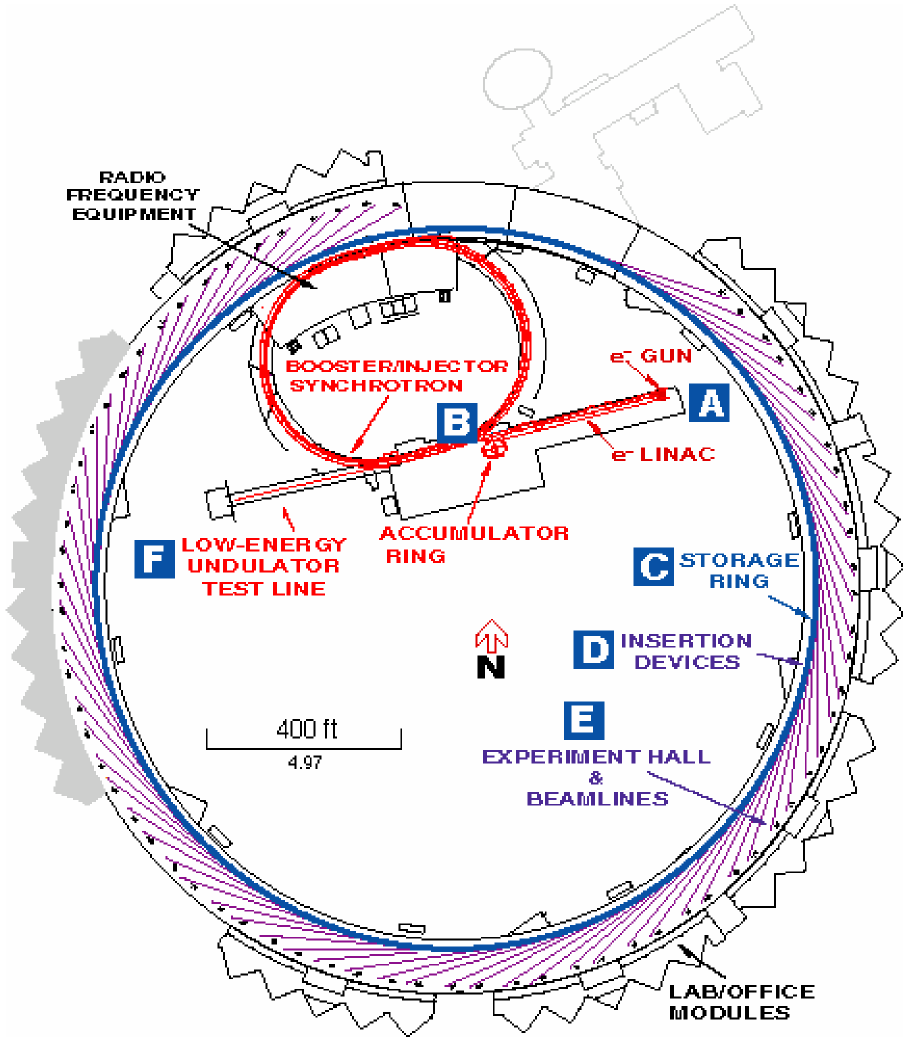
Use scatterometry targets

- Beam spot size (40x40) µm

High Precision for sub-45 nm

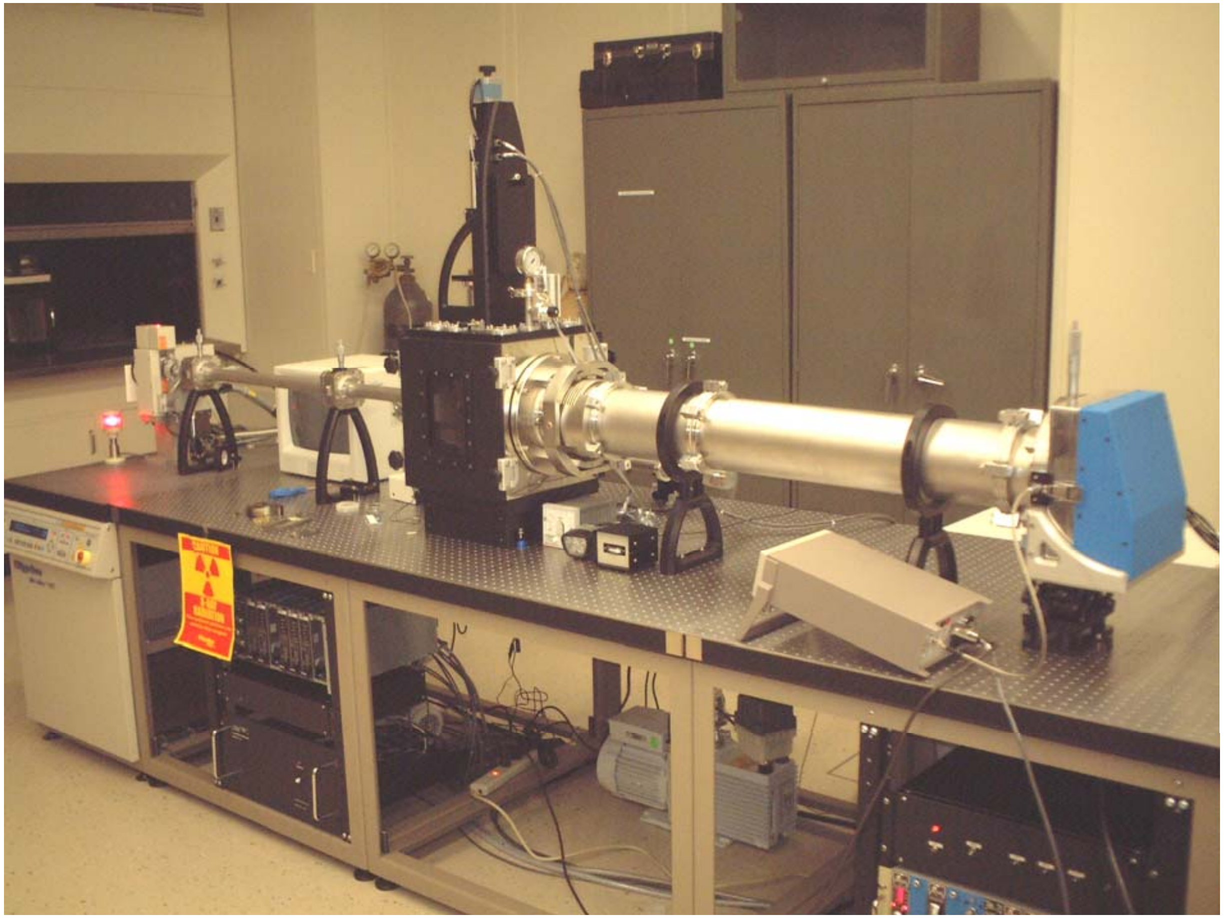
- Sub-nm precision in pitch and linewidth
- Pattern Cross Section
- Technique easier with smaller structures

The Advanced Photon Source

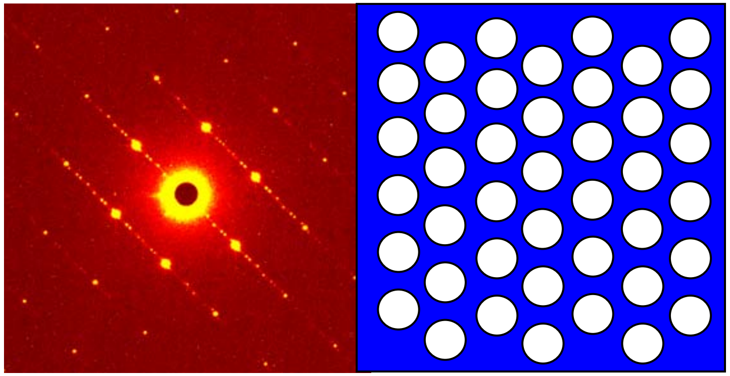


- First synchotron to feature constant x-ray flux, most synchotrons have decaying fluxes that are “refilled” every 10-12 hours
- Approximately 9 orders of magnitude more intense than conventional tube sources.

Lab Scale CD-SAXS Prototype



Cross Section with CD-SAXS



Measure "2-D" patterns

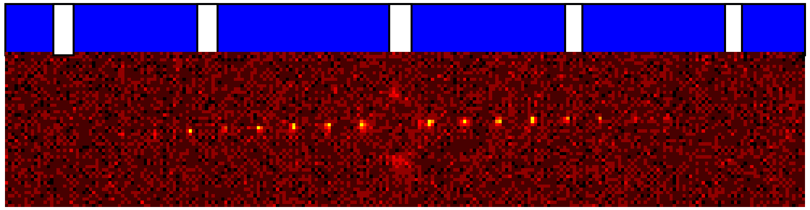
Contact holes

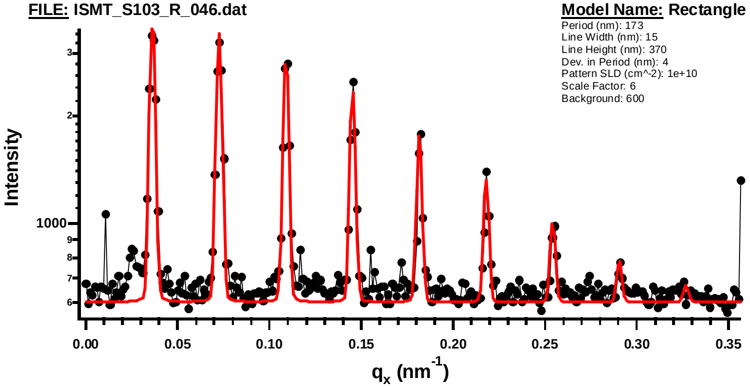
Measure "3-D" patterns

Multilevel interconnects

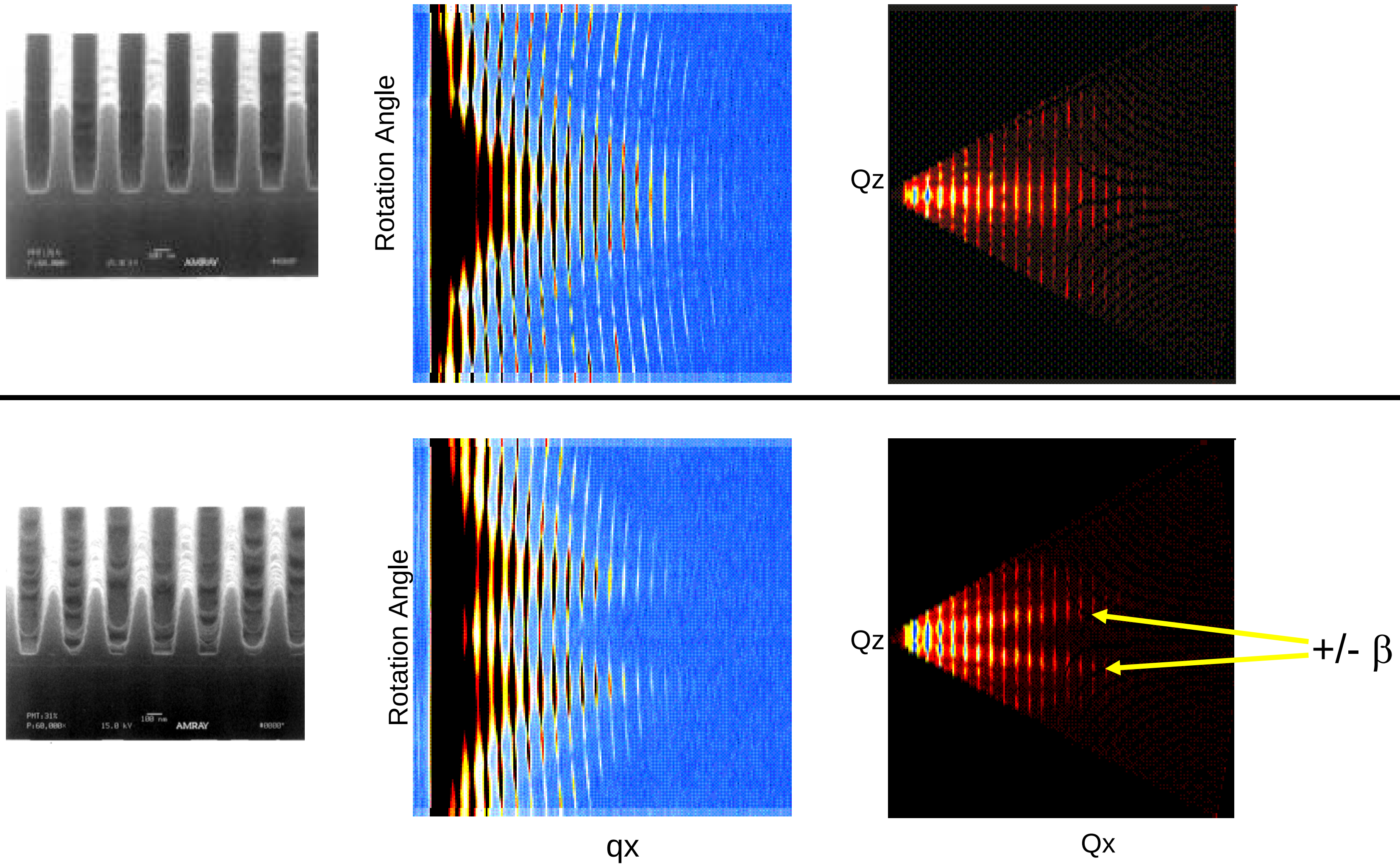
3-D DRAM

Double Damascene



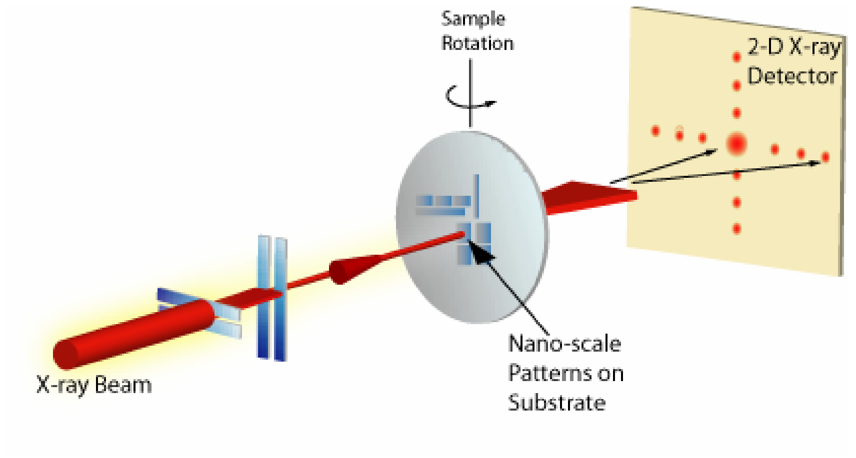


Cross Section Metrology



Experimental Data from Patterned Photoresists (w. Q. Lin, IBM Yorktown Hgts)

LER measurement with CD-SAXS



Potential for LER related quantities:

- Distribution in Periodicity
- Frequency spectrum of sidewall roughness
- Periodic errors (stitching and standing wave)
- Distribution in cross sectional shape

CD-SAXS and CD-SEM, CD-AFM:

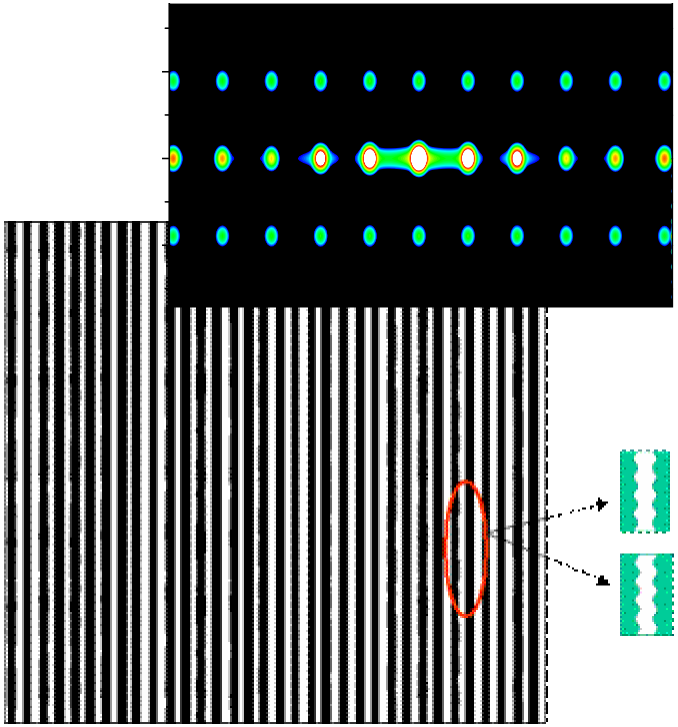
- Average vs. Single line
- Deconvolution of LER, LWR, and possible other classes of variation.
- 3-D Average vs. top-down image

CD-SAXS and OCD:

- Measure same targets
- Help develop OCD in current nodes
- Potential workhorse for sub-45 nm

LER measurement with CD-SAXS

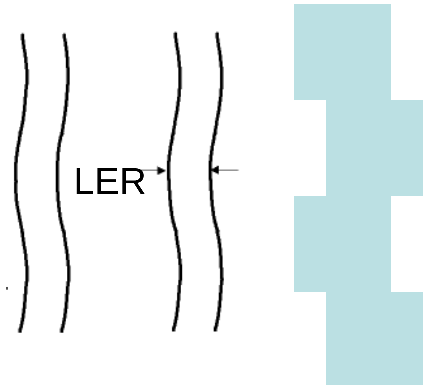
Simulated CD-SAXS pattern

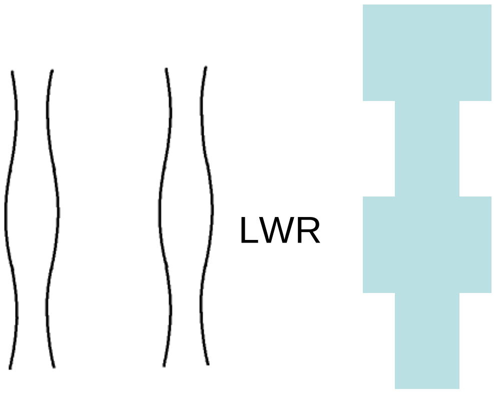


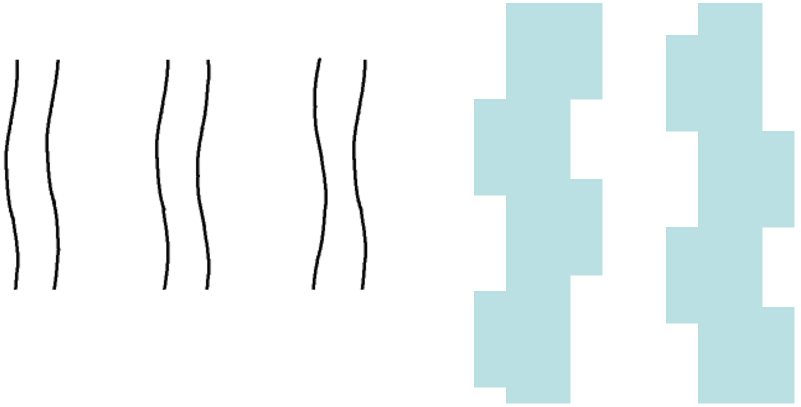
Signatures of LER

- Diffraction parallel to line edge
  Accessible frequencies are on the order of the inverse linewidth
- Decay of intensity along main diffraction axis may provide integrated RMS over large range in frequencies.
- Other measures possible with more refined models.

Approach: Line/space structures with controlled roughness





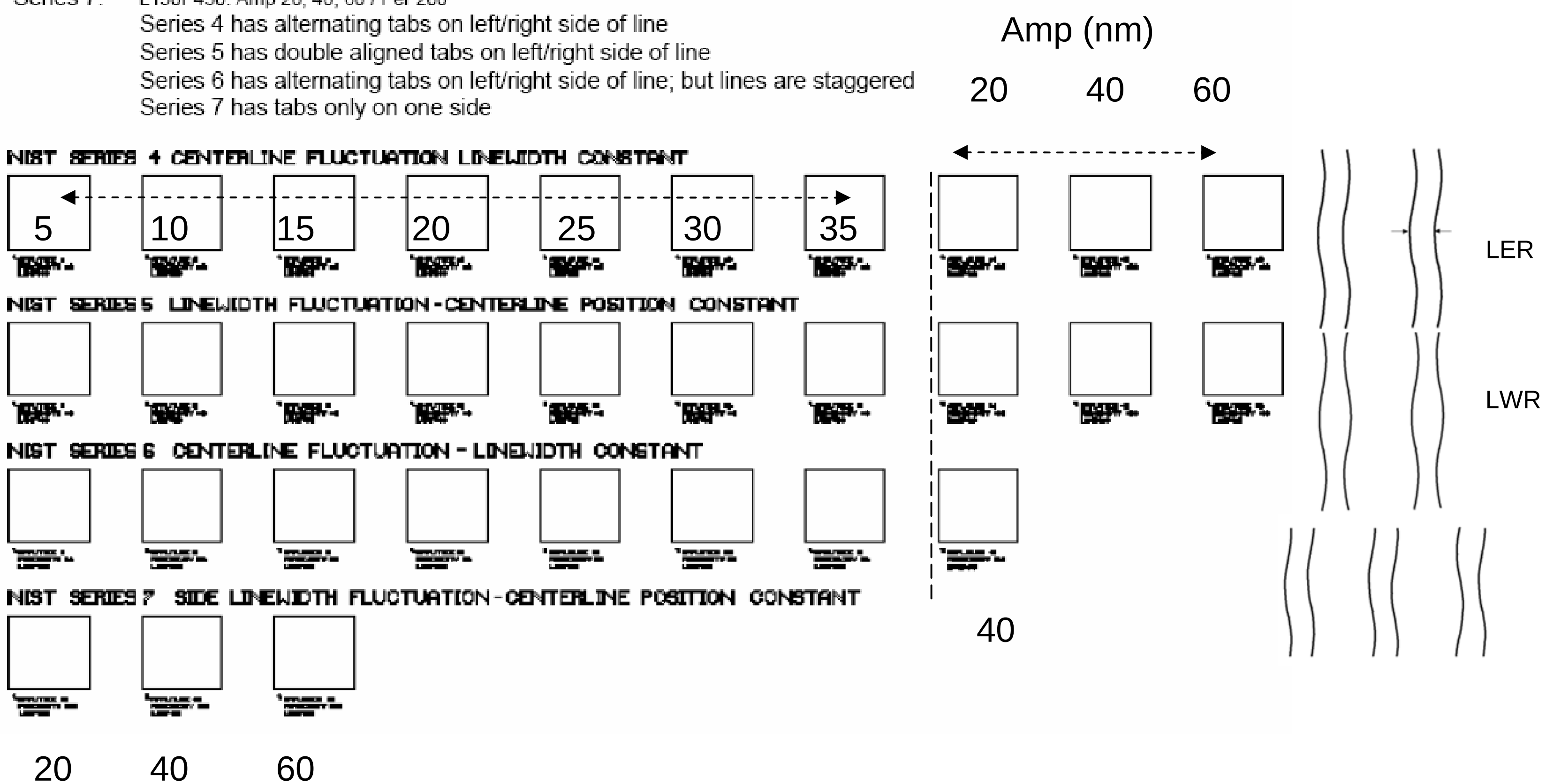


Design of the AMAG "NIST LER" structures

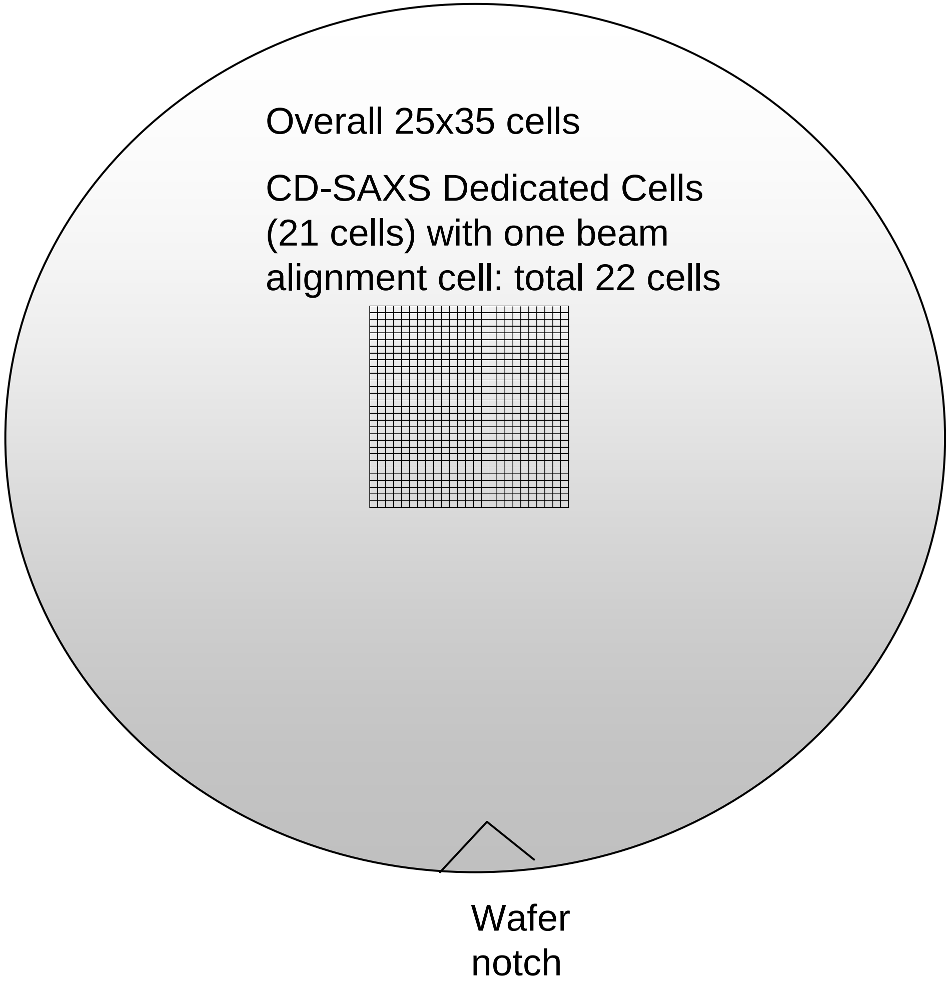
LERNIST_NIST

Tabs are 1/2 of periodicity.

Series 4 - 6: L100P300: Amp 5-35 (5nm steps) / Per 110; L150P450: Amp 20, 40, 60 / Per 200
Series 7: L150P450: Amp 20, 40, 60 / Per 200
Series 4 has alternating tabs on left/right side of line
Series 5 has double aligned tabs on left/right side of line
Series 6 has alternating tabs on left/right side of line; but lines are staggered
Series 7 has tabs only on one side



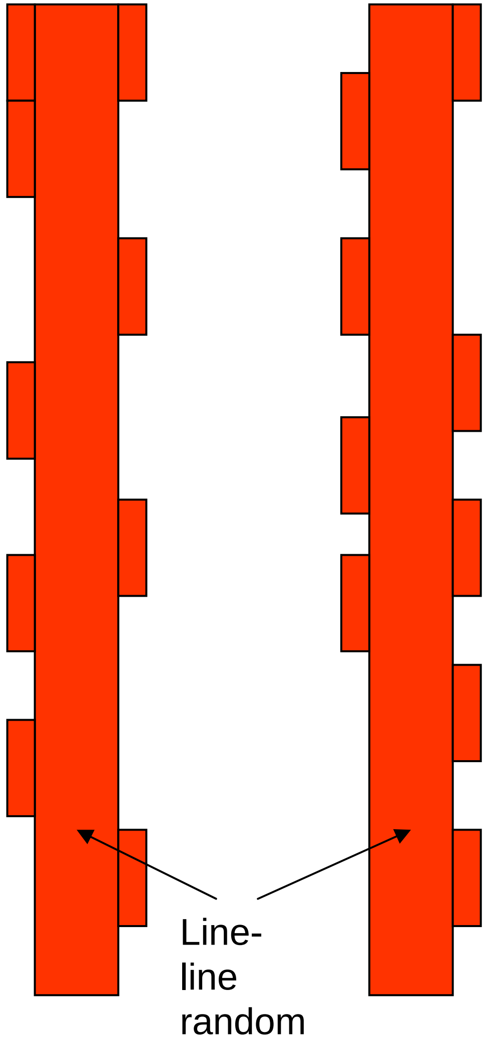
Design of the NIST-Intel LER structures



Highlights of Design:

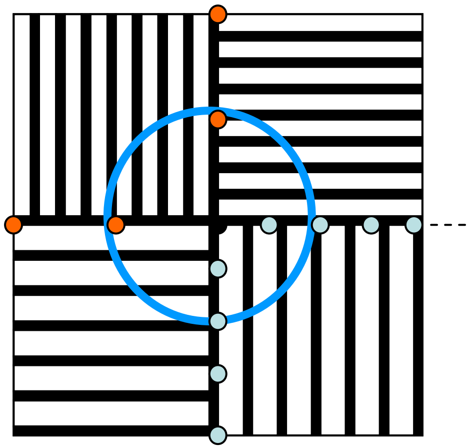
- Controlled LER on the scale of EUV nodes
- Wider variation in controlled LER design
- Mask design based on experiences with AMAG features
- Some cells specifically designed for measurements on NIST lab-scale prototype (larger beam size)

Design of the NIST-Intel LER structures

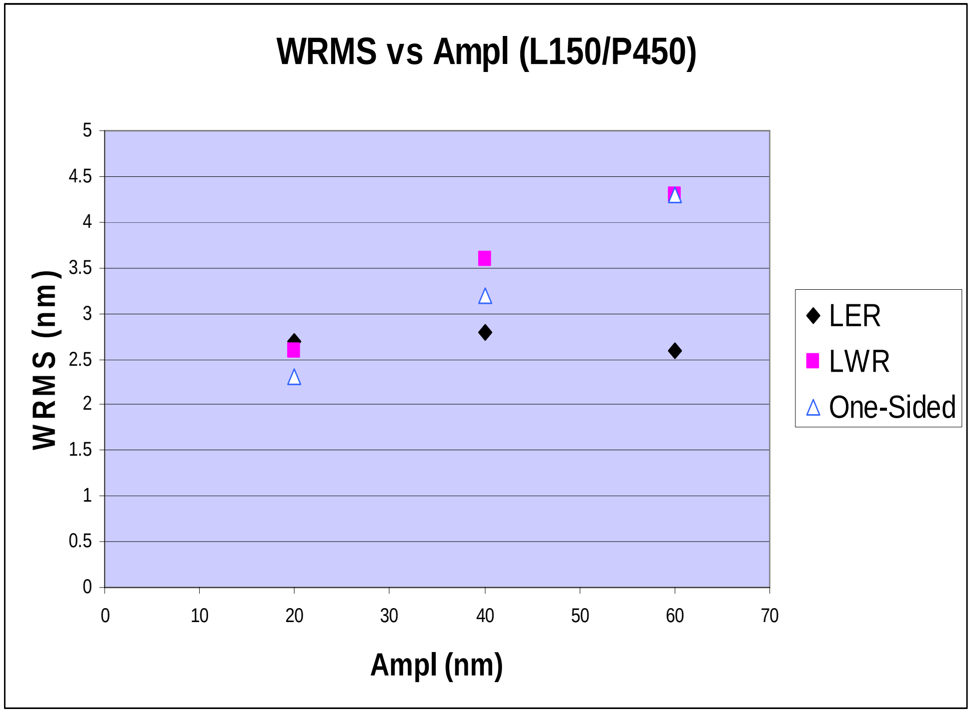


Highlights of Design:

- Controlled LER on the scale of EUV nodes
- Measured spectrum of roughness frequencies on order of the line width.
- Compare AMAG data at 100nm with NIST-Intel data at 40 nm line width.
- Alignment pattern will enable more precise definition of beam location
- Enhanced capability to compare quantitatively with SEM and OCD.



RMS Amplitude from SEM measurements

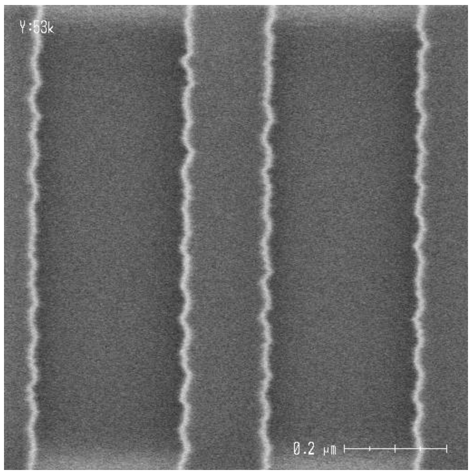


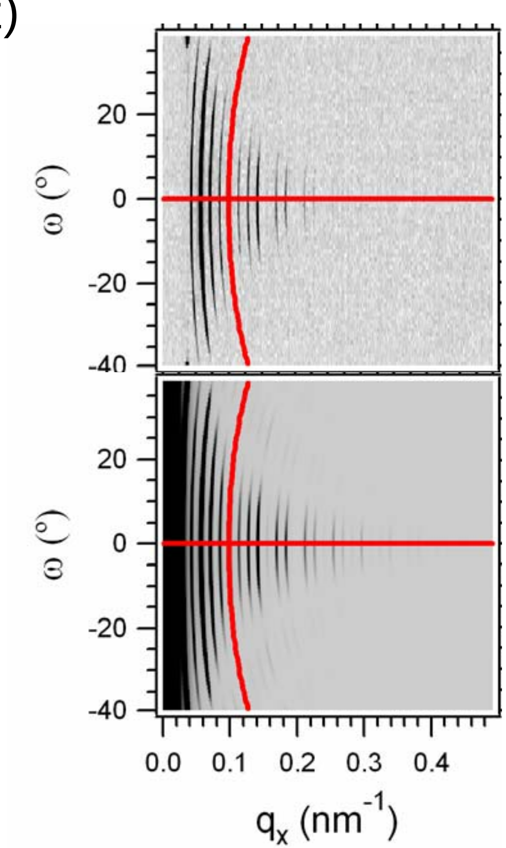
SEM LER Data:

- Small differences in the RMS amplitude (1 sigma) from SEM measurements.
- Measurements are of line width roughness.
- Amplitudes are significantly smaller than designed, approaching the random roughness values.

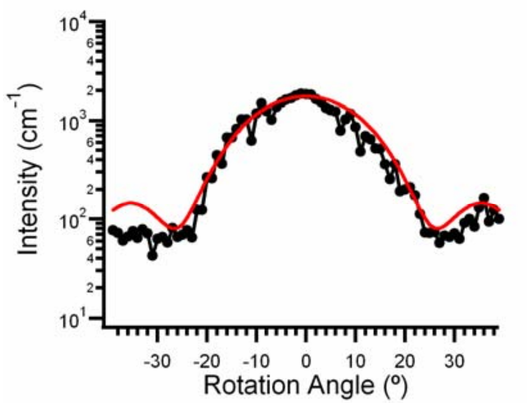
Cross Sectional Measurements of AMAG "NIST LER"

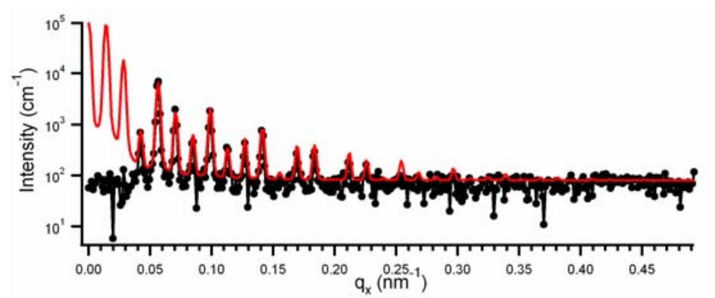
CD-SEM (Vert = 2x Horiz)





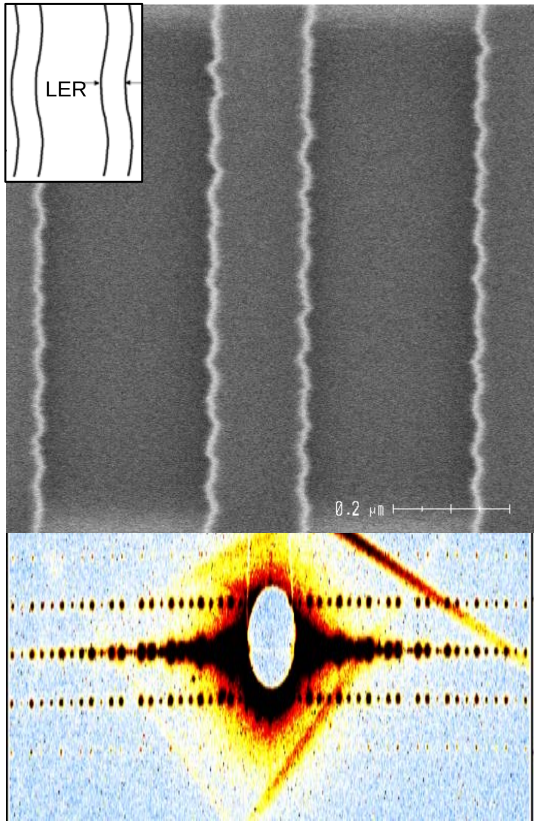
<u>Measured (Designed):</u>
Pitch = 446 nm (450 nm)
LW = 159 nm (150 nm)
Hgt = 127 nm
Side Ang. = 0



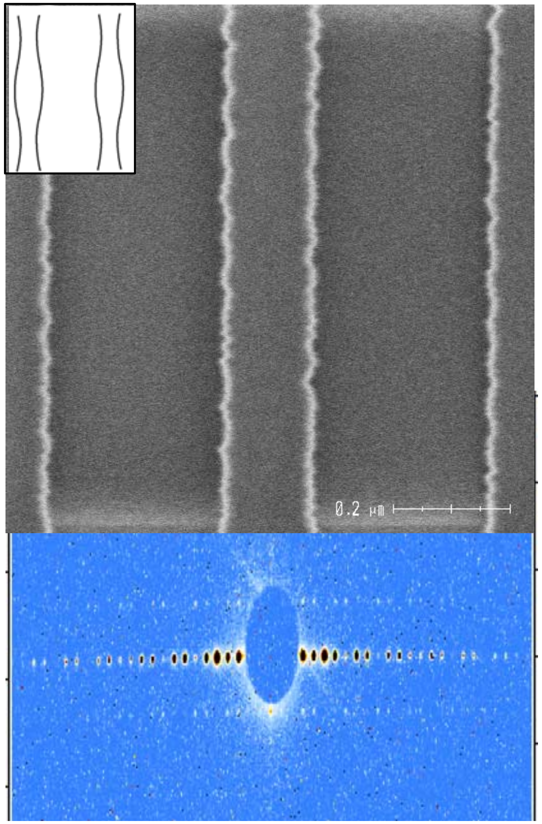


Three classes of edge roughness

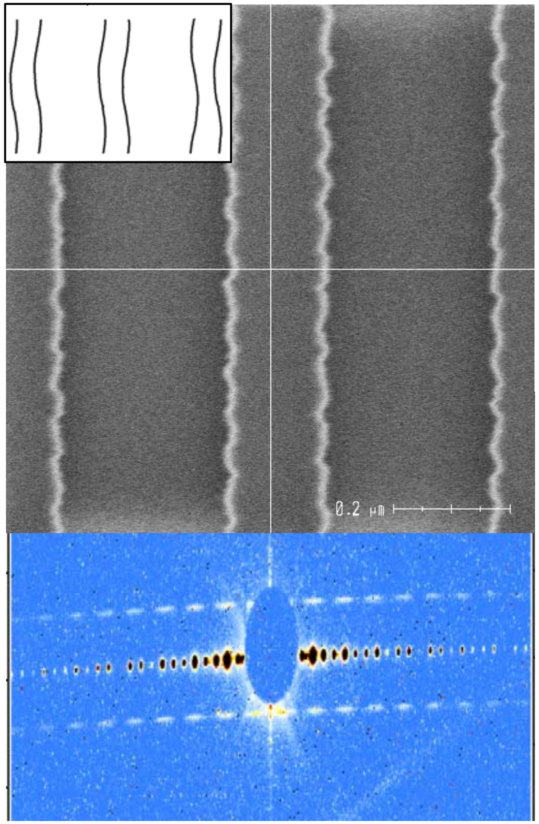
Note: CD-SEM (Vert = 2x Horiz)



Satellite peaks mirror main diffraction axis



Satellite peaks out of phase with main diffraction axis

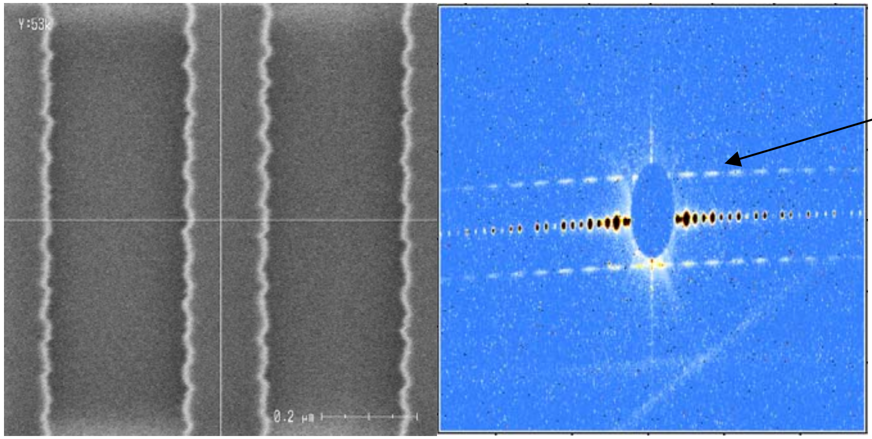


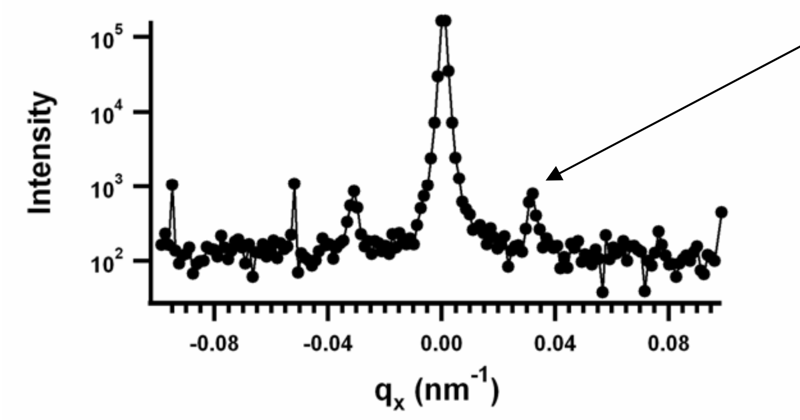
Satellite peaks smeared by randomness

Periodic portion of LER is emphasized in scattering along line direction

Qualitative differences in form of scattering between three classes

Quantitative information on LER





Relative intensities along qx provide information on type of LER

Magnitude of intensity related to amplitude of periodic portion of LER

Summary of CD-SAXS LER work to date

Design of Controlled LER Structures

- Printed AMAG series has amplitudes significantly smaller than designed
- Extracting periodic component from SEM for comparison with CD-SAXS will be challenging.
- Small differences in the RMS amplitude from pattern to pattern which challenges model verification.
- EUV based reticle design and fabrication nearing completion
- Patterns will feature more variations of roughness, from periodic to random.

Preliminary CD-SAXS results

- Qualitative differences observed between classes of LER.
- Intensity of satellite peaks should provide measure of RMS amplitude of periodic component.
- Model development in progress to make measurements quantitative.

Ongoing work and future plan

Planned Measurements

- Obtain a more complete set of data to decouple effects from different classes of LER on CD-SAXS data from Intel-NIST EUV series.
- Direct comparison of CD-SAXS measurements, in both LER and cross sectional measurements, with CD-SEM and OCD.
- Evaluation of lab-based CD-SAXS capabilities using Intel-NIST EUV patterns.

Technique Development

- Develop other measures of LER, including the total RMS value over all accessible frequencies.
- Development of new models for LER and quantitative analysis of CD-SAXS data.