Direct Visualization of the Impacts of EUV Mask Roughness

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Berkeley Lab Center for X-ray Optics, UC Berkeley, SEMATECH, and Samsung

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SEMATECH

IMPACT+ integrated modeling process and computation for technology

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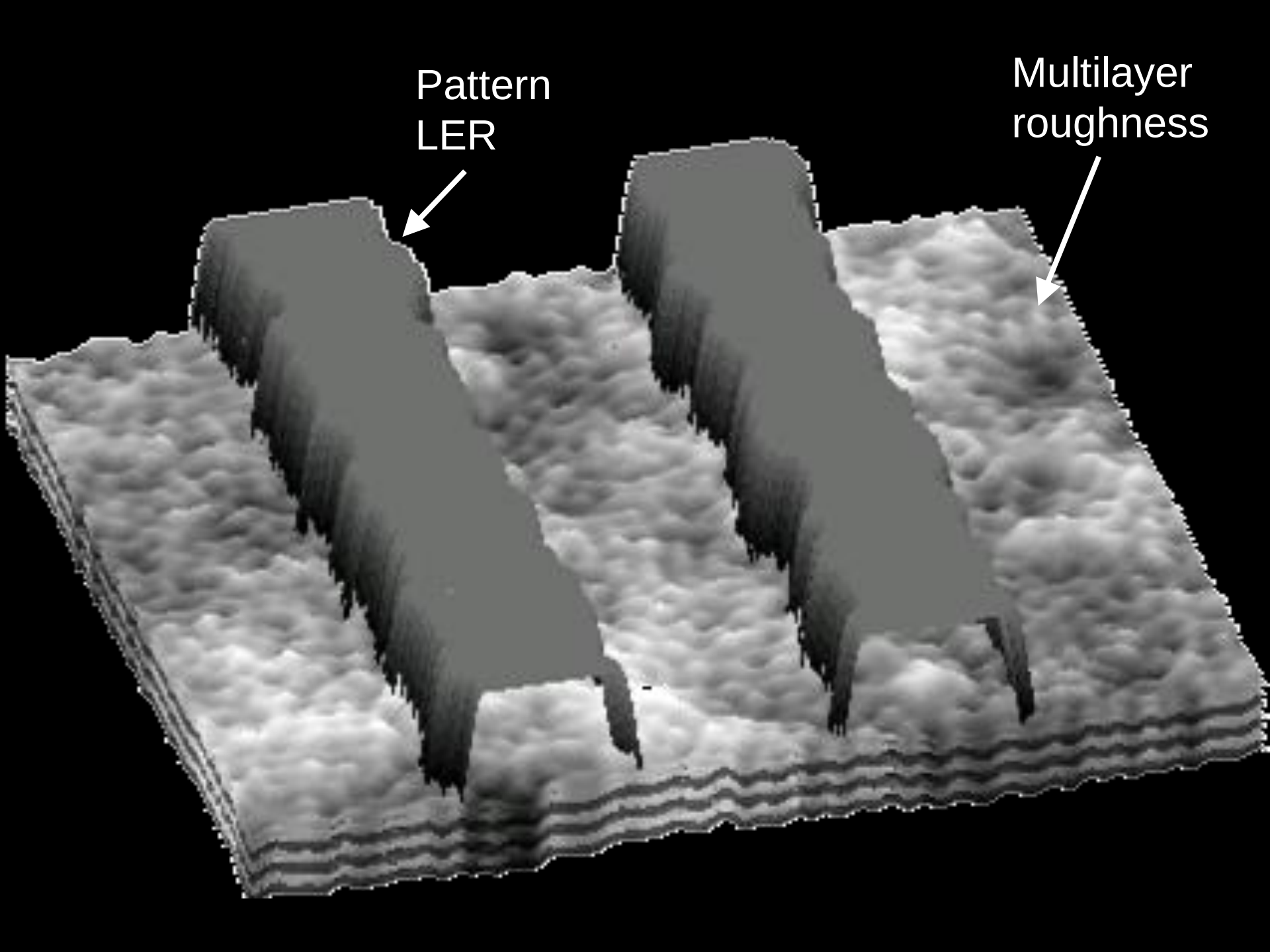
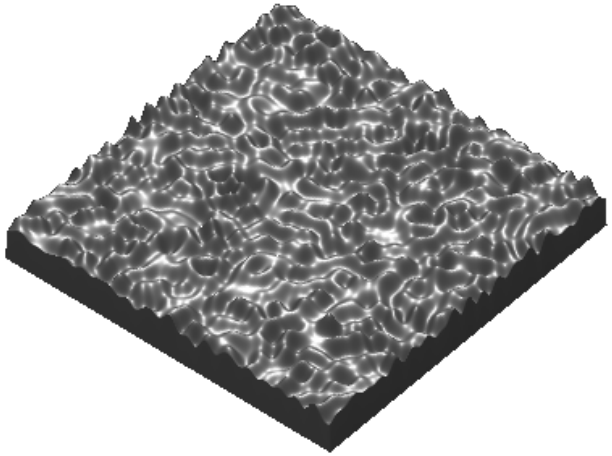
EUVL Workshop Maui HI, June 26, 2014


Pattern
LER
Multilayer
roughness

Band-limited imaging and propagation transforms phase roughness to intensity speckle

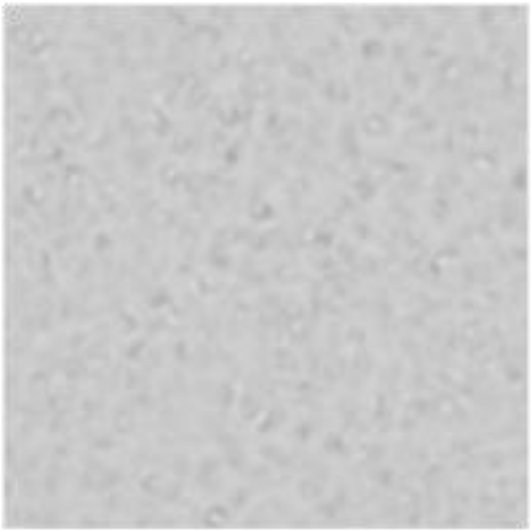
230 pm RSR



In focus

$\sigma = 0.5$

Contrast = 0.9%



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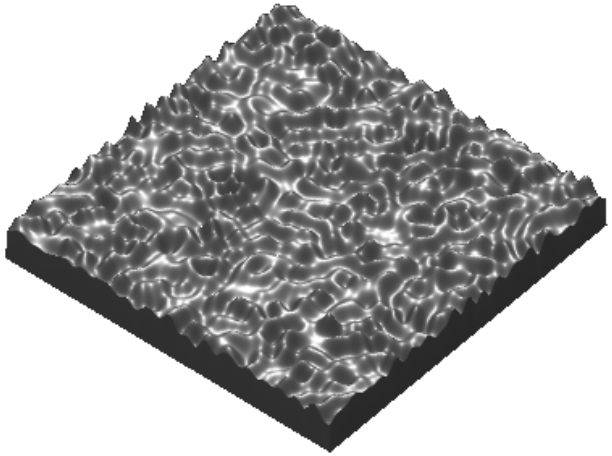
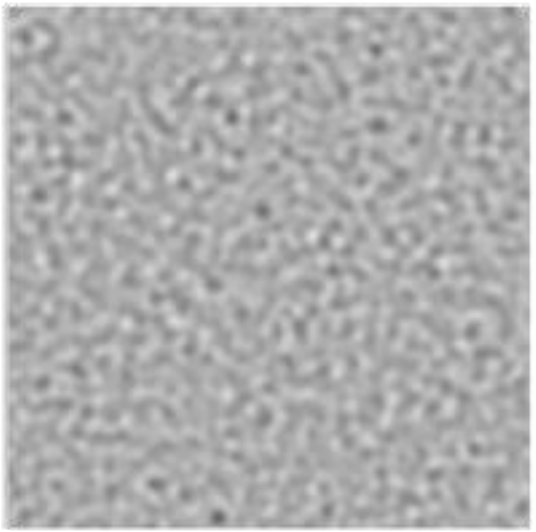


50-nm defocus

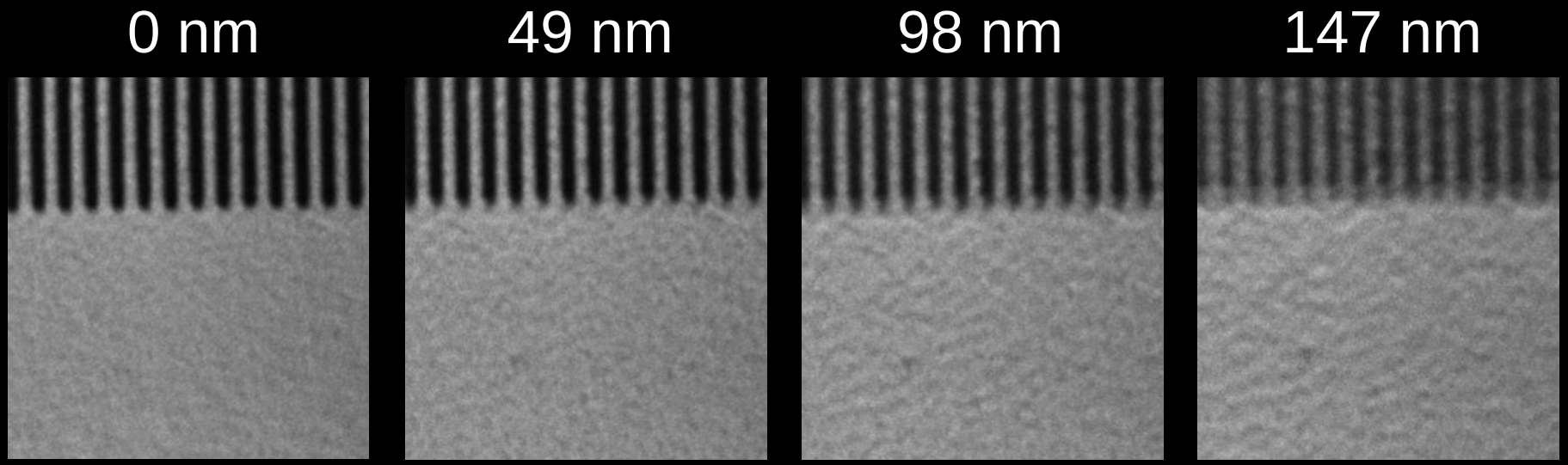
$\sigma = 0.5$

Contrast = 6%



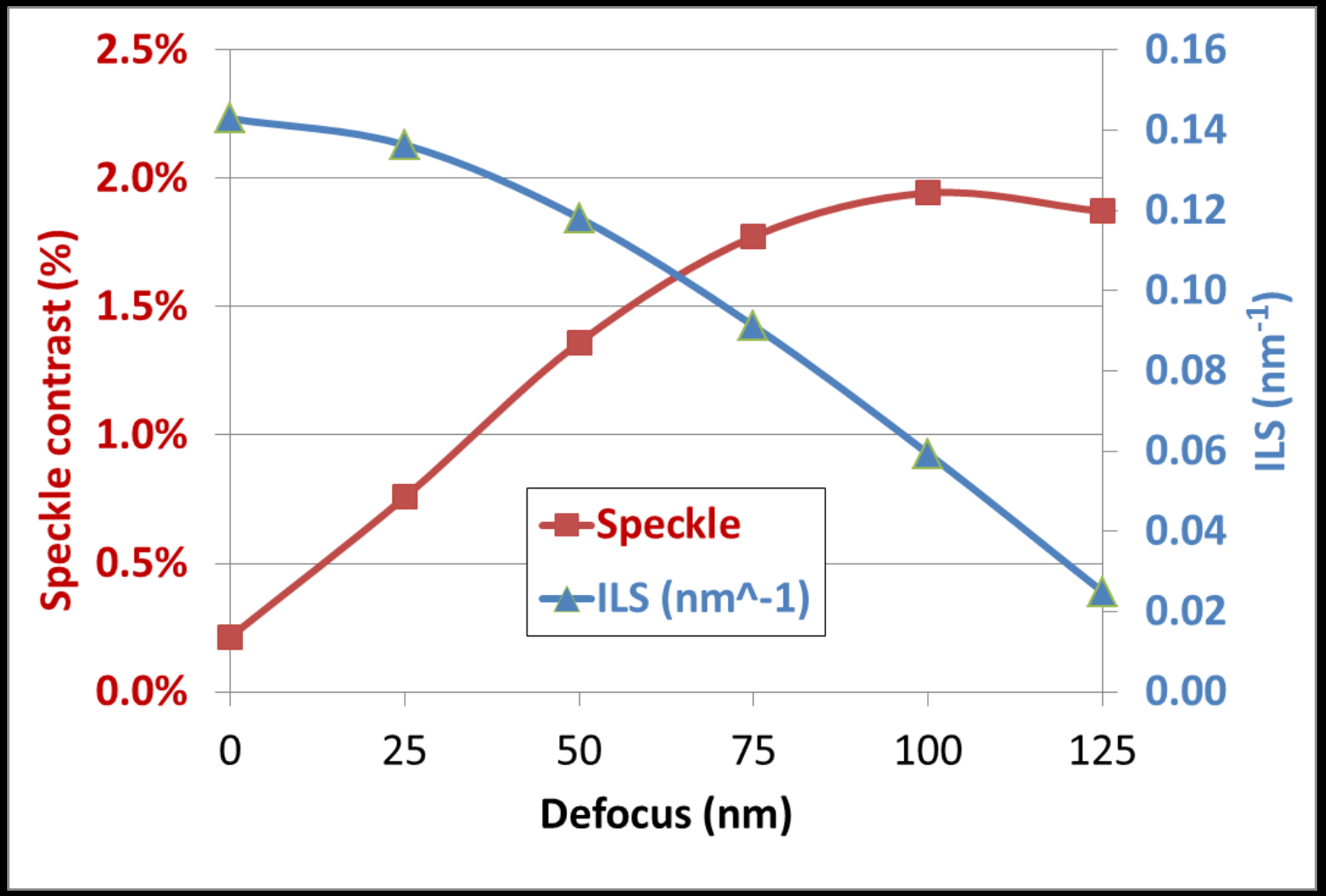
Multilayer speckle directly observed with EUV microscope

Defocus



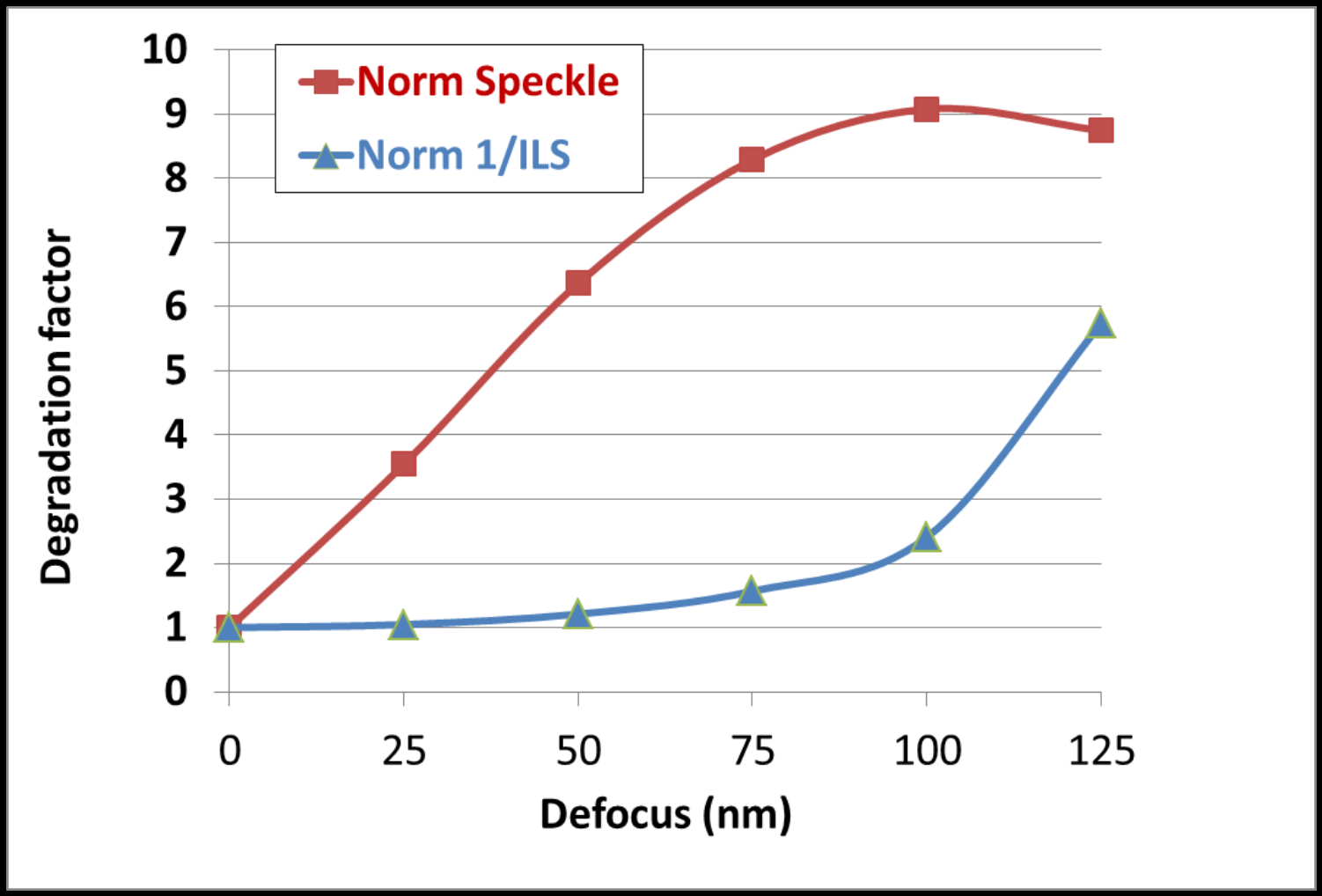
Images from SEMATECH Berkeley AIT, courtesy of Ken Goldberg, LBNL

Focus plays dominant role in roughness induced LWR



75-pm roughness, 0.33 NA, 0.7 Sigma, 22-nm HP

Focus plays dominant role in roughness induced LWR



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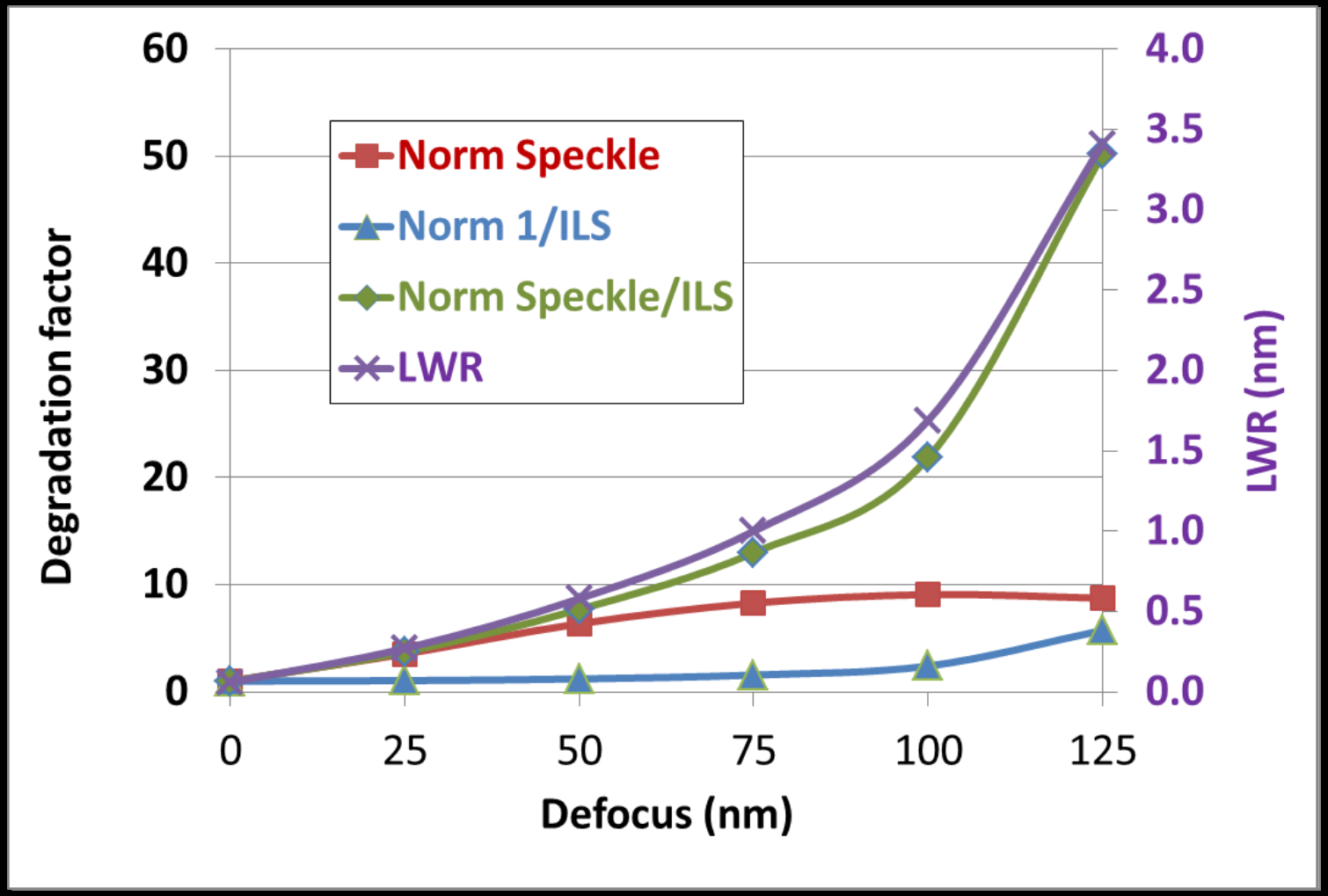

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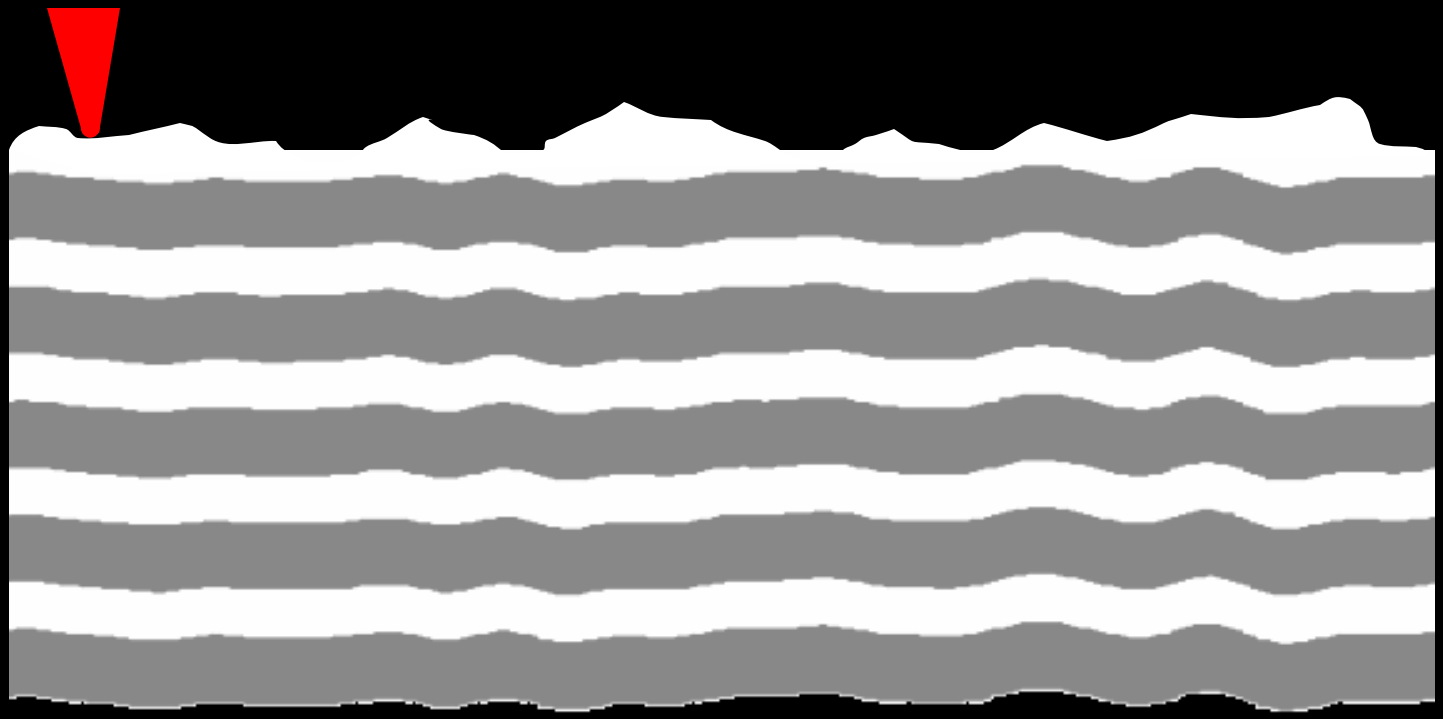
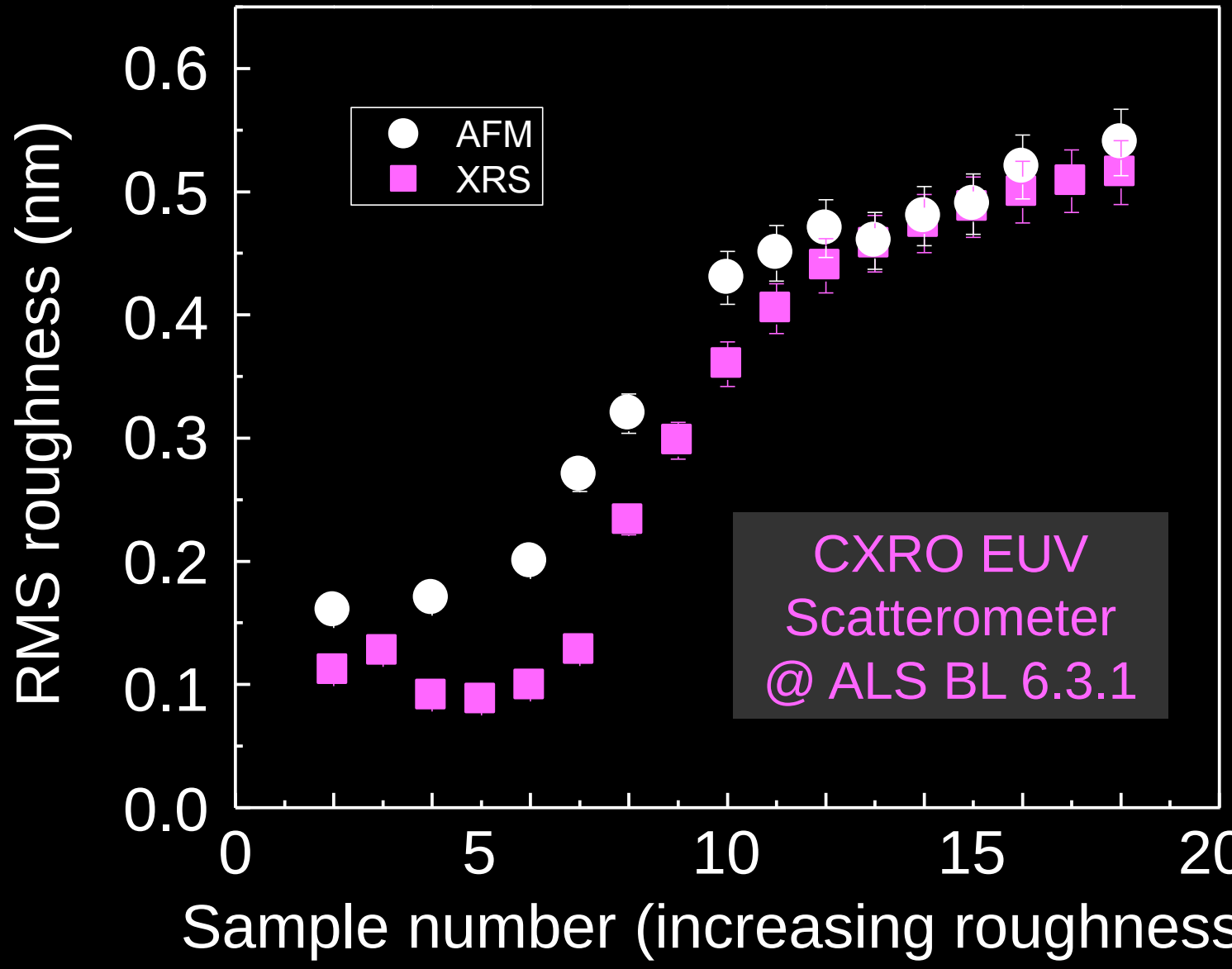
Measuring multilayer roughness

AFM blind to true EUV roughness

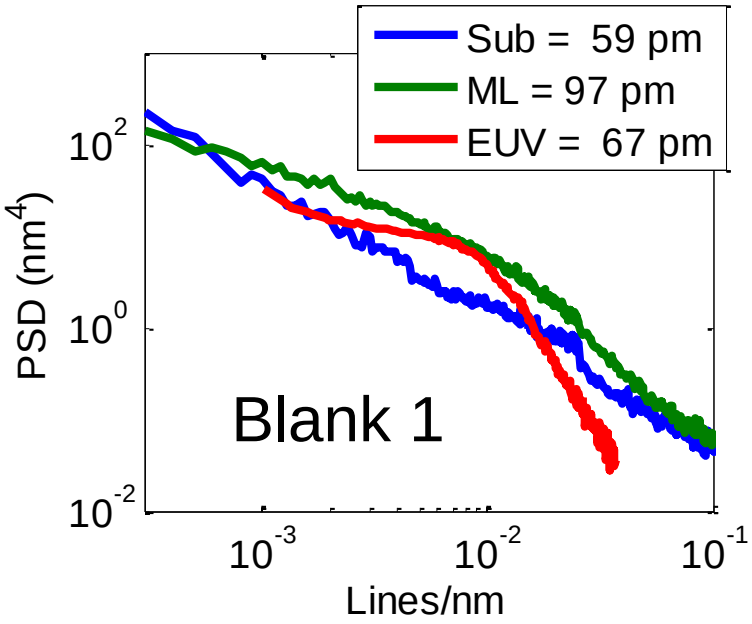


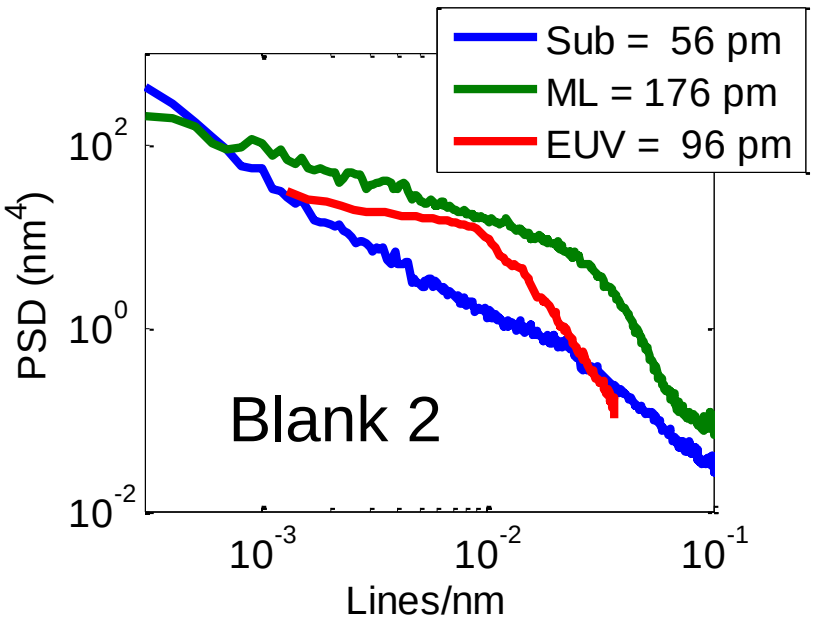
AFM blind to true EUV roughness

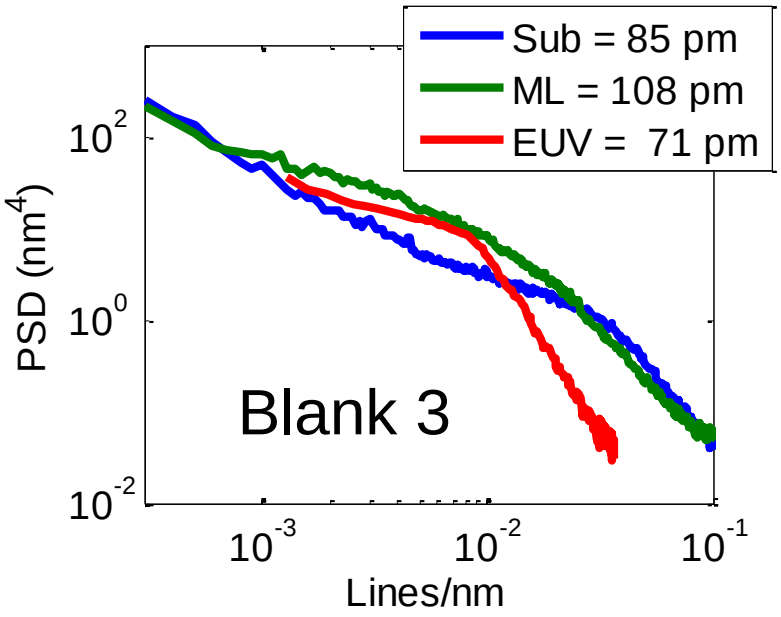


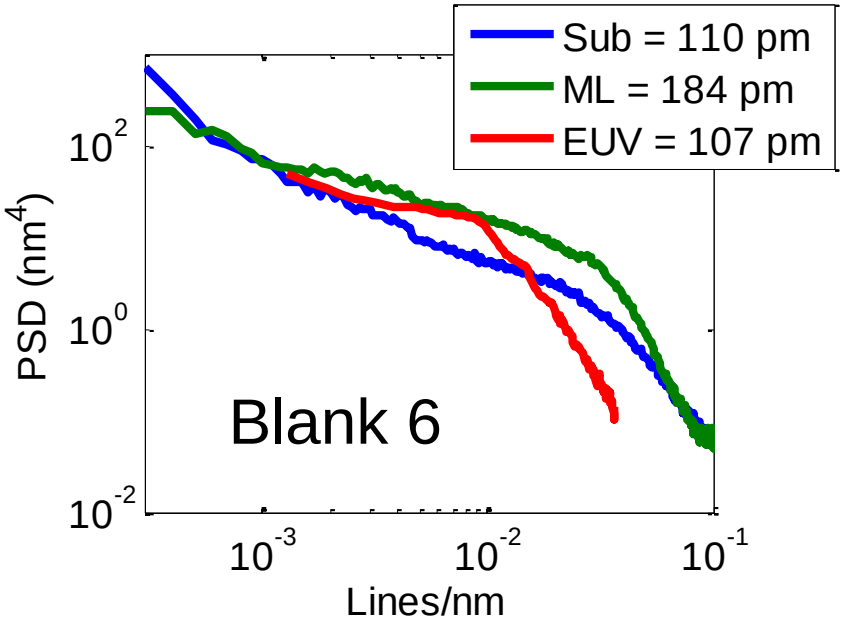
S. George et al., Proc. SPIE **7969**, 79690E (2011)

Scatterometry measures true EUV roughness









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Demonstration 1: Measure multilayer speckle with SHARP

Source: Synchrotron

Optics: Mirrors & Zoneplate-lenses

4×NA: 0.25–0.625

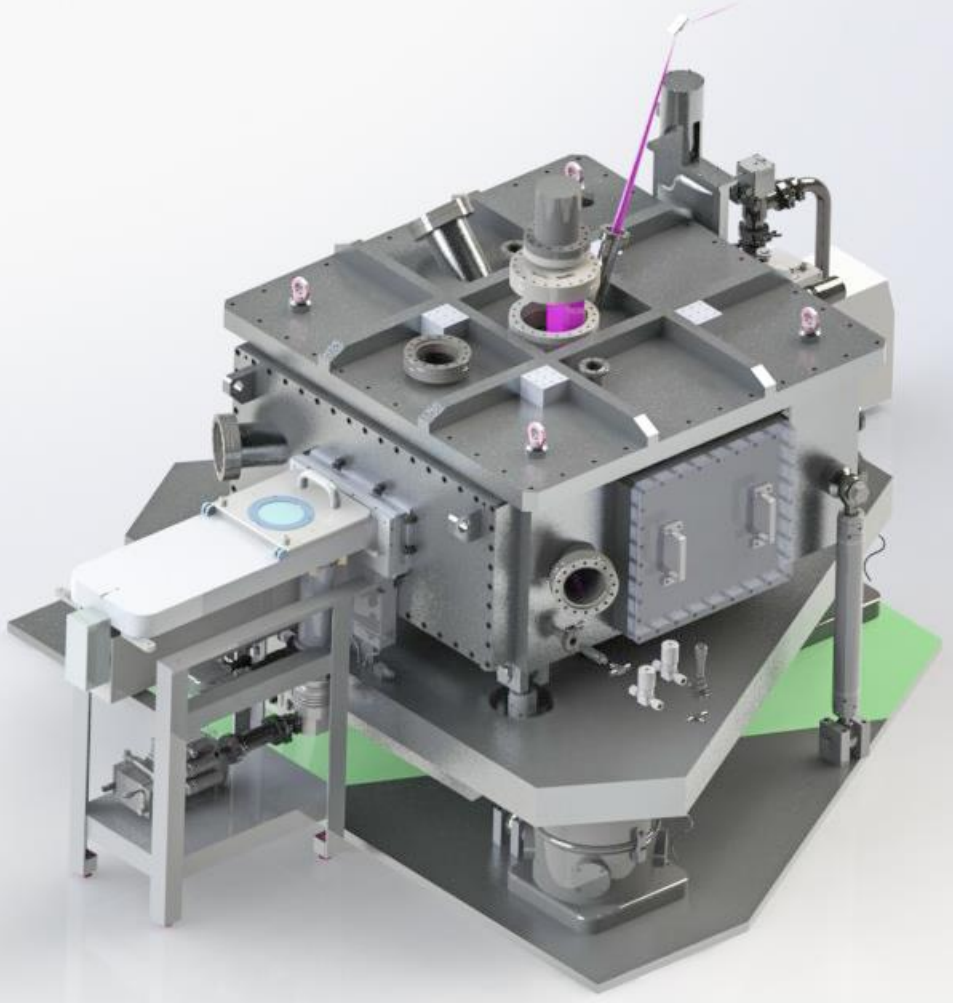
σ: Programmable

Nav: Full-mask *xy*

Speed: ~8 series/hr

SHARP

SEMATECH HIGH-NA ACTINIC RETICLE REVIEW PROJECT

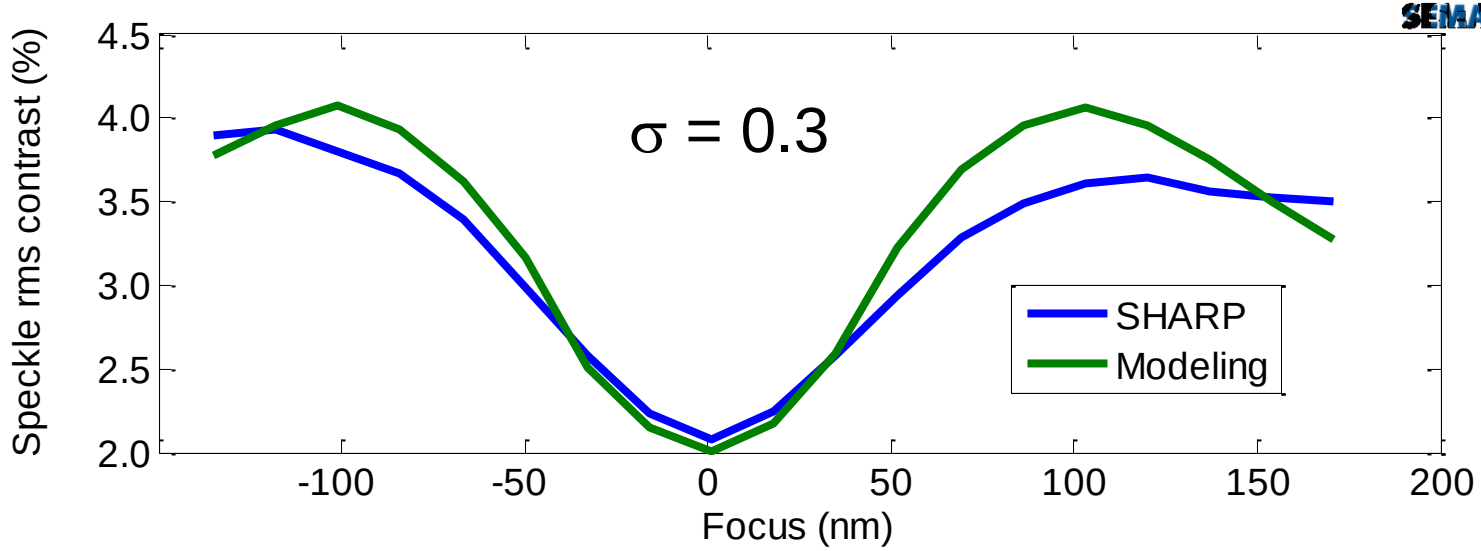


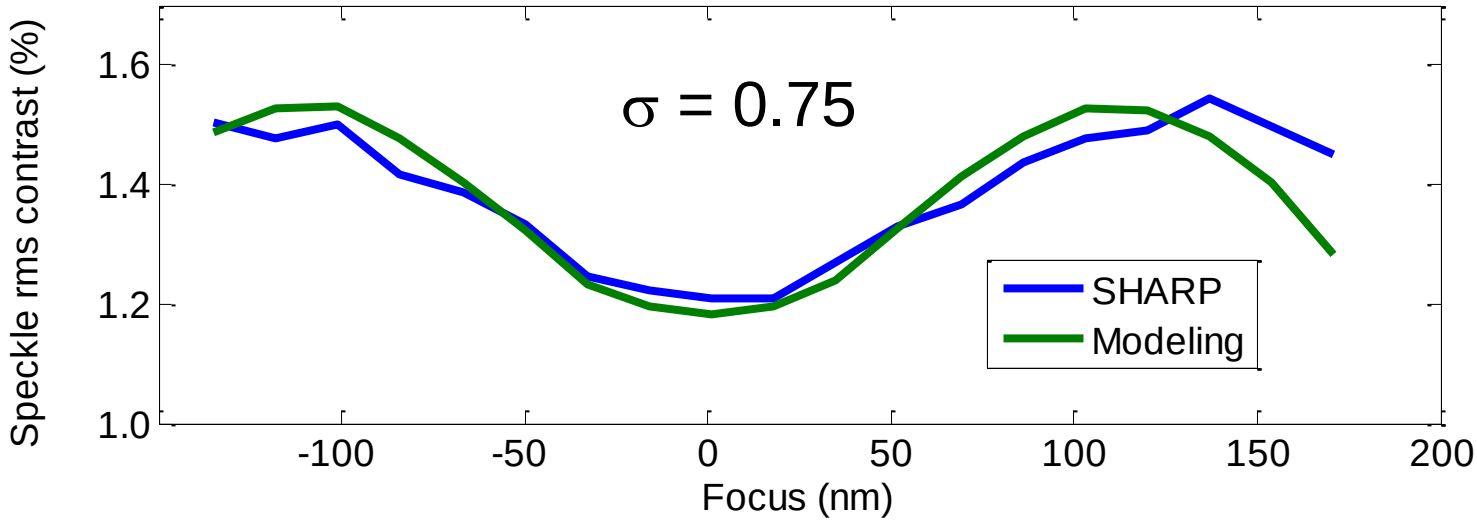
Defocus

Defocus

Good fit between SHARP and modeling

Blank 1, EUV roughness = 67 pm





Demonstration 2: Measure multilayer-induced LWR with Samsung SERM tool

Scanning EUV Reticle Microscope

Outline of the tool development

- The zone plate optics was designed and fabricated by LBNL.
- The high harmonic source was developed by Samsung and FST using COHERENT Ti:Sapphire femtosecond laser(λ = 800nm, pulse width= 46fs) and the whole system was integrated by Samsung.

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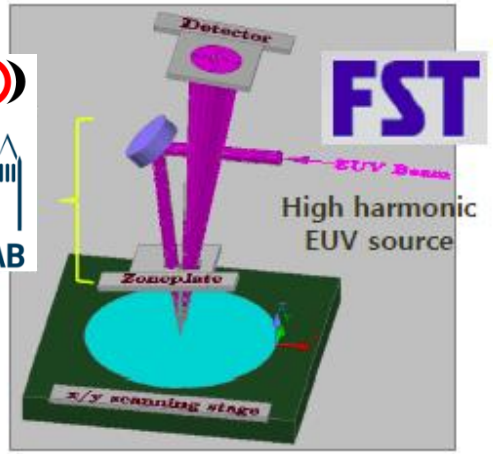
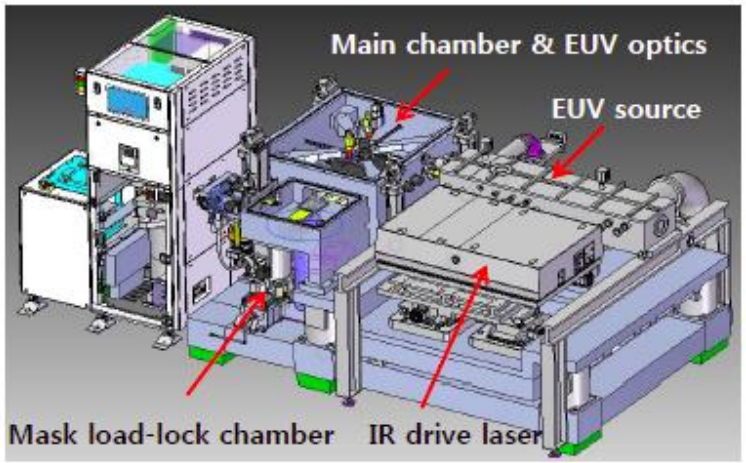
Zone plate Optics package





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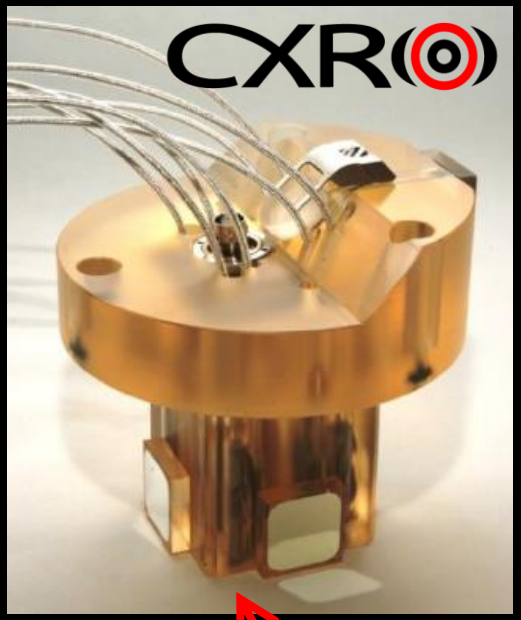
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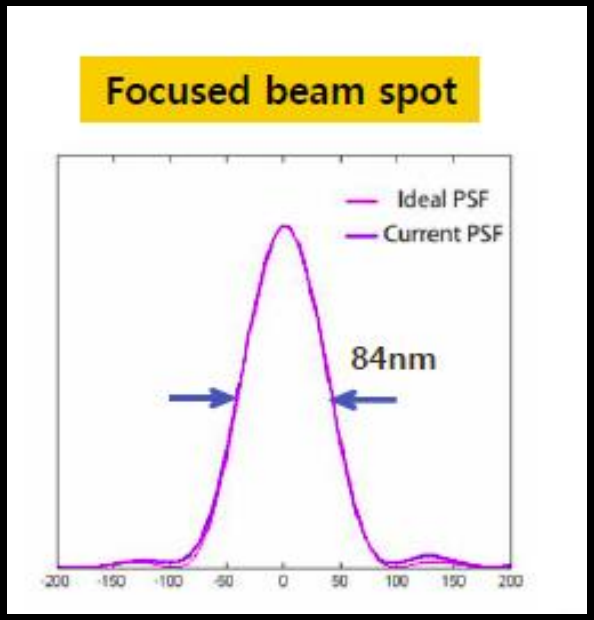
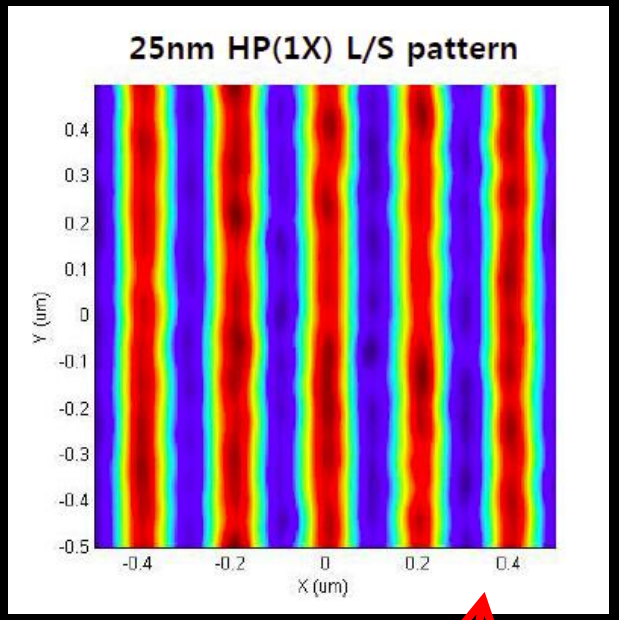

Focused beam spot
Ideal PSF
Current PSF
84nm
-200
-150
-100
-50
0
50
100
150
200


25nm HP(1X) L/S pattern
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Y (um)
-0.4
-0.2
0
0.2
0.4
X (um)

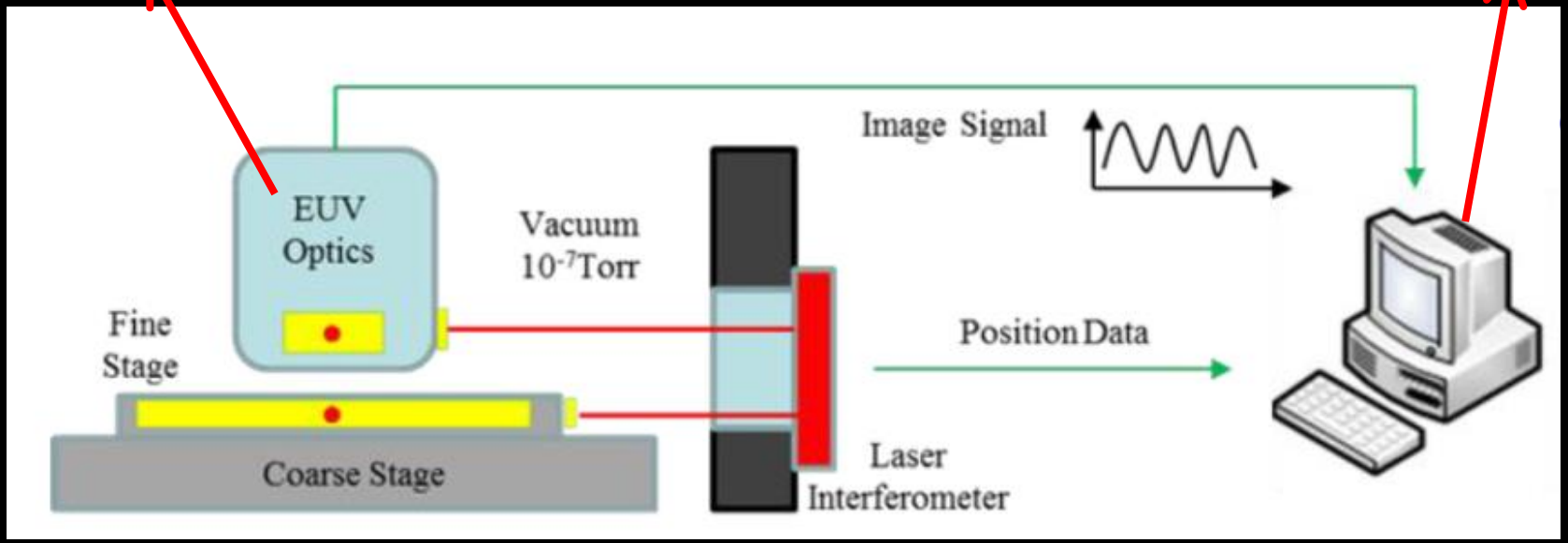


Image Signal
EUV
Optics
Vacuum
10-7Torr
Fine
Stage
Position Data
Coarse Stage
Laser
Interferometer

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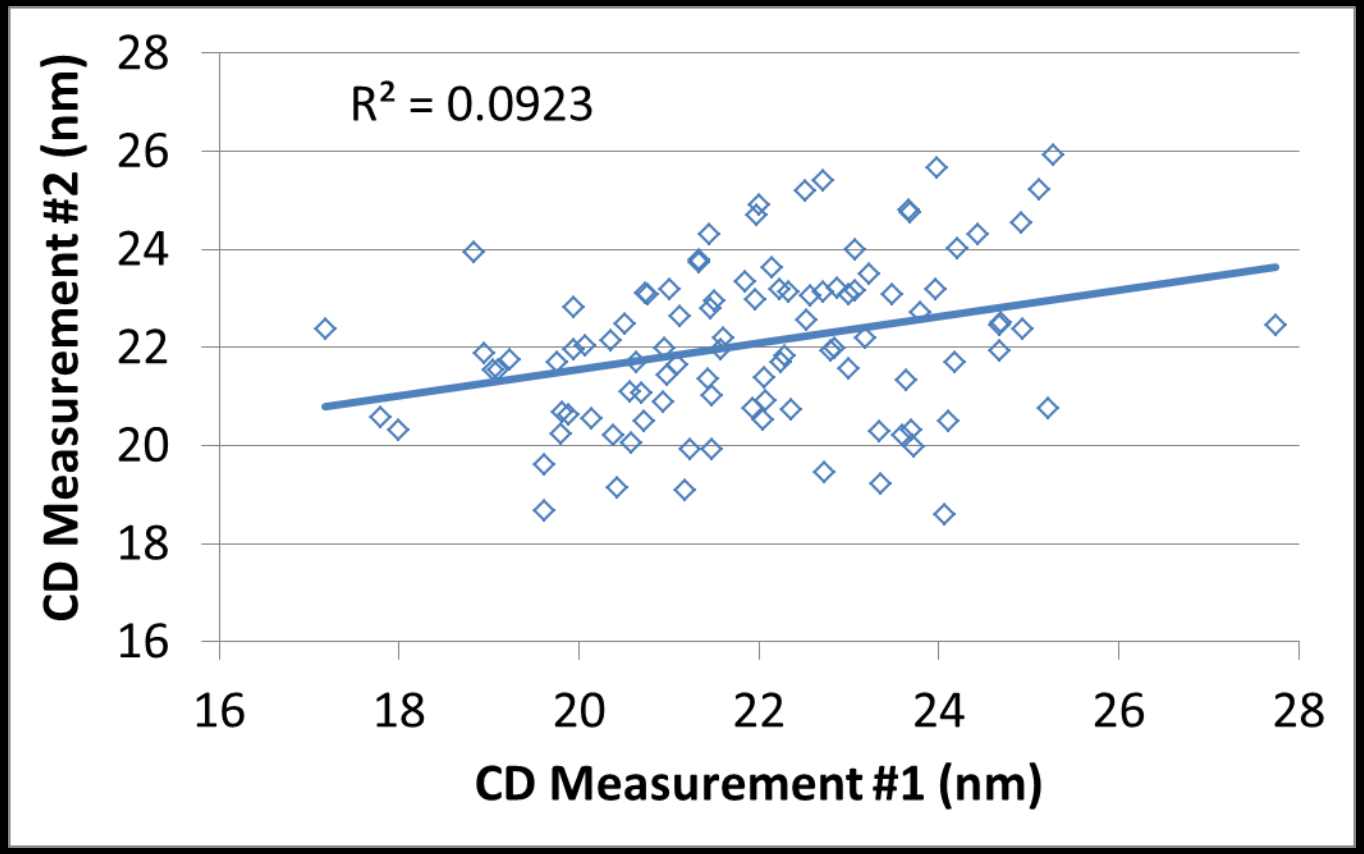
Correlation method used to extract mask roughness in presence of noise



Total Mask-induced LWR
1.60 nm

Pattern LWR
1.48 nm

Multilayer LWR
0.62 nm

Simulated Multlayer LWR
0.60 nm

$LWR_{msk} = R \times LWR_{meas}$*

* Appl. Opt. **48**, 3302-3307 (2009)

Impact on inspection

Patterned mask inspection

RSR (pm)	Speckle LWR (nm)	CDU Requirement 10%	CDU Requirement 20%
20	0.16	2.81E-08	4.00E-63
30	0.24	2.77E-04	2.65E-47
44	0.35	7.39E+00	7.93E-30
56	0.45	4.37E+03	6.15E-19
69	0.55	3.40E	
81	0.65	6.89E	
94	0.75	5.83E	
106	0.85	2.77E	
119	0.95	8.90E	

~50-pm required

Brightfield blank inspection

RSR (pm)	Printable defect height (nm) 0.3	0.4	0.5	0.6
50	6.59E-05	3.44E-17	6.40E-33	4.16E-52
55	3.74E-02	2.52E-12	2.42E-25	3.26E-41
60	4.71E+00	1.28E-08	1.43E-19	6.40E-33
65	2.05E+02	9.92E-06	4.47E-15	1.84E-26
70	4.15E+03	1.96E-03	1.67E-11	2.48E-21
80	3.48E+05	4.71E+00	2.96E-06	8.51E-14
90	7.44E+06			
100	6.77E+07			
110	3.52E+08			
120	1.25E+09			
130	3.37E+09			

Darkfield blank inspection

RSR (pm)	Target defect height (nm) 0.4	0.6	0.8	1.0
50	5.28E+06	8.00E-08	2.22E-44	3.90E-121
60	3.79E+08	5.72E+01	1.01E-16	7.75E-54
70	2.63E+09	4.10E+05	8.39E-05	6.37E-25
80	7.24E+09	3.37E+07	5.72E+01	7.71E-11
90	1.30E+10	3.79E+08	7.92E+04	2.64E-03
100	1.88E+10	1.59E+09	5.28E+06	5.72E+01
110	2.40E+10	3.95E+09	7.04E+07	2.54E+04
120	2.84E+10	7.24E+09	3.79E+08	1.26E+06

Summary

- Roughness has significant impact on inspection
- Actinic characterization likely required
- Model verified using two different actinic microscopes
- System modeling points to EUV roughness requirements close to 50 pm

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Thank You