Material Challenges for EUVL

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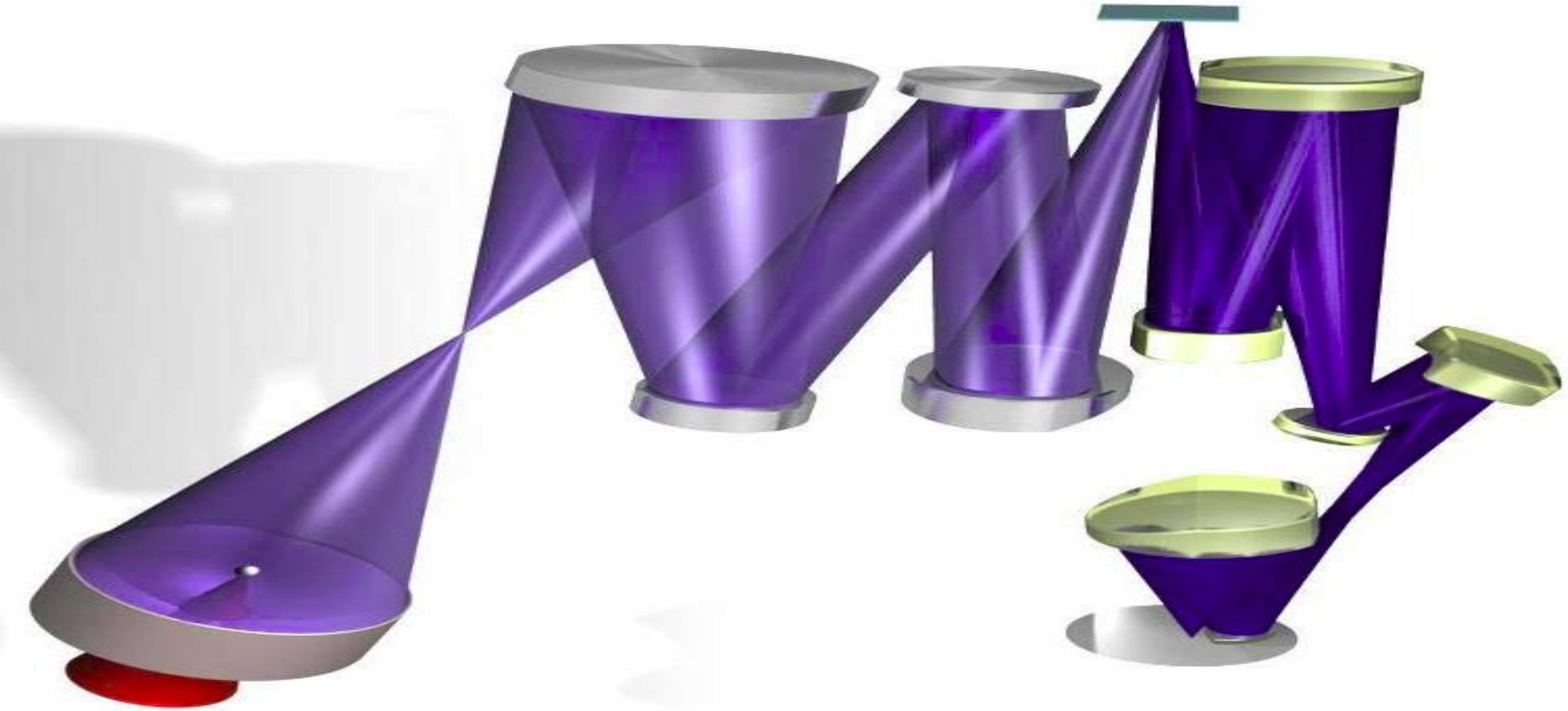
AVS: Material Opportunities for Semiconductors
Thursday, September 25, 2014



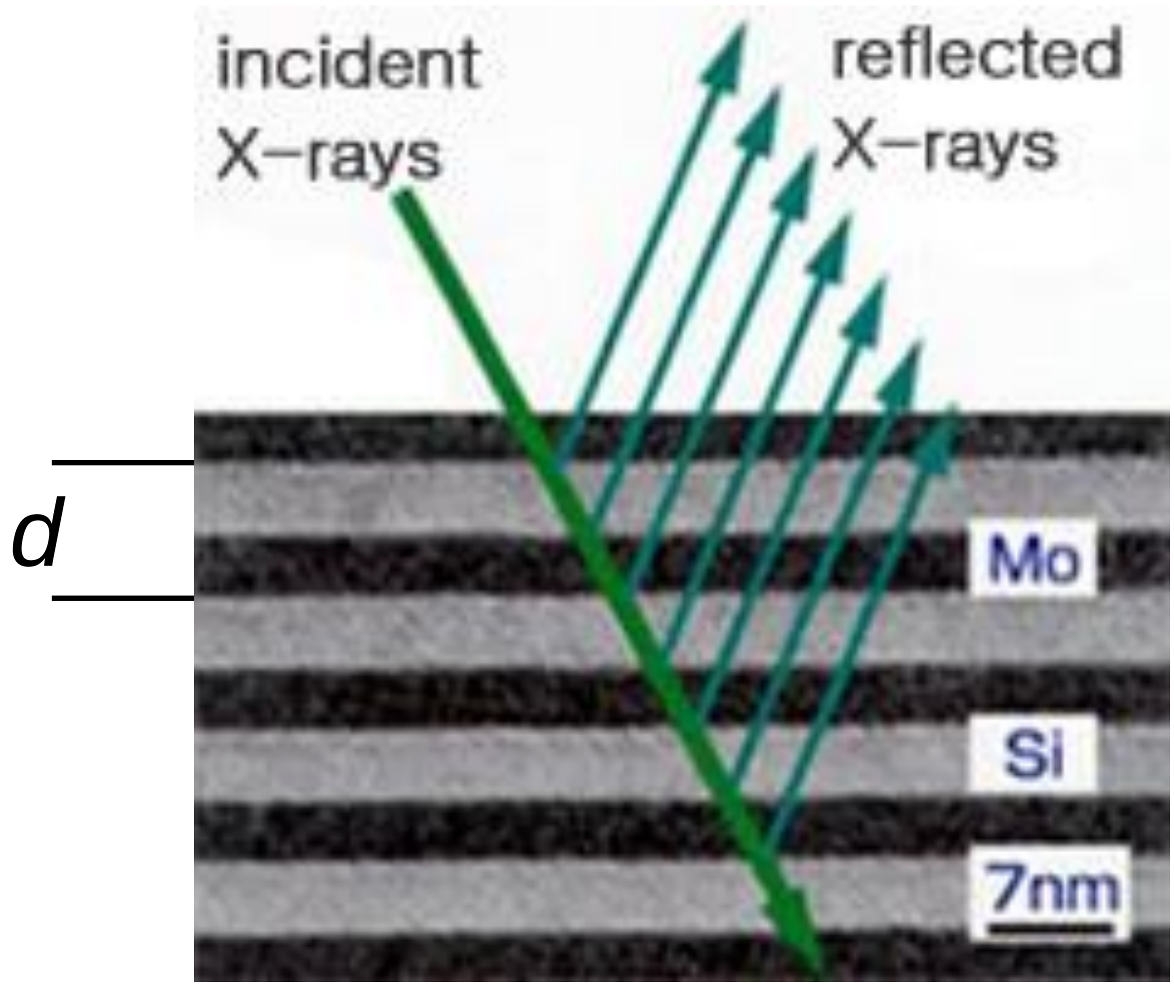
Challenges

- ***Source***
  - ***High thermal load multilayers***
  - ***In situ tin removal***
- ***Optics***
  - ***Spectral filters***
  - ***Robust capping layers***
- ***Mask***
  - ***High efficiency pellicle***
  - ***Defects***
  - ***Roughness***
- ***Resist***
  - ***Photon harnessing***
  - ***Materials stochastics***

Multilayers

Multilayer mirrors required to build up adequate near normal reflectivity

$$d = \lambda/2\sin\theta$$



Multilayer Defects

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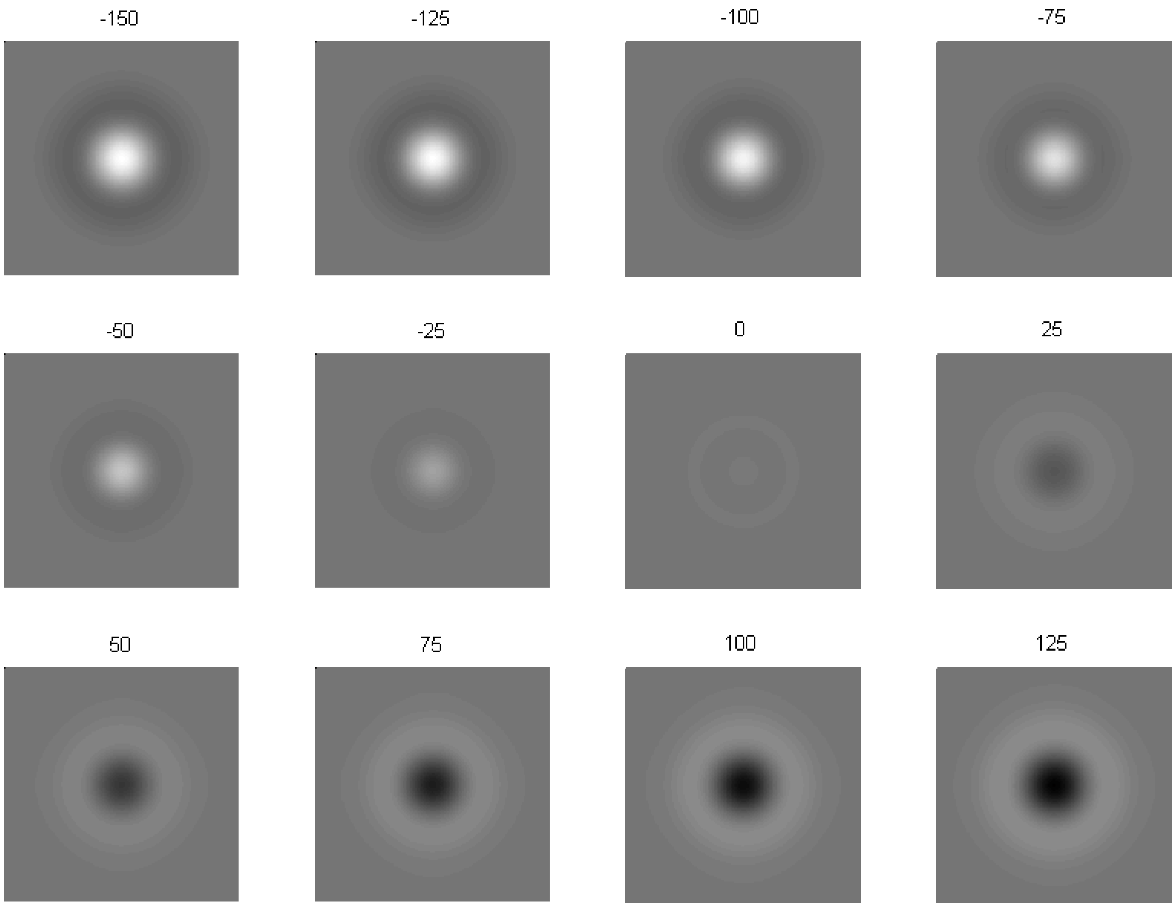
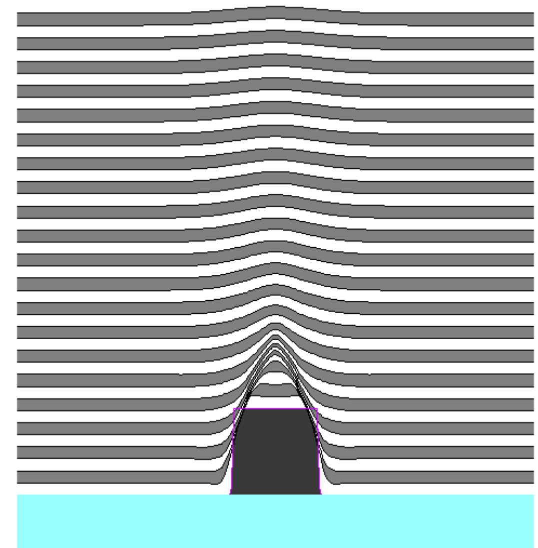
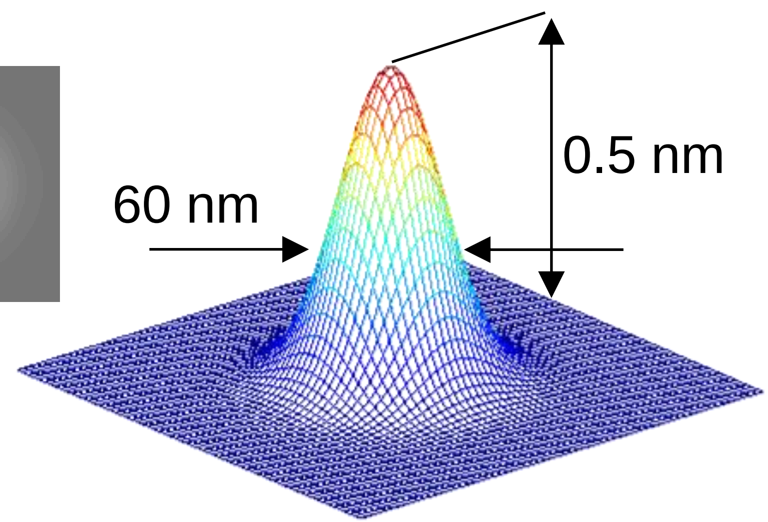
Buried (phase) defects lead to intensity variations at wafer





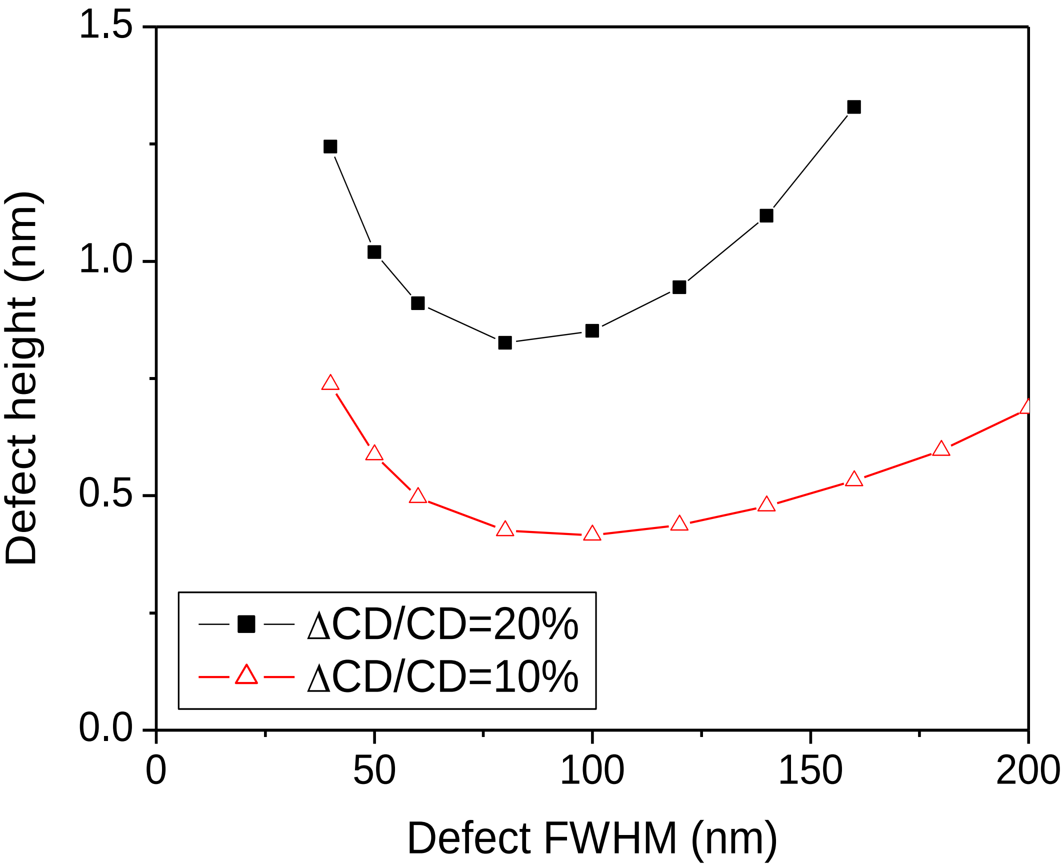


Modeled aerial image of 60-nm wide, 1-nm tall isolated defects through focus (25-nm steps)

NA=0.35, σ = 0.5, Ideal optic

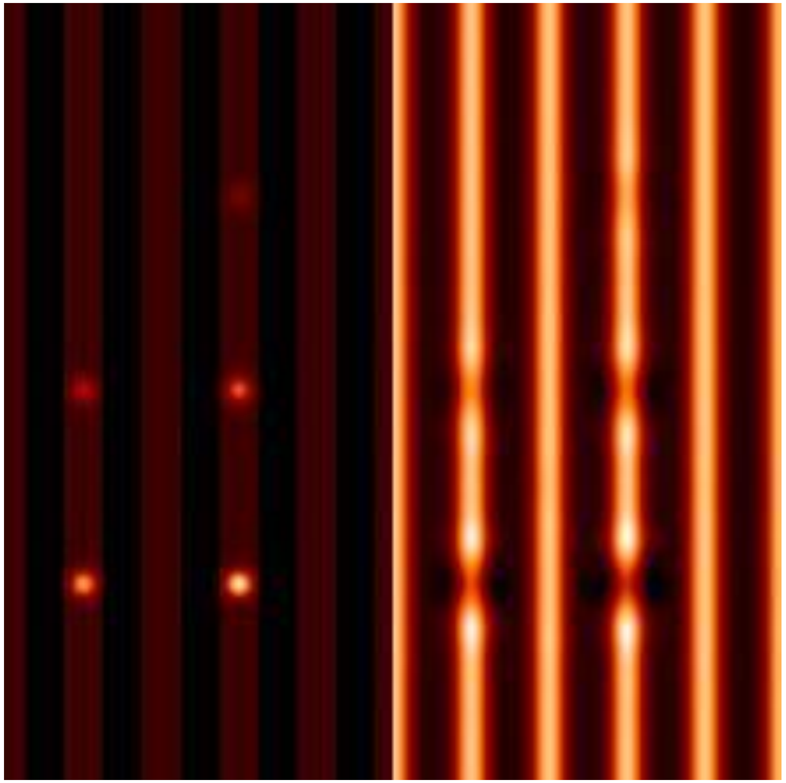
Sub-half-nm defect tolerance at 22-nm half pitch

NA=0.35, σ = 0.5, Centered defect



- 50 nm defocus

+ 50 nm defocus



$\lambda/2NA^2$ = 55 nm

Data courtesy of E. Gullikson, Berkeley Lab

Near-quarter-nm defect tolerance at 16-nm half pitch

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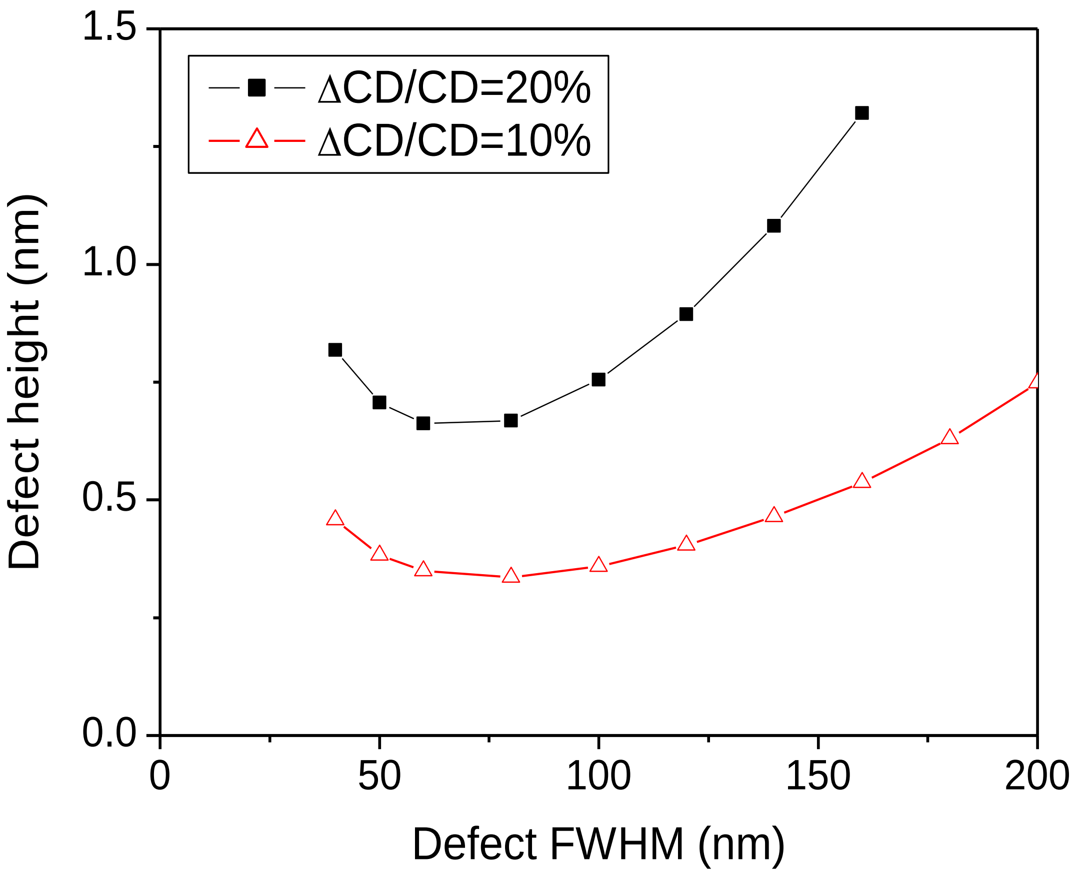
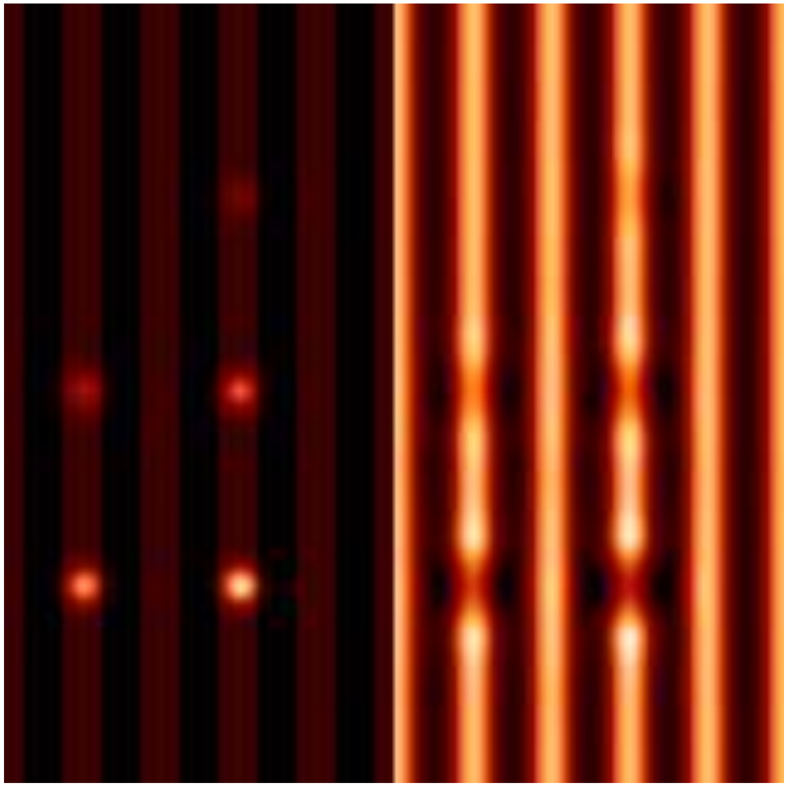
NA=0.45, σ = 0.5, Centered defect



- 30 nm defocus

+ 30 nm defocus



$\lambda/2NA^2$ = 33 nm

CXRO

Data courtesy of E. Gullikson, Berkeley Lab

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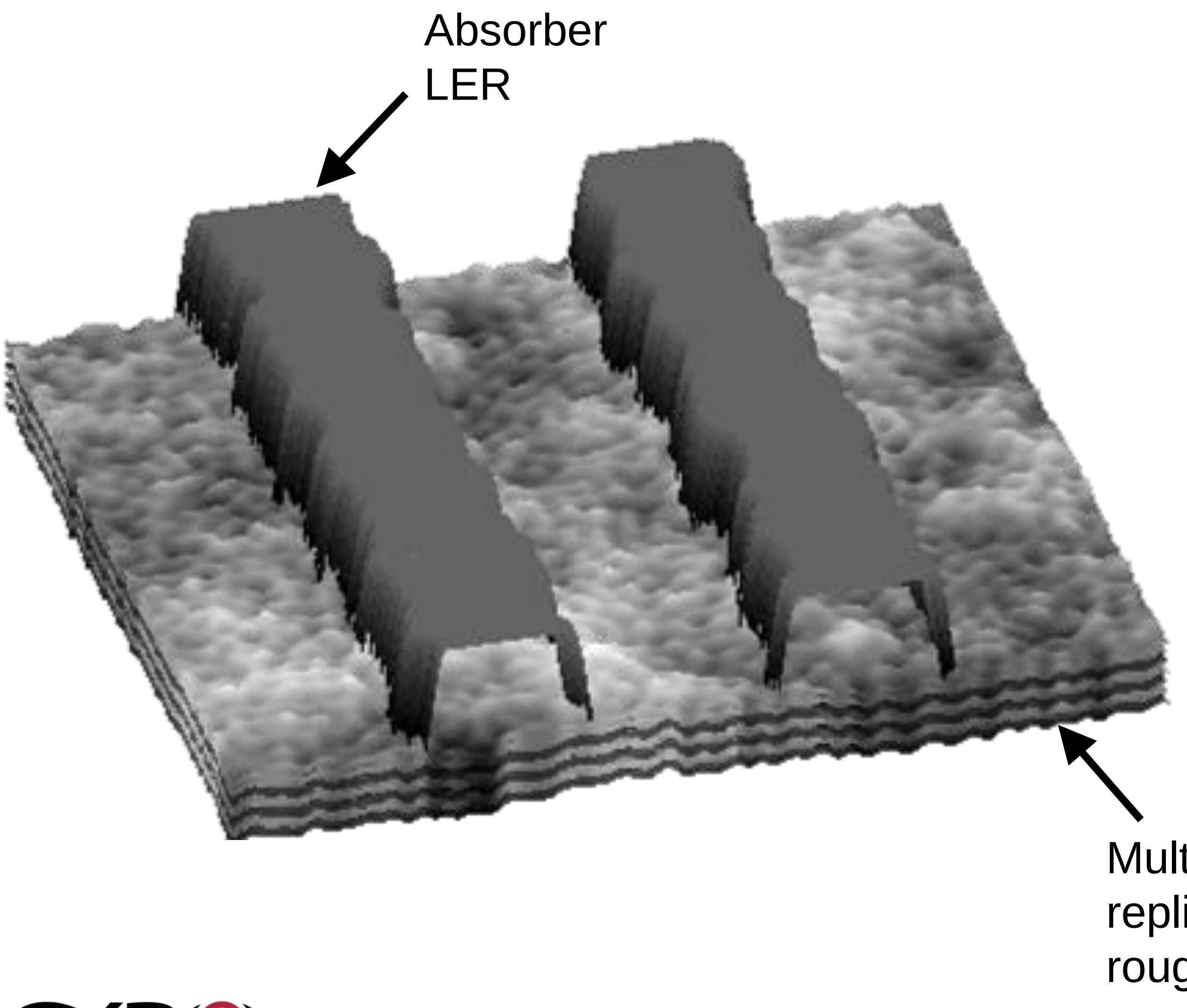
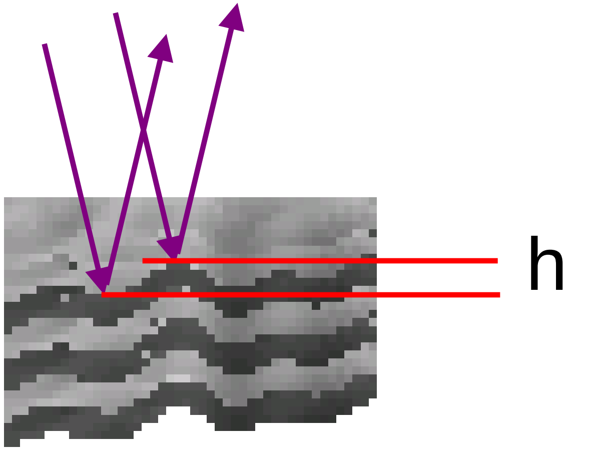
Mask Roughness

Mask sources of LER

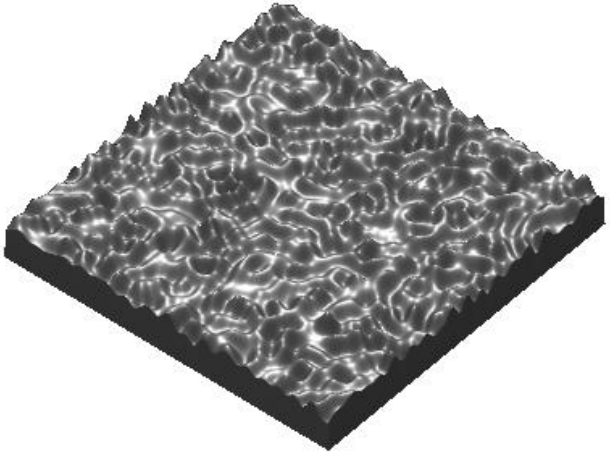




$$\Delta\theta = 2h(2\pi/\lambda)$$

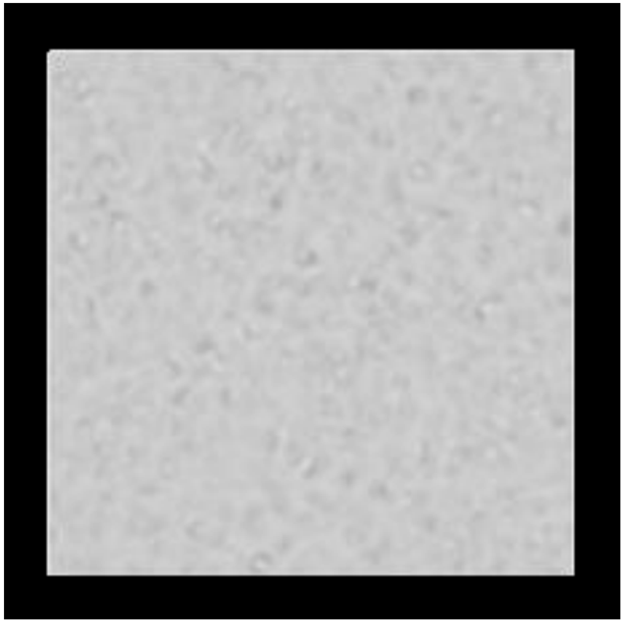
Imaging transforms phase roughness to intensity speckle

230 pm RSR



In focus
$\sigma = 0.5$

Contrast = 0.9%



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Imaging transforms phase roughness to intensity speckle

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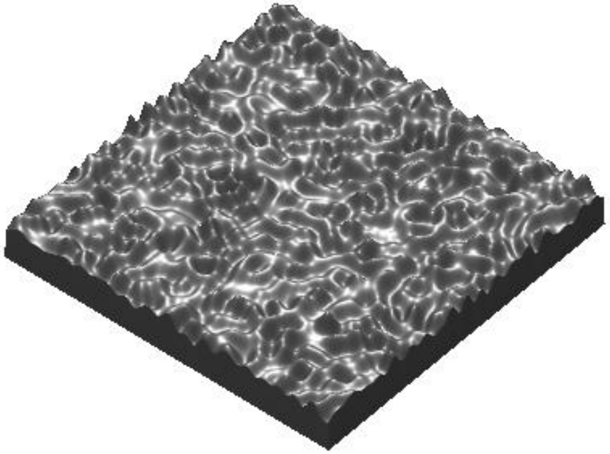
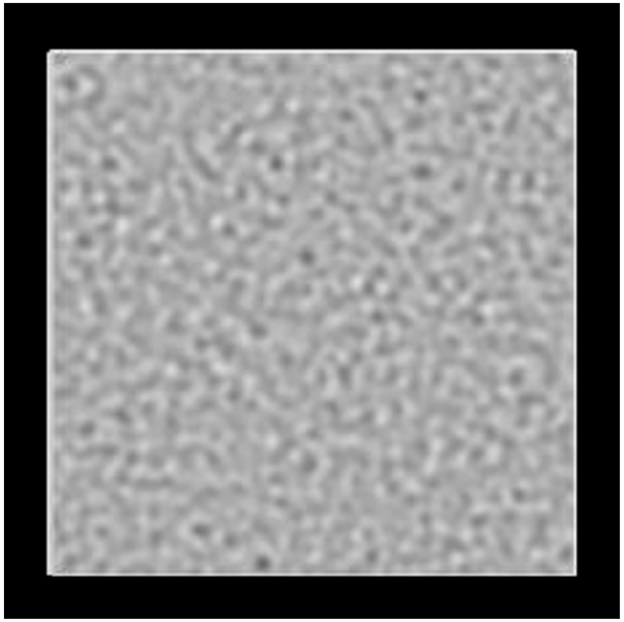


50-nm defocus
$\sigma = 0.5$

Contrast = 6%



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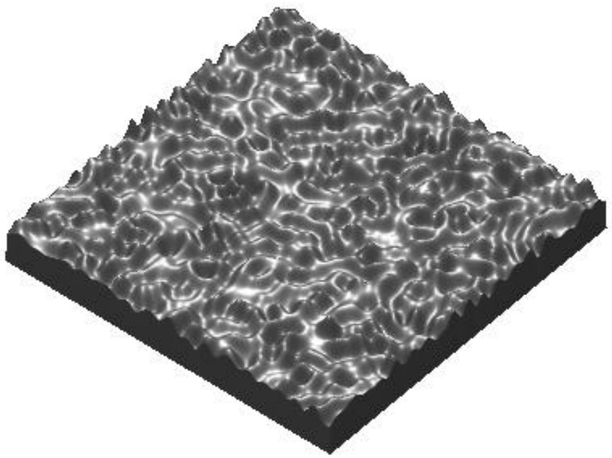
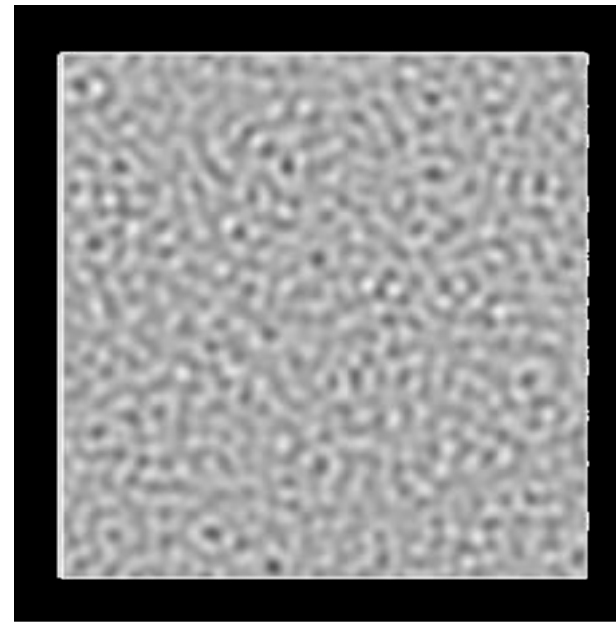
Imaging transforms phase roughness to intensity speckle

230 pm RSR

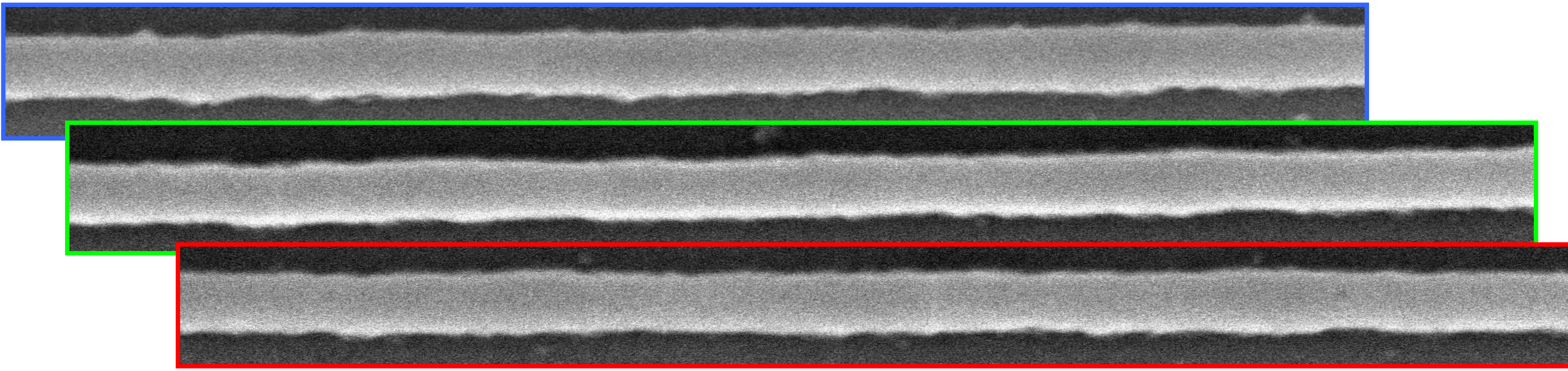


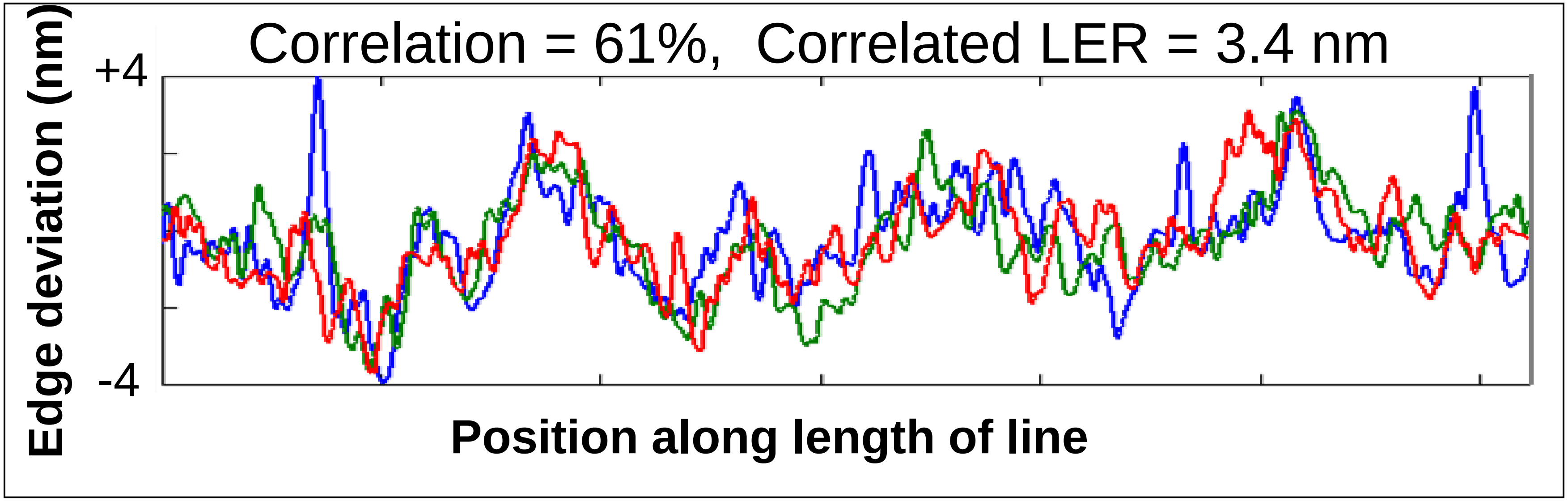
50-nm defocus
$\sigma = 0.3$

Contrast = 9%



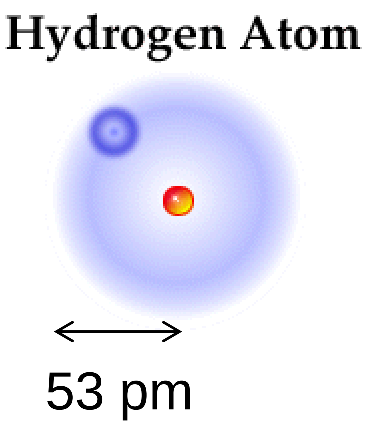
Wafer print demonstration





Model-based roughness specifications

Configuration	RSR limit (pm)
22-nm, disk 0.5, 0.32 NA	46
16-nm, quad, 0.32 NA	77
16-nm, annular, 0.42 NA	77



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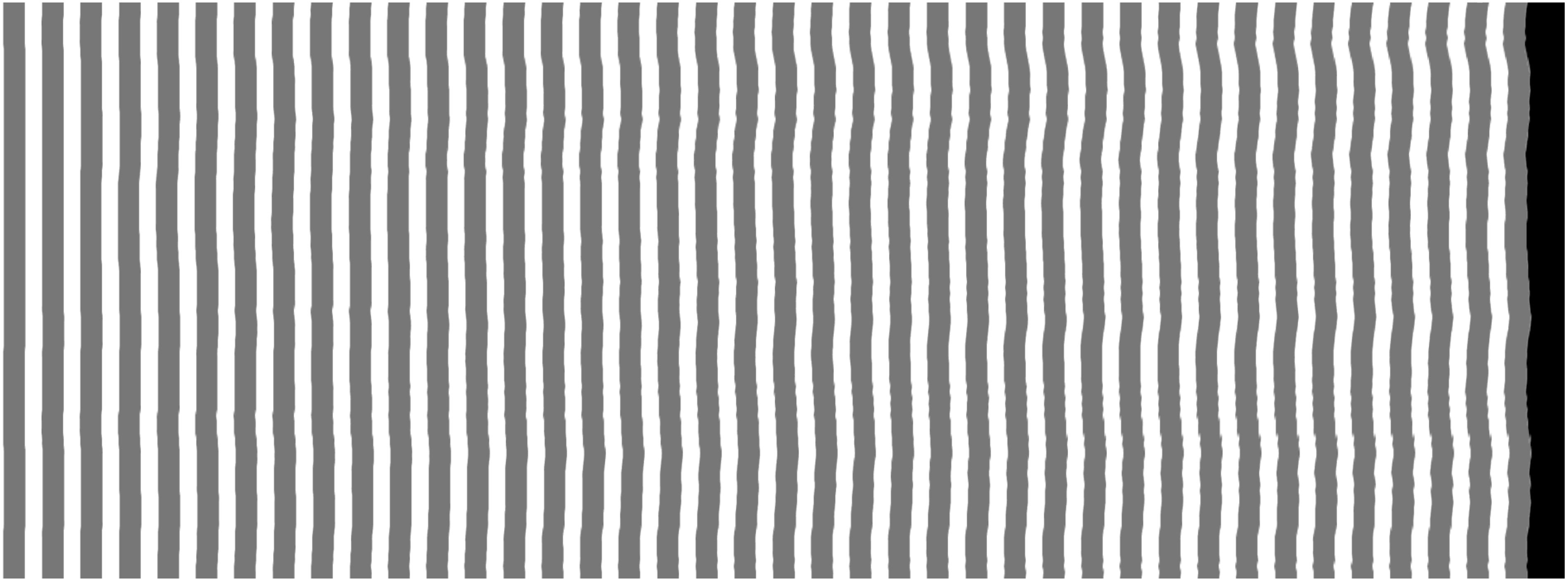
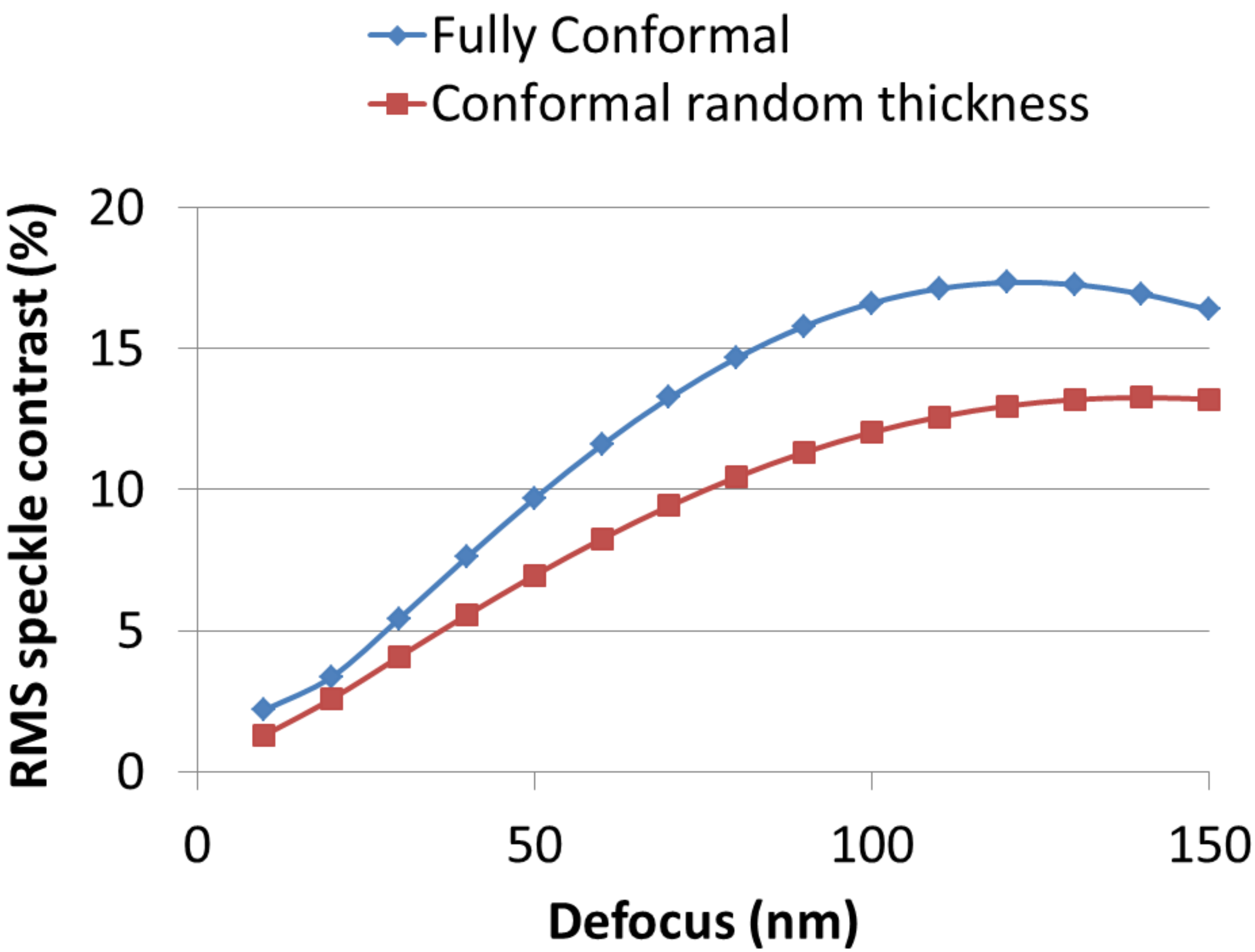
Conformal growth of layers with random roughness



Individual layer roughness = total roughness/sqrt(N_{Layers})

Interlayer roughness 38% more tolerant



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Model-based interlayer roughness specifications

Configuration	Single layer roughness* (pm)
22-nm, disk 0.5, 0.32 NA	7
16-nm, quad, 0.32 NA	12
16-nm, annular, 0.42 NA	12

* Assume 80 layers

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Photoresist

Simultaneously meeting resolution, sensitivity, and LER crucial issue for EUV resists

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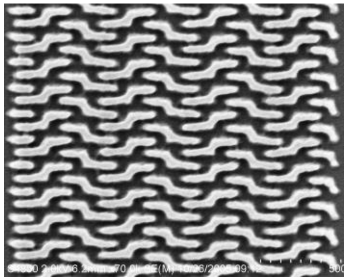
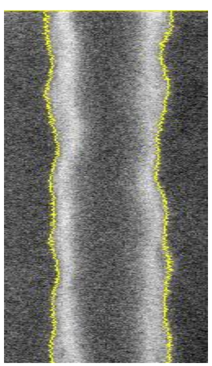
"RLS" Tradeoff

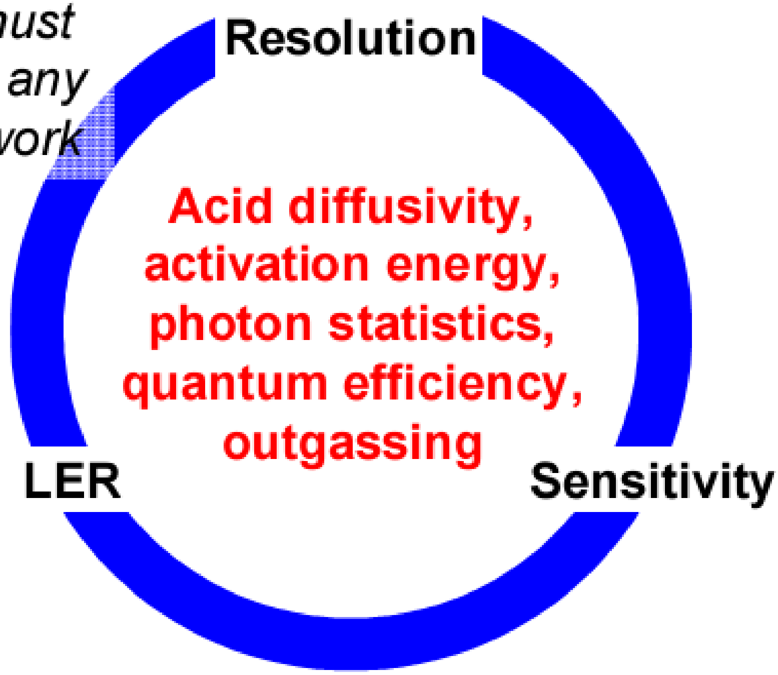


22-nm half pitch - 2016
17-nm half pitch - 2019
13-nm half pitch - 2022

All three requirements must be met and balanced for any technology or it will not work



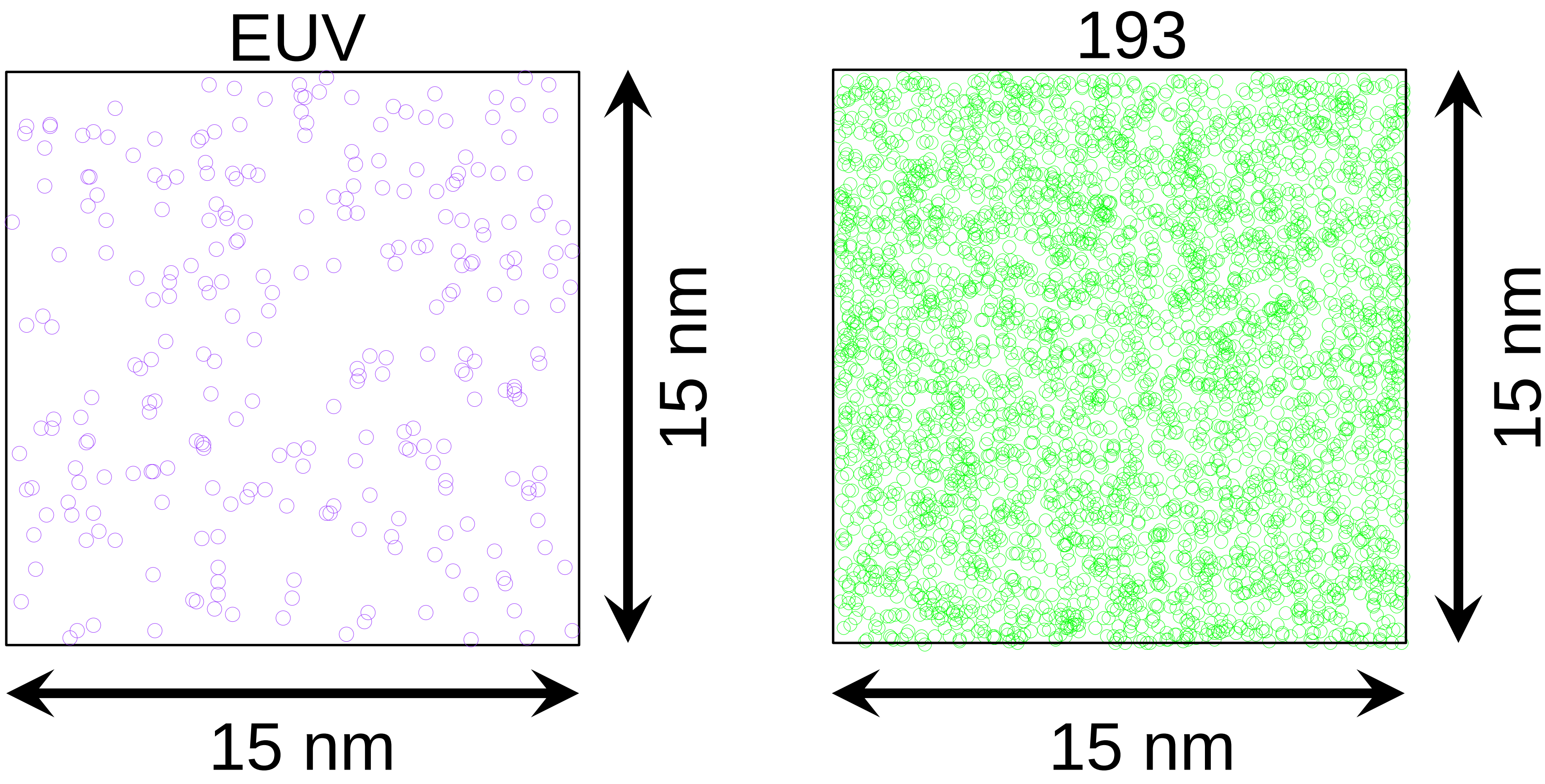
1.3 nm
1.0 nm
0.8 nm



10 mJ/cm^2
15 mJ/cm2
20 mJ/cm^2

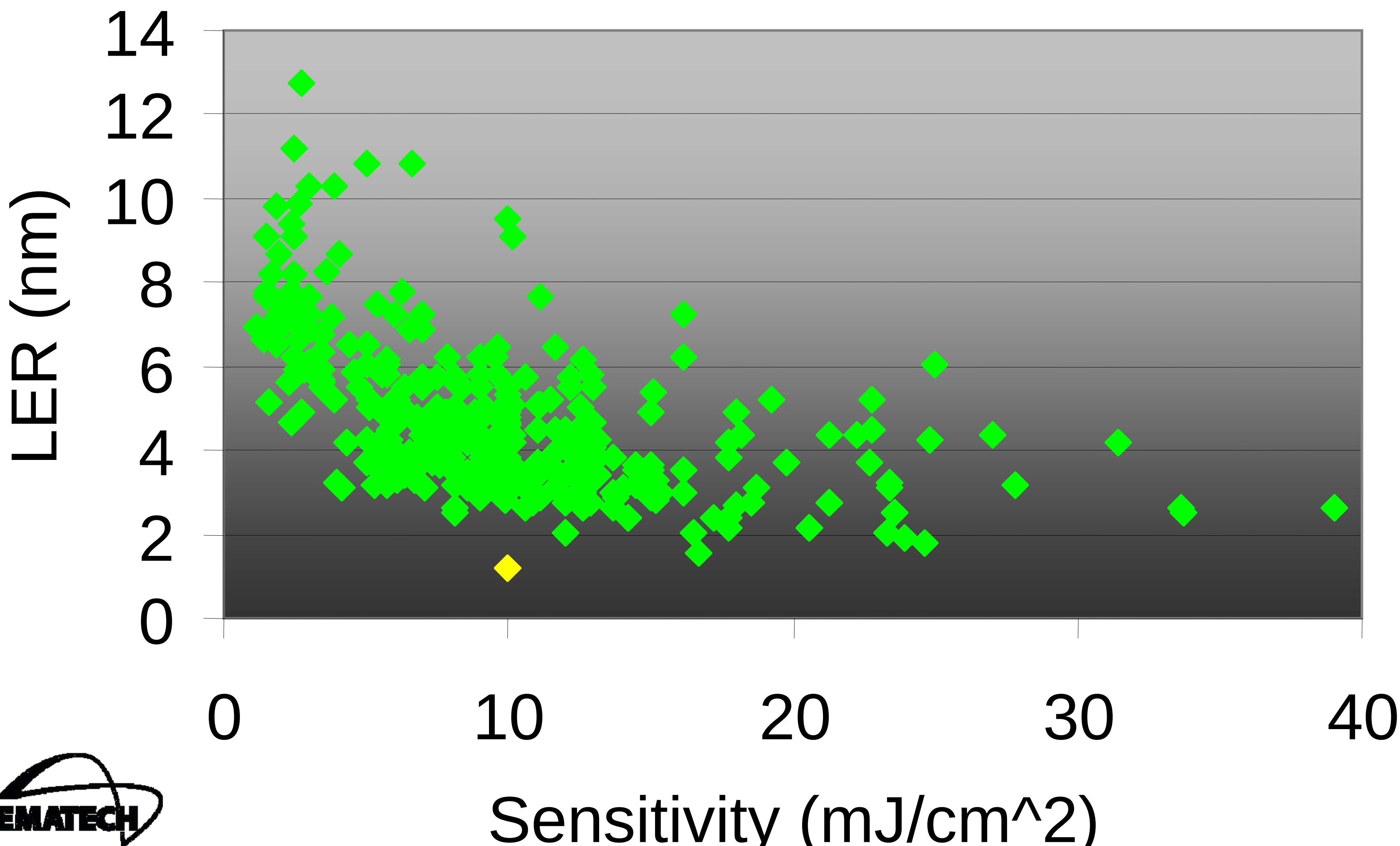
2013 ITRS Roadmap

EUV photons 14x more energetic than 193nm photons



Thickness = 22nm, absorption = 4.2μm^{-1}, dose = 20mJ/cm^2

LER/sensitivity trends



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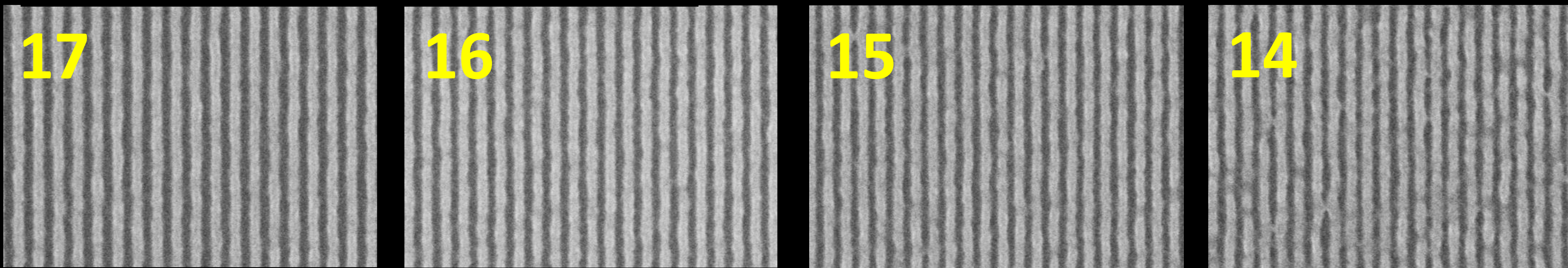
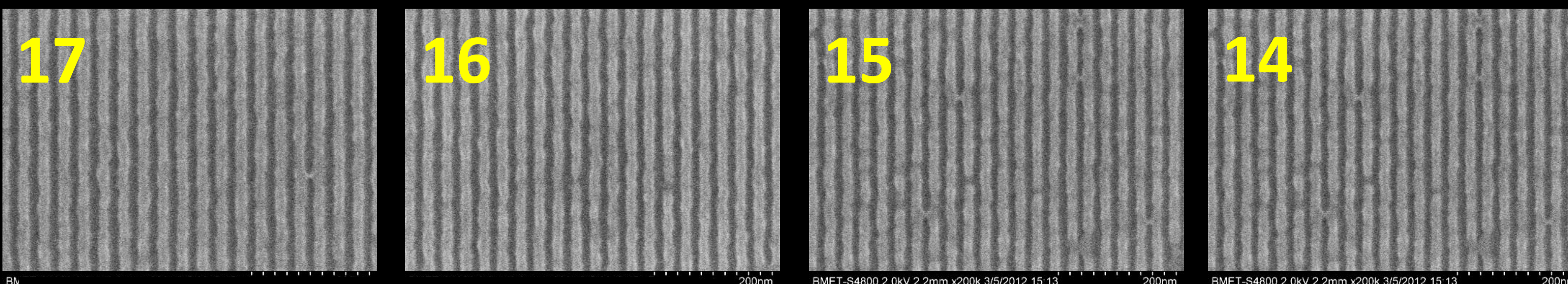
CA resists surpassing 16-nm HP

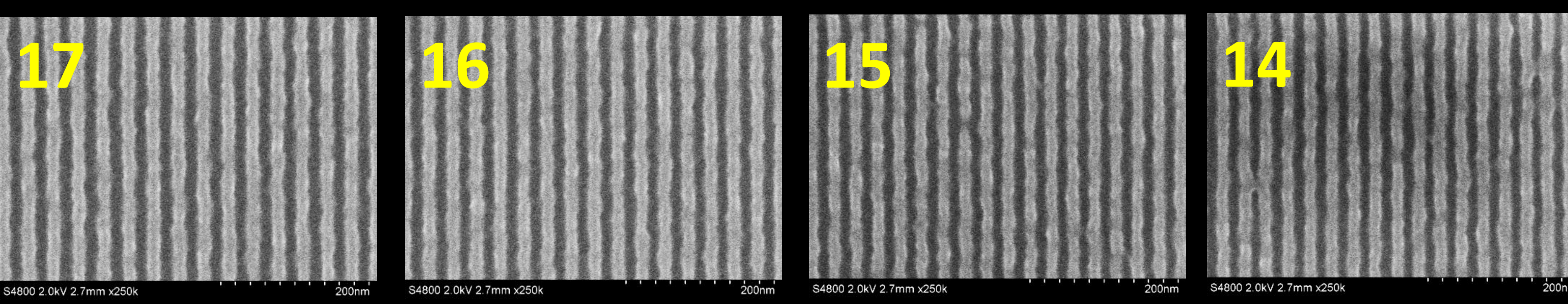
Resist A: 30 mJ/cm^2

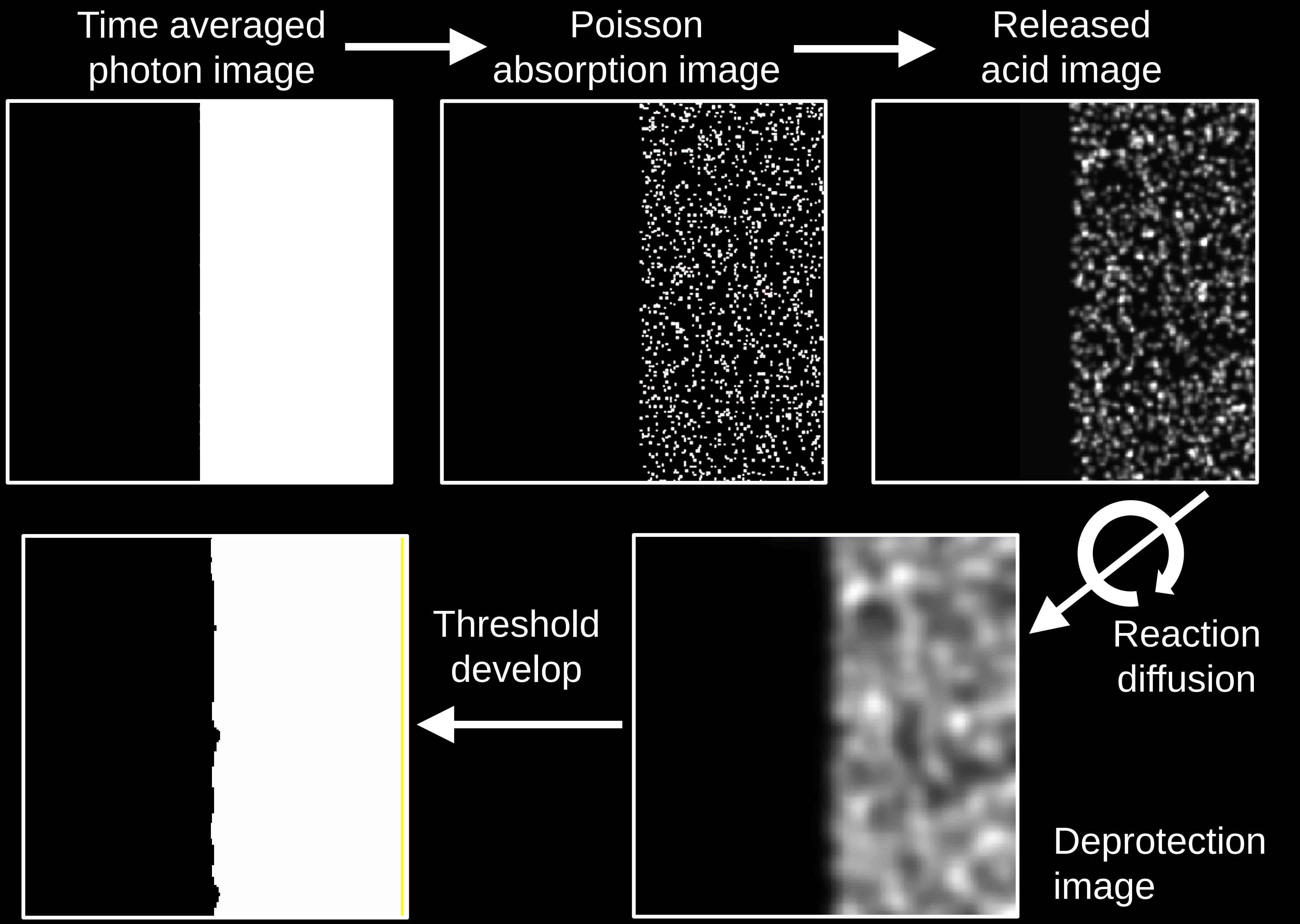


Resist B: 20mJ/cm^2



Resist C: 22mJ/cm^2





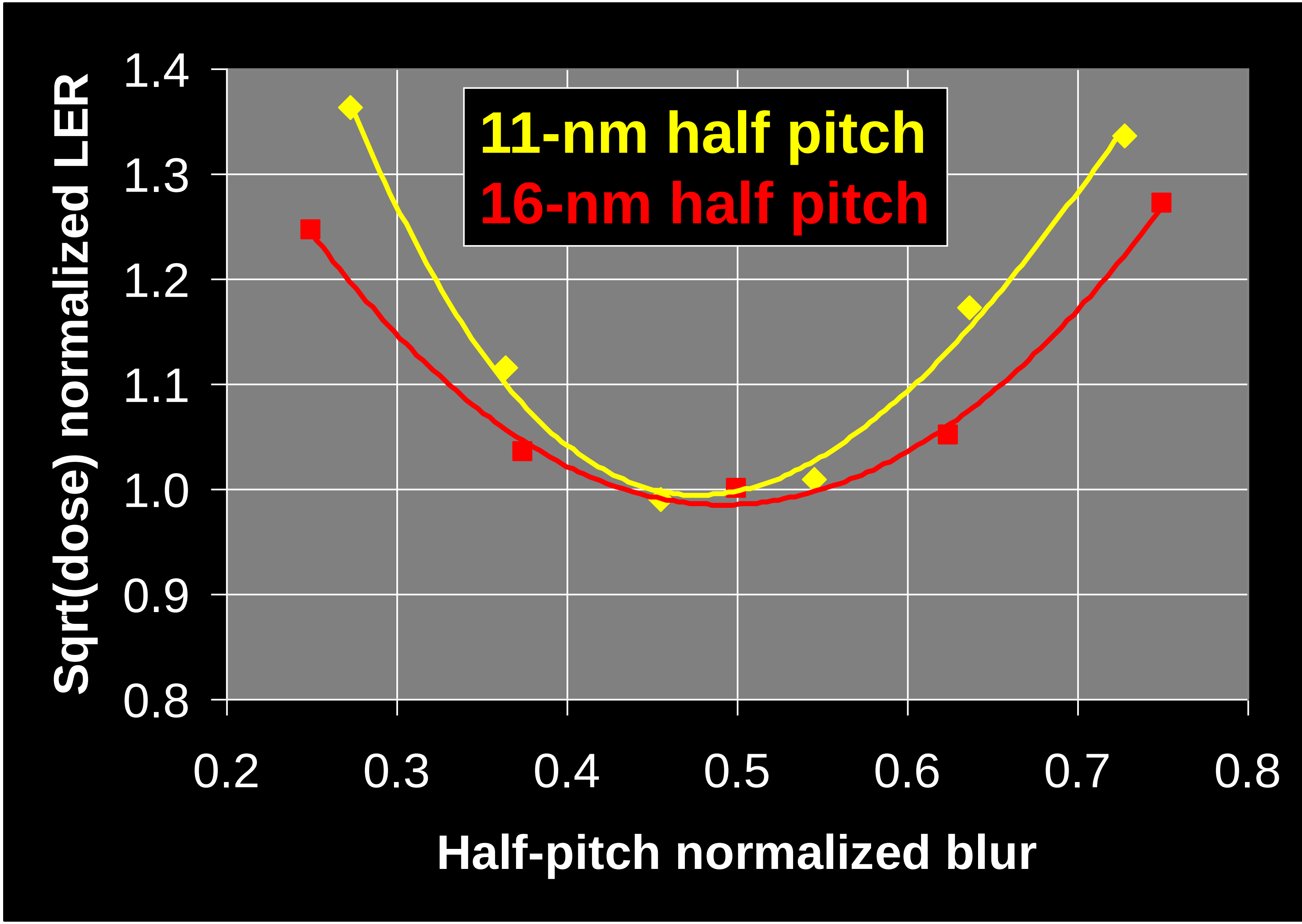
Multivariate Poisson Propagation Model, Gallatin SPIE 2005; Naulleau, Gallatin JVST 2010

	Resist A	Resist B	Resist C
Measured LWR @ 16 nm (nm)	3.1	4.8	3.8
Modeled Photon limited LWR (nm)*	2.1	2.7	2.5
Estimated material limited LWR (nm)	2.3	4.0	2.9
Modeled material limited LWR (nm)**	2.4	2.4	2.4

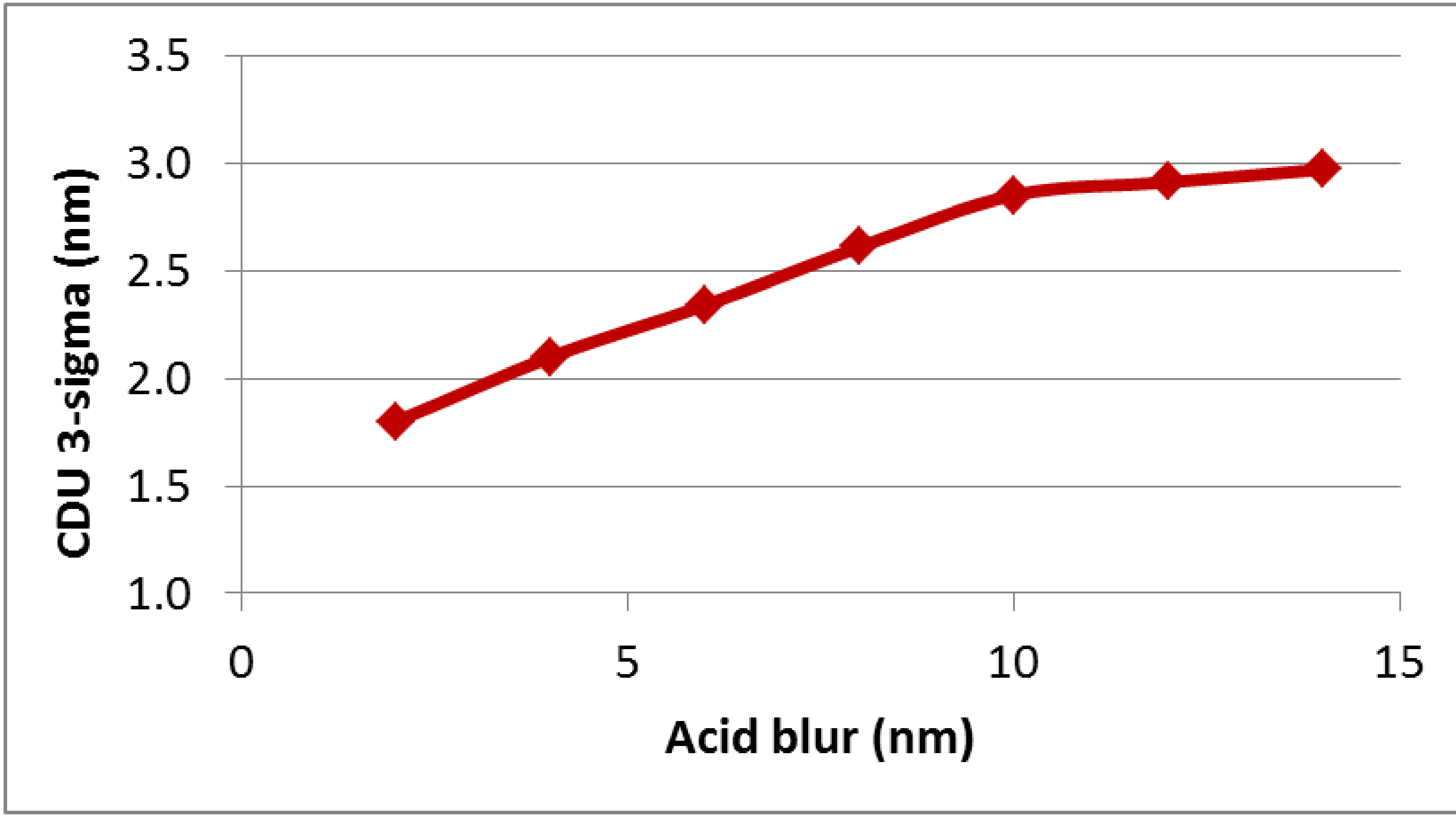
* Use Multivariate Poisson Propagation Model, SPIE 2005, JVST 2010 …
Use ~11-nm resist blur determined from measured LER PSD
Use supplier provided resist absorptivity = 0.0042 nm^{-1}

**Includes acid, PAG, and Quencher random variables based on assumed typical material parameters

Optimal blur = 0.5 × half pitch

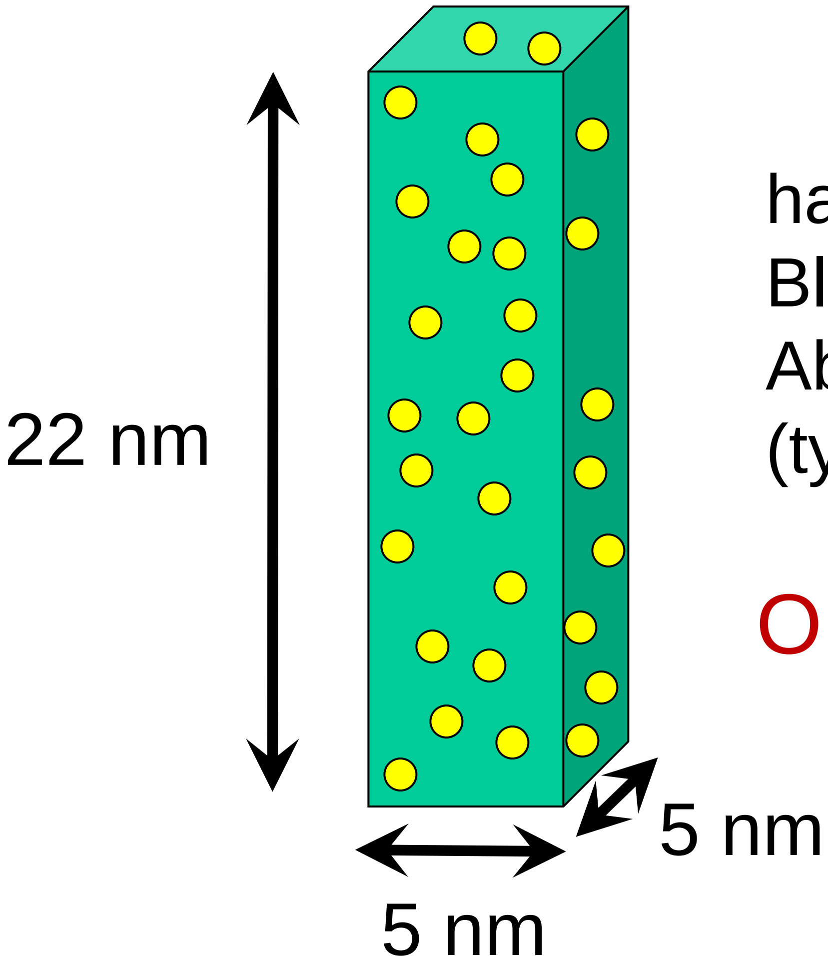


For contacts, smaller blur is better



16-nm contact photon-limited CDU

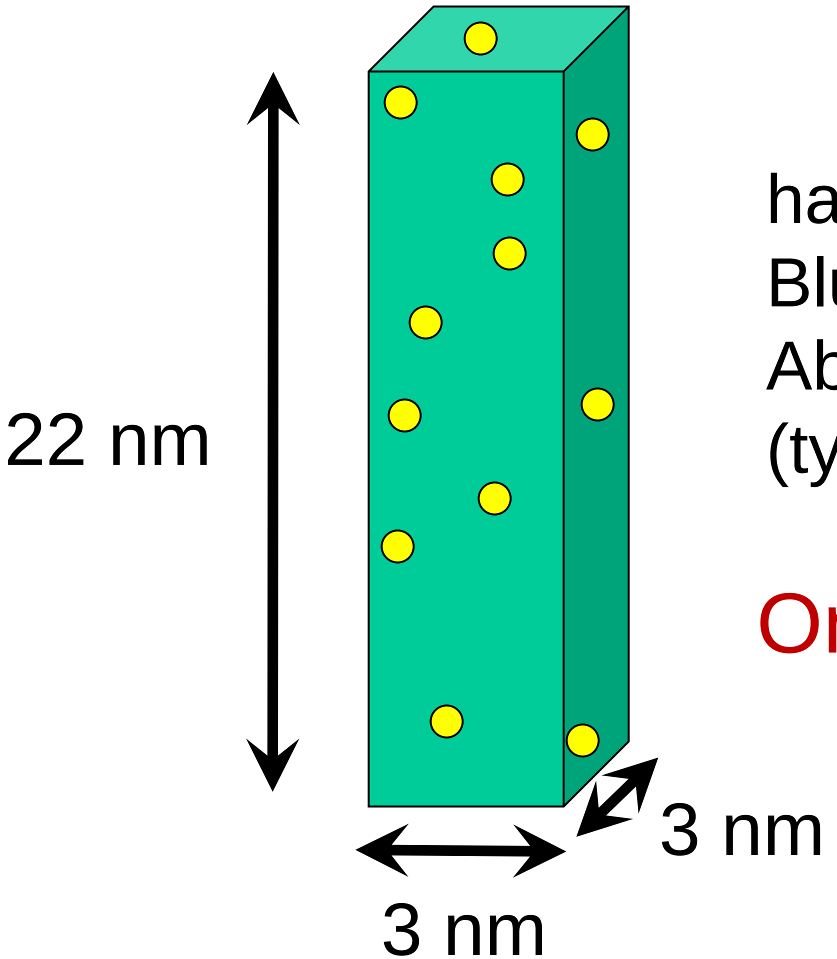
Shrinking photon count big problem for future nodes



half pitch (HP) = 11-nm
Blur (pixel size) = 5 nm (0.5HP)
Absorptivity = 0.0042 nm^{-1}
(typical polymer resist value)

Only 30 photons absorbed!

Shrinking photon count big problem for future nodes



half pitch (HP) = 11-nm
Blur (pixel size) = 3 nm (0.25HP)
Absorptivity = 0.0042 nm^{-1}
(typical polymer resist value)

Only 12 photons absorbed!

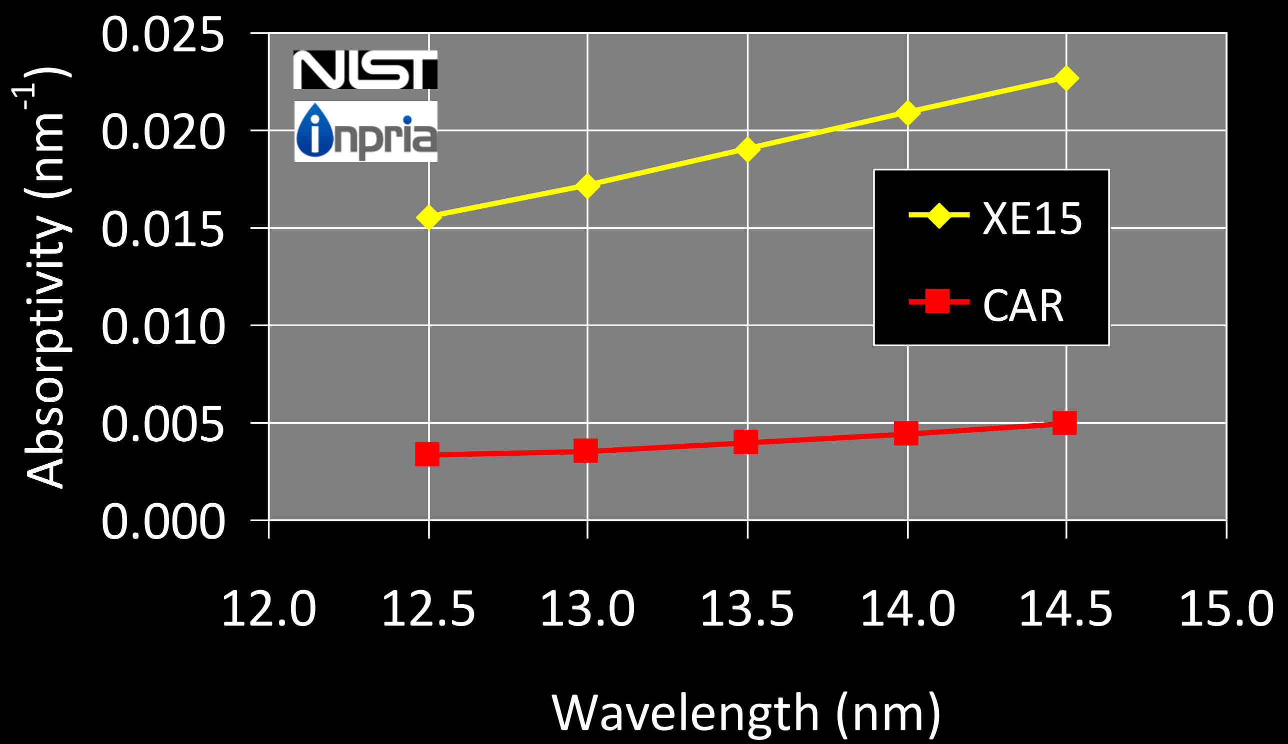
What would it take to enable 20-mJ/cm^2 with 14-nm contacts?

A potential future resist

- Assume absorptivity of 0.02 nm^{-1}

A potential future resist

- Assume absorptivity of 0.02 nm^{-1}



A potential future resist

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- Assume QE of 6

A potential future resist

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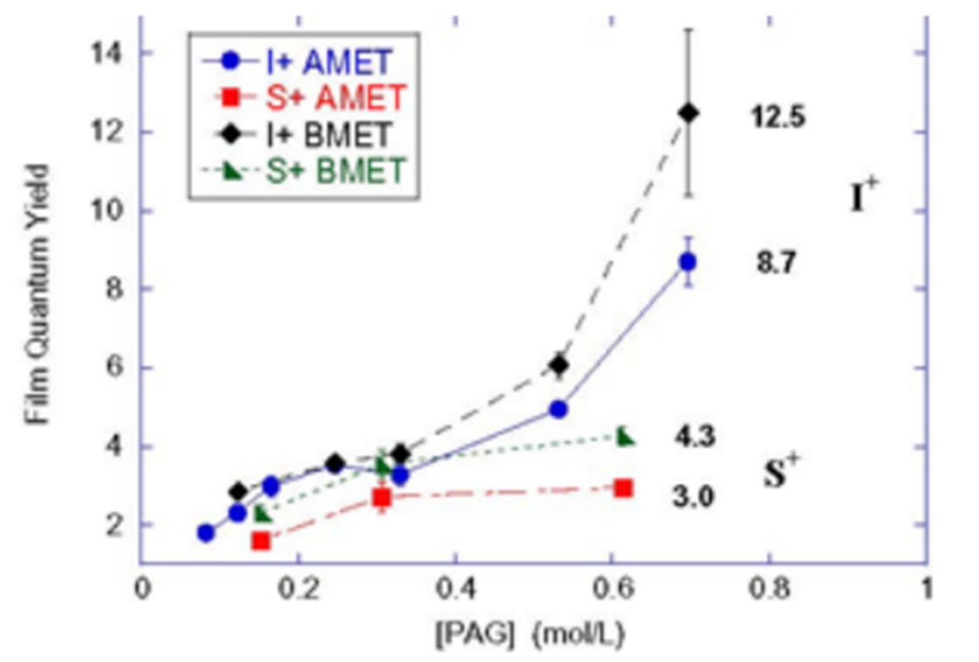

Fig. 8. Film Quantum Yield *vs.* PAG concentration.

Brainard et al. J. Photopolym. Sci. Technol. (2008)

A potential future resist

- Assume absorptivity of 0.02 nm^{-1}
- Assume QE of 6
- Assume PAG loading of 0.5/nm^3

A potential future resist

- Assume absorptivity of 0.02 nm^{-1}
- Assume QE of 6
- Assume PAG loading of 0.5/nm^3

%PAG	TPS-PFBS (Sulfonium, S+)			
5		Good		
7.5	**OS-S1**	Good		
10		Good		
15	**OS-S2**	Good	315	11
20		Good	318	13
25	OS-S3	Good	377	17
30	**OS-S4**	Good	501	21
40	OS-S5	Good	961	83
50	OS-S6	Good	1248	217
60	OS-S7	Good	1248	547
70	OS-S8	Good	1246	731

0.7/nm^3 → 70

Brainard et al. J. Photopolym. Sci. Technol. (2008)

A potential future resist

- Assume absorptivity of 0.02 nm^{-1}
- Assume QE of 6
- Assume PAG loading of 0.5/nm^3
- Acid blur = 3 nm, electron blur = 2 nm

A potential future resist

- Assume absorptivity of 0.02 nm^{-1}
- Assume QE of 6
- Assume PAG loading of 0.5/nm^3
- Acid blur = 3 nm, electron blur = 2 nm

Would enable 20 mJ/cm^2
for 14-nm contacts

Summary

- ***Biggest remaining EUV challenge is source power***
- ***Multilayer materials challenges include defects and roughness***
- ***Future photoresist materials will need to be more absorbing***

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