Investigation of the current resolution limits of advanced EUV resists

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Outline

- System description
- Demonstration of resist-limited performance
- Resist MTF
- LER versus speed trends

Berkeley MET exposure tool

- **Based on MET optic**
- **Magnification = 5x, NA = 0.3**
- **Rayleigh resolution = 27 nm**
- **Field size = 200x600 μm**
- **Programmable coherence illuminator for low k_1**
- **Reticle and wafer load-lock and manual transfer systems**
- **Wafer-height sensor**
- **nm-resolution wafer-height sensor and focus actuation**
- **Pupil-fill monitor**

From synchrotron

Scanner module

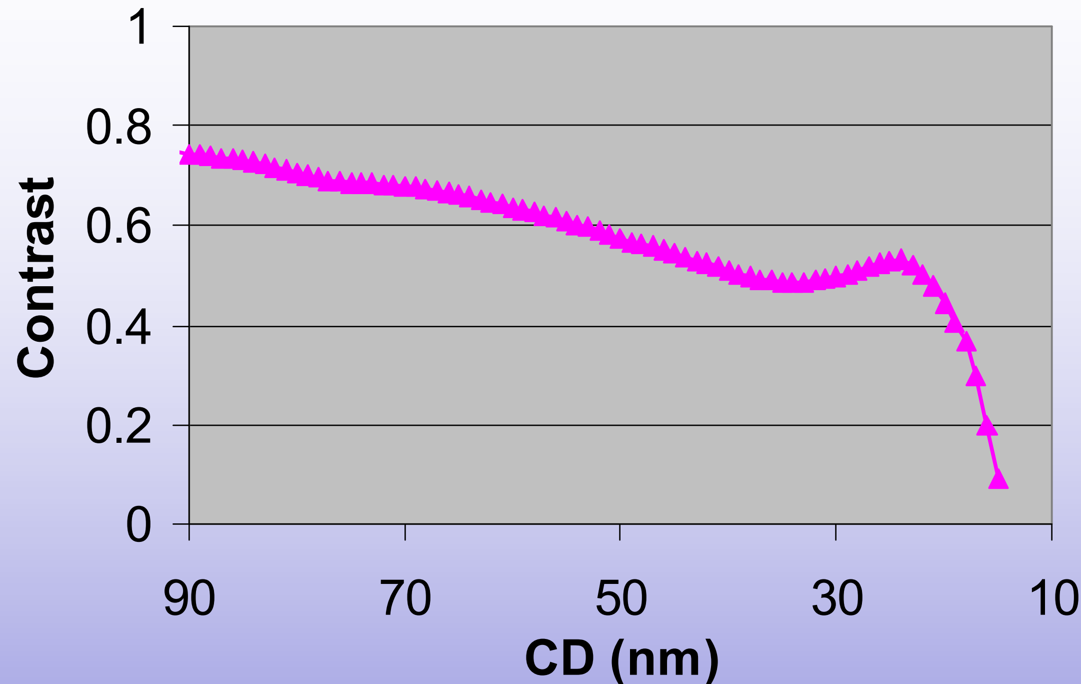
Reticle stage

MET

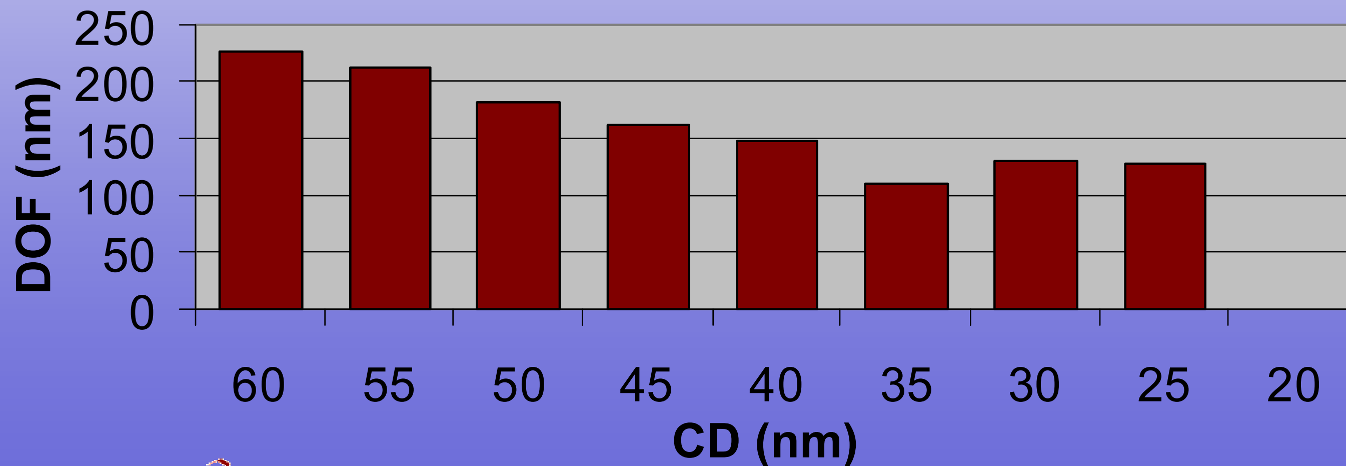
Wafer stage and height sensor

Pupil-fill monitor

Berkeley MET modeled to have good DOF down to 25 nm with annular illumination

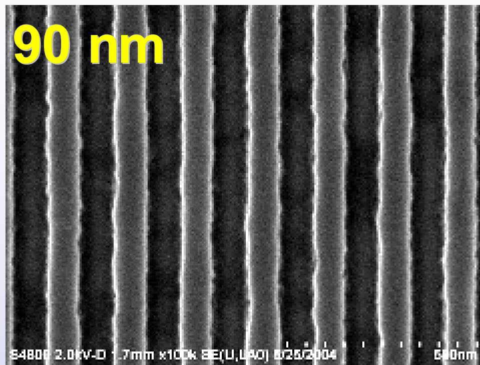


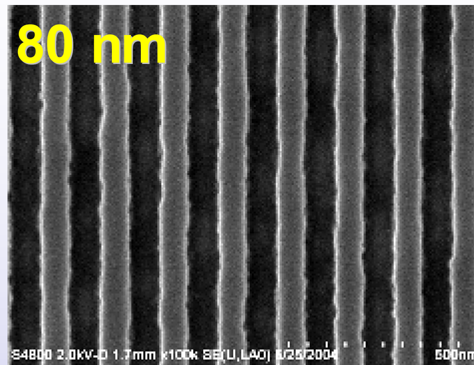
Predicted aerial-image contrast

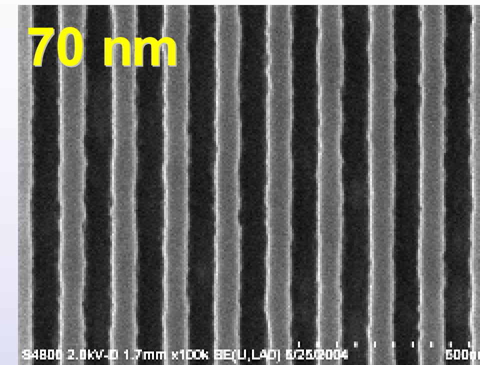


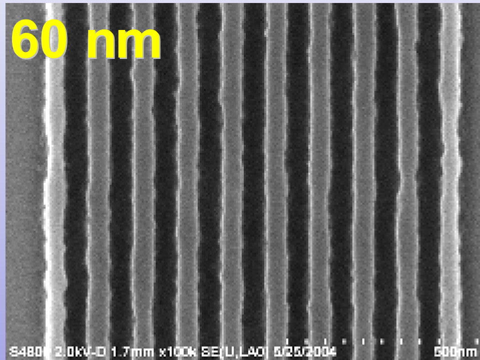
Predicted aerial-image DOF:
+/-10% CD control
10% Total EL
contrast > 45%
ILS > 20

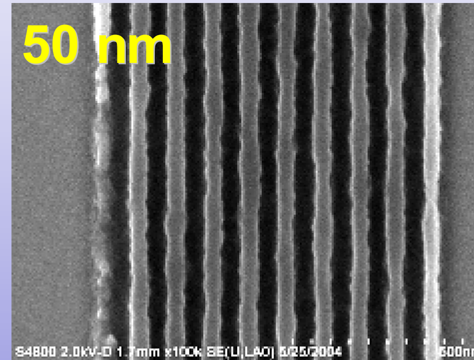
Resolution of previous baseline resist (EUV-2D) falls well short of MET capabilities

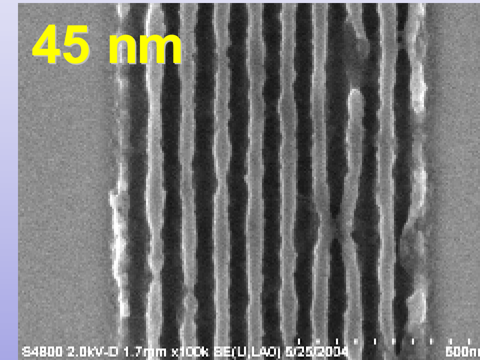


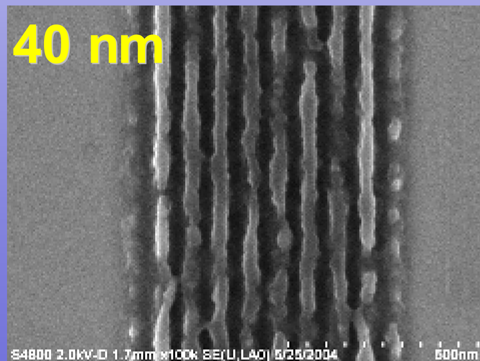












Processing Conditions:

- Thickness 125-nm
- PEB 130 °C 90 Sec
- Develop 45 Sec
- E_{size} 100-nm 6.8 mJ/cm^2

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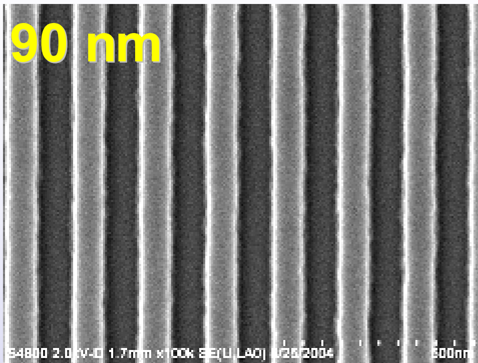
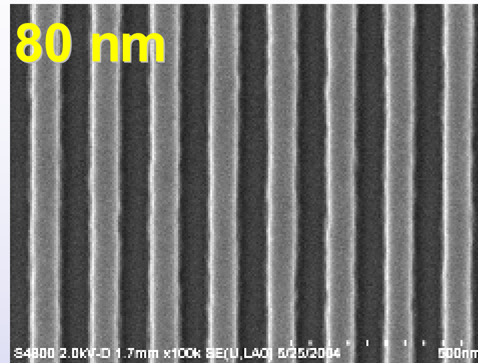
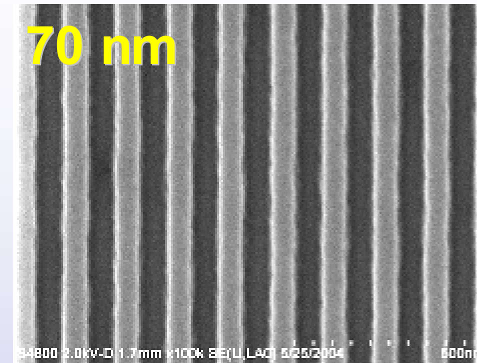
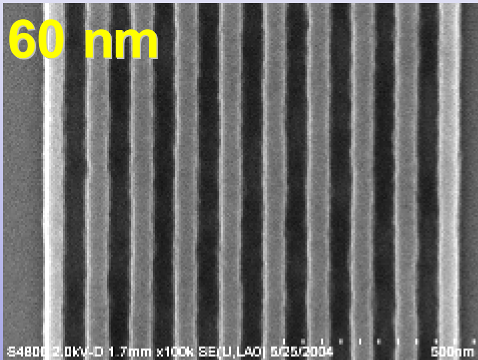
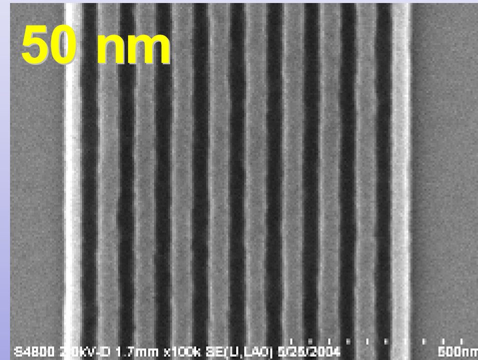
Rohm and Haas MET 1K: example of rapid resist learning with high-NA tool

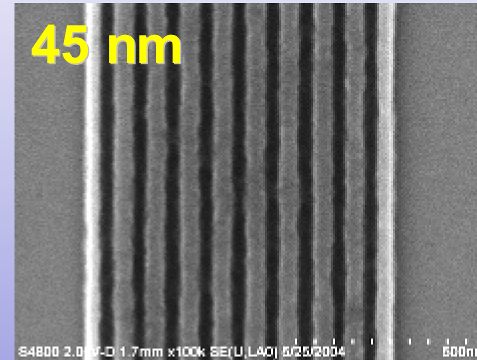


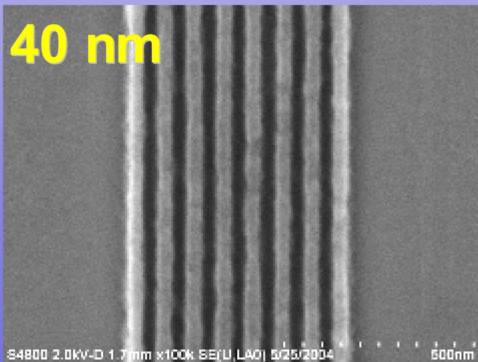


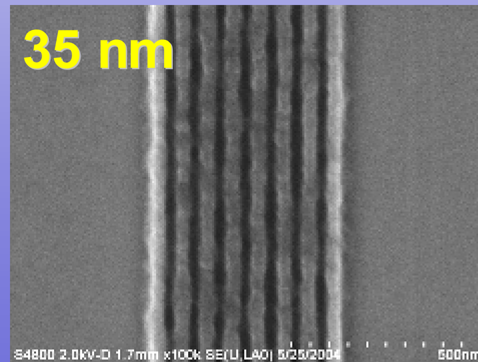












Processing Conditions:

- Thickness 125-nm
- PEB 130 °C 90 Sec
- Develop 45 Sec
- E_{size} 50-nm 21 mJ/cm^2

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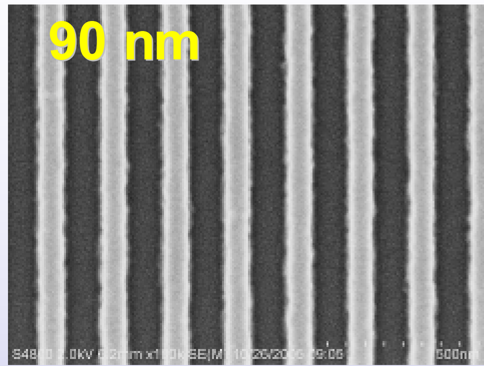
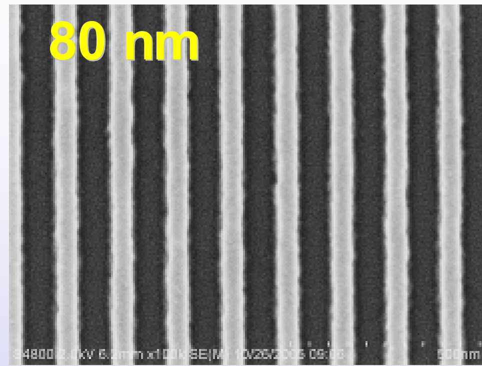
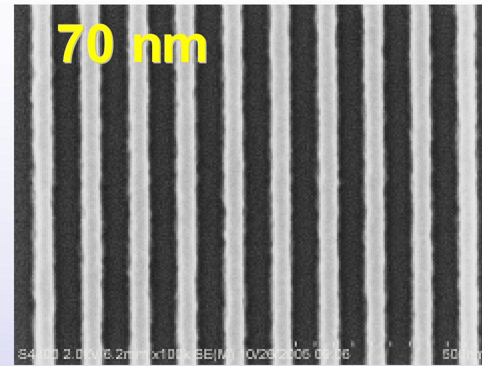
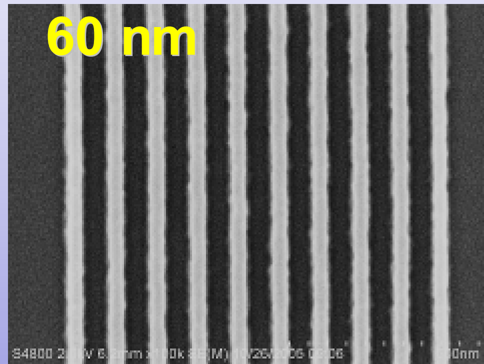
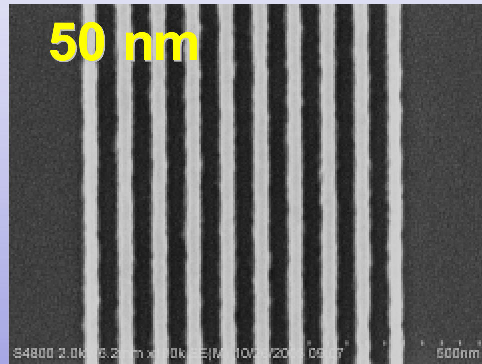
Low-activation energy resists: potential pathway for resolution improvements

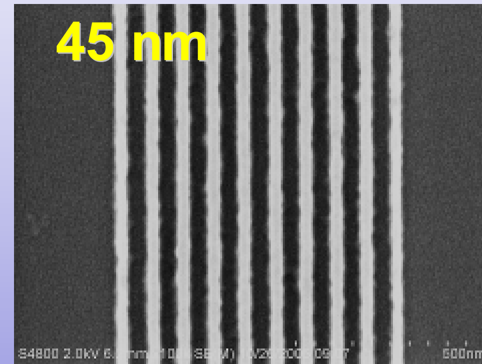


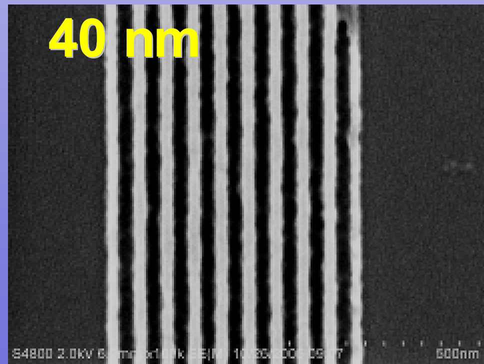


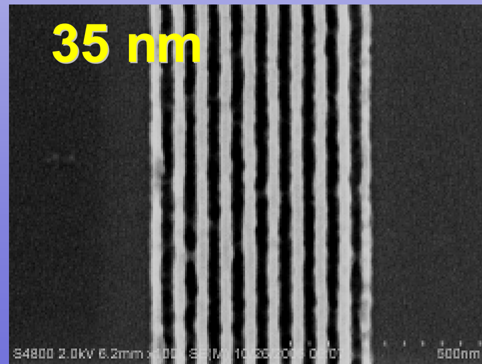












Processing Conditions:

- **Thickness 125-nm**
- **Develop 45 Sec**
- **E_{size} 50-nm 19 mJ/cm^2**

KRS resist provided by Carl Larson and Greg Wallraff, IBM

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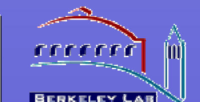
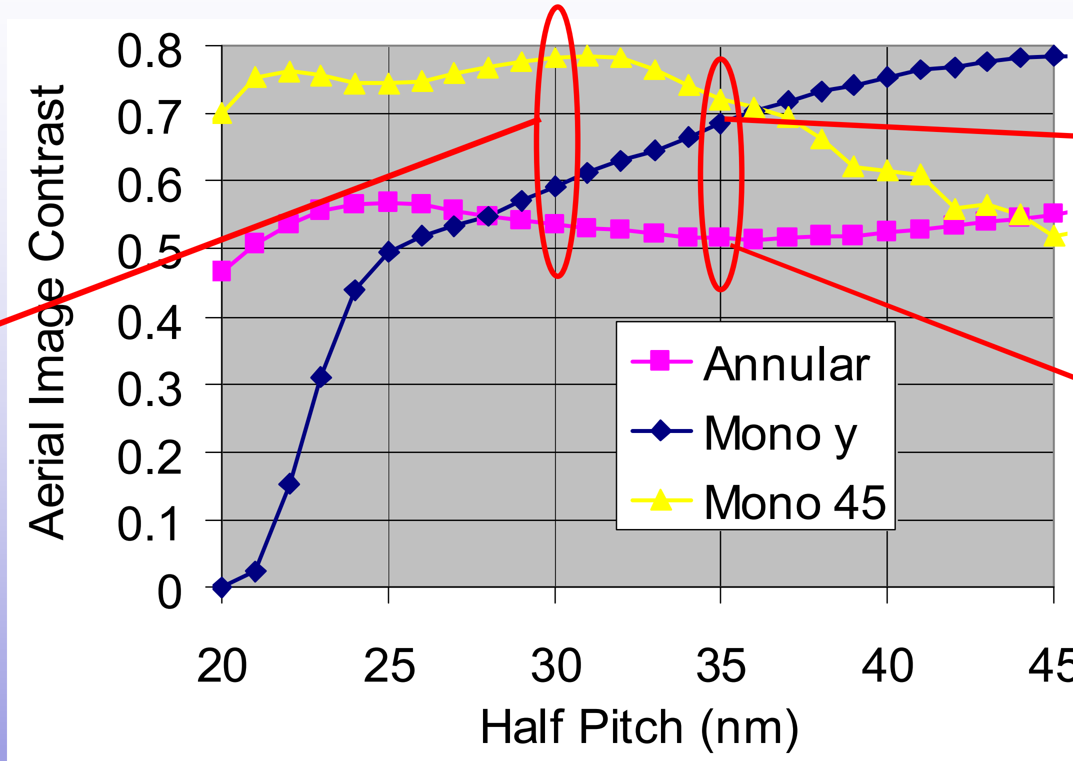
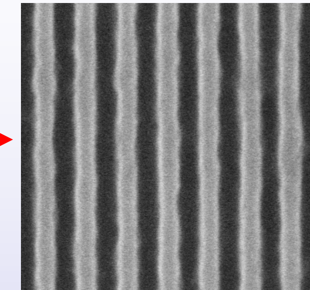
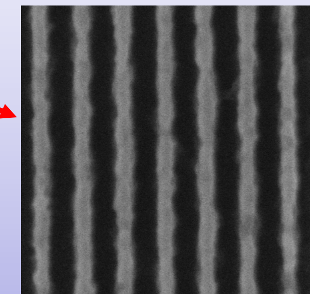


Response to pupil fill changes used to verify resist-limited status

Little difference observed in imaging performance for 30-nm features







35-nm features still respond to aerial-image change

- Variable pupil fill illuminator enables large changes in aerial-image quality
- Performance at the 30-nm half-pitch level observed to be poor independent of pupil fill
- Resist is playing dominant role in observed through pitch behavior

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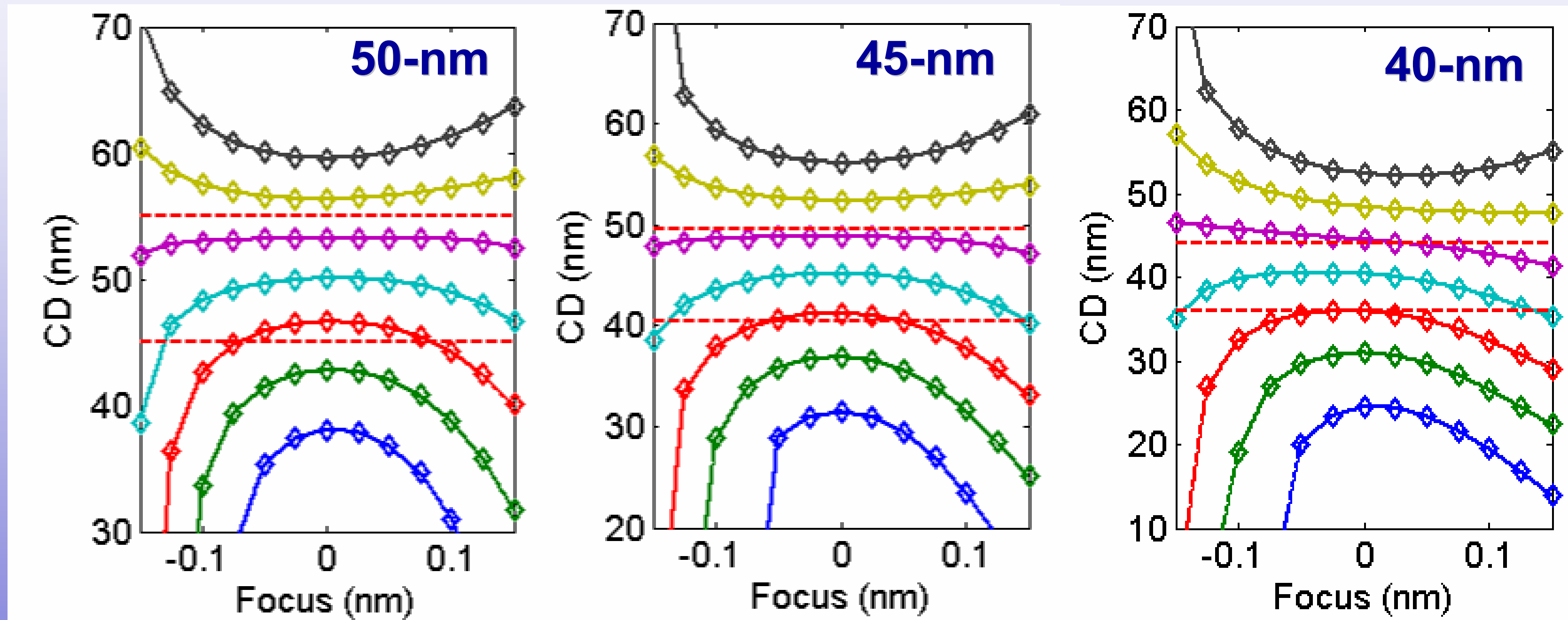
Modeled aerial-image performance shows good process latitude

Bossungs based on 10% dose increments



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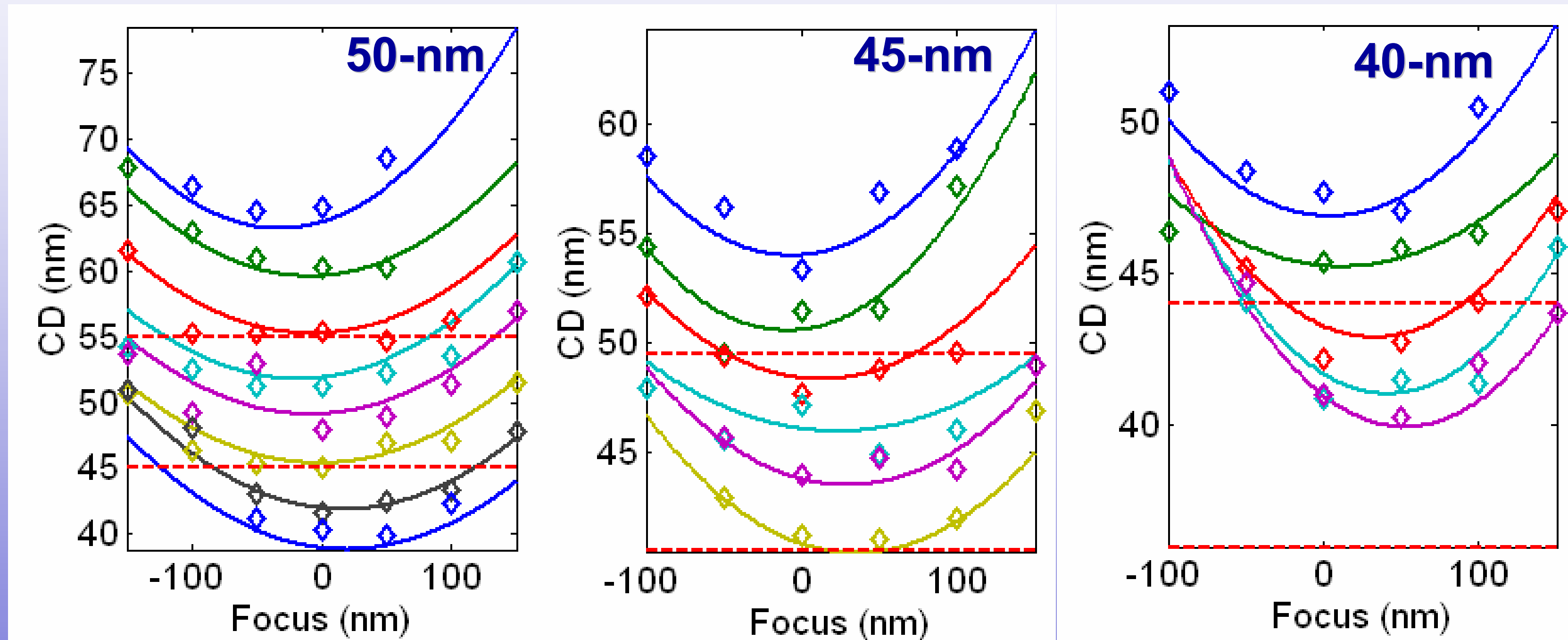
MET 1K exposure latitude limits prevent it from reaching sizing at CDs <= 40 nm

Bossungs based on 5% dose increments
Nominal dose = 21 mJ/cm^2



Intrinsic bias difficult to determine due to top loss

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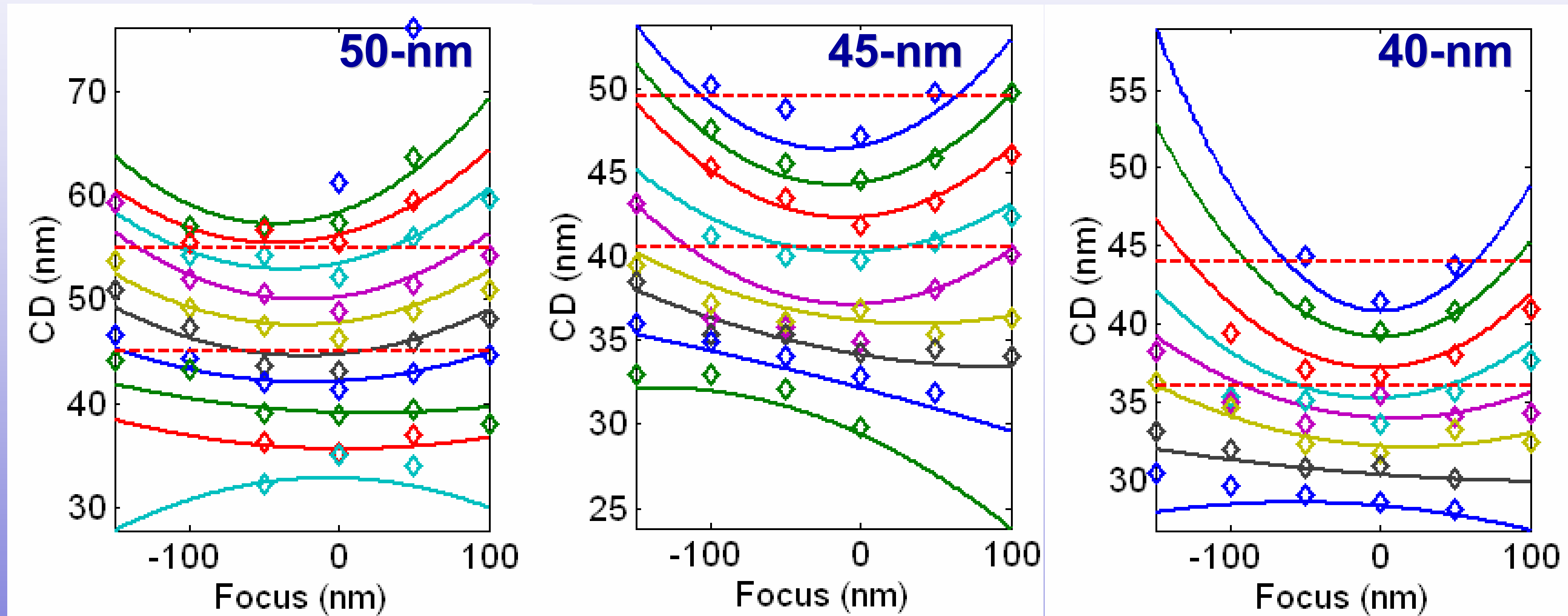
KRS shows much improved exposure latitude and intrinsic bias of ~19 nm

Bossungs based on 5% dose increments
Nominal dose = 19 mJ/cm^2



Intrinsic bias = 19 nm

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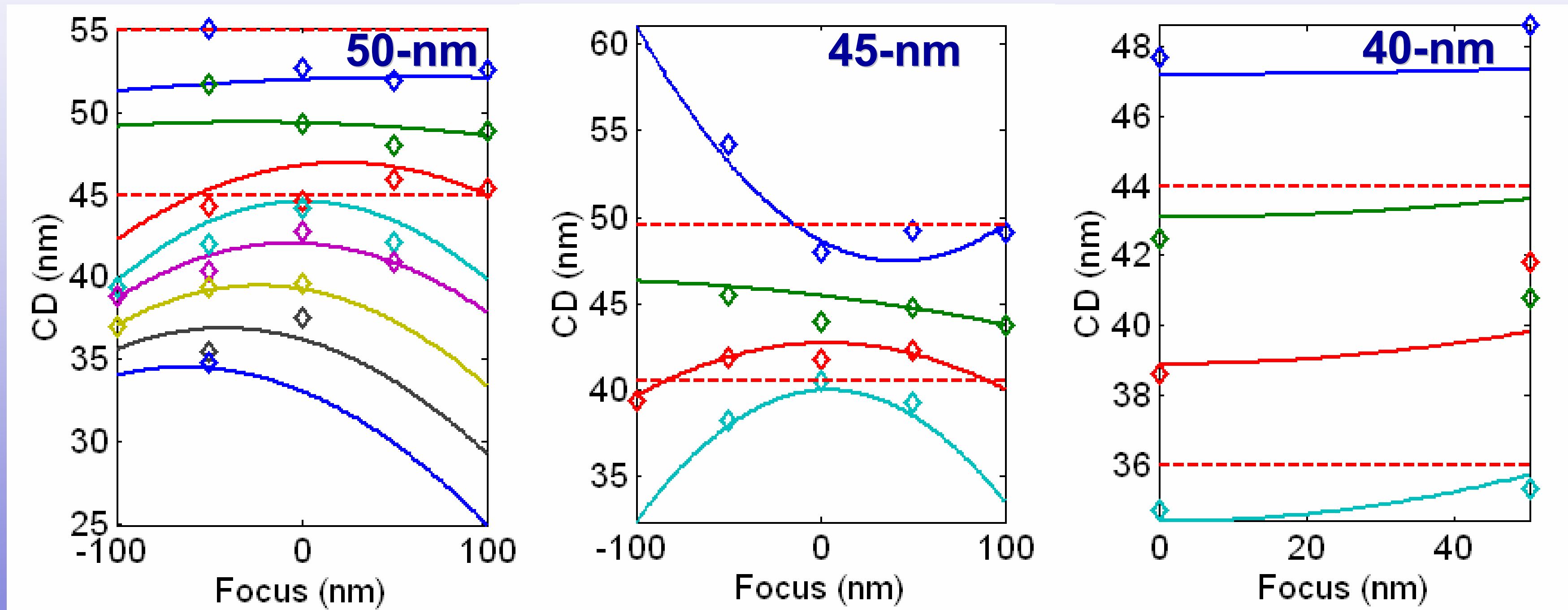
Supplier A shows low intrinsic bias but poor process latitude below 45 nm half pitch

Bossungs based on 5% dose increments
Nominal dose = 11 mJ/cm^2



Intrinsic bias = 4 nm

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Supplier C also shows low intrinsic bias but limited exposure latitude at 40-nm half pitch

Bossungs based on 5% dose increments
Nominal dose = 46 mJ/cm^2

50-nm | 45-nm | 40-nm

CD (nm) vs. Focus (nm)

Intrinsic bias = 4 nm

Y monopole enables definitive resist-resolution limit testing

	KRS	MET 1K	Supplier A	Supplier C
35-nm				
32.5-nm				Severe collapse
30-nm				Severe collapse

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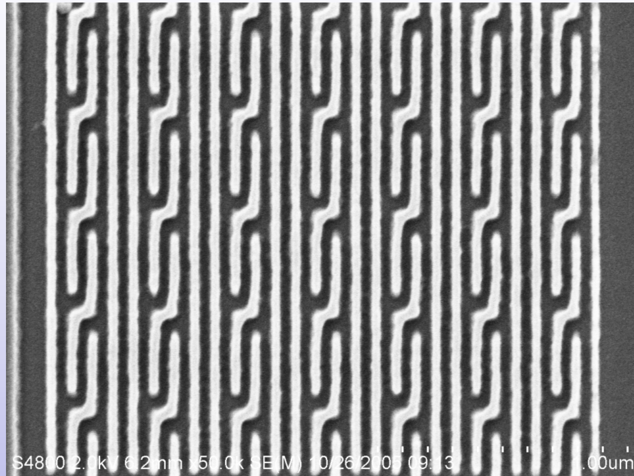
Summary of top-tier chemically-amplified resist performance

Resist	Speed (mJ/cm^2)	Res.* (nm)	LER (nm)	Failure Mechanism	Intrinsic Bias (nm)
Supplier A	11	35	4.5	Top Loss	4
KRS	19	32.5	3.3	Collapse/ Top Loss	19
MET 1K	21	35	3.6	Top Loss	> 16
Supplier D	21	45	3.0	Collapse	NA
Supplier C	46	35	2.5	Collapse	4

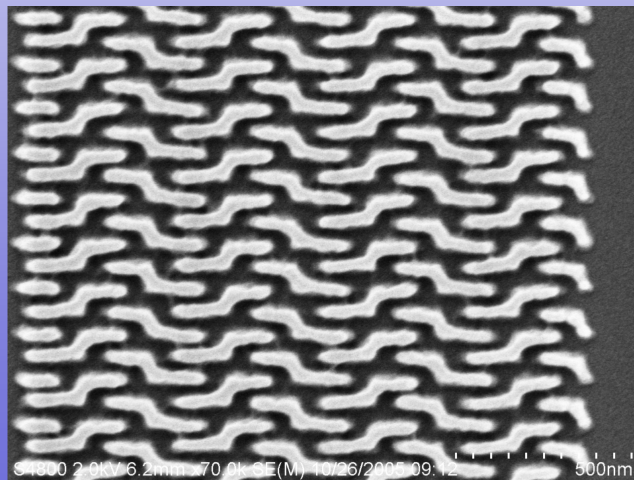
*** Resolution defined as smallest observed well-defined half pitch**

Assorted images from best performing resist tested in Berkeley MET (KRS)

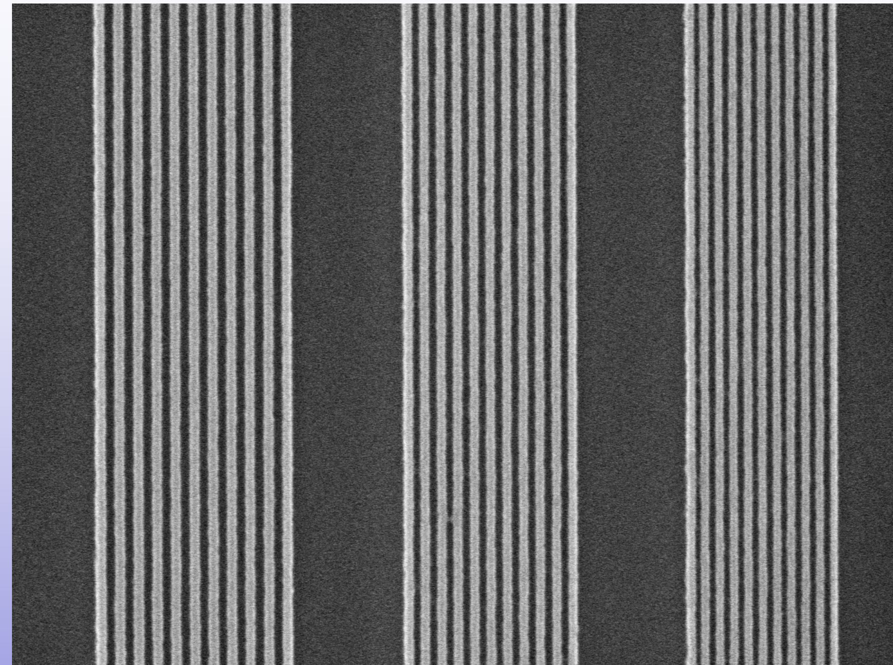
45 nm

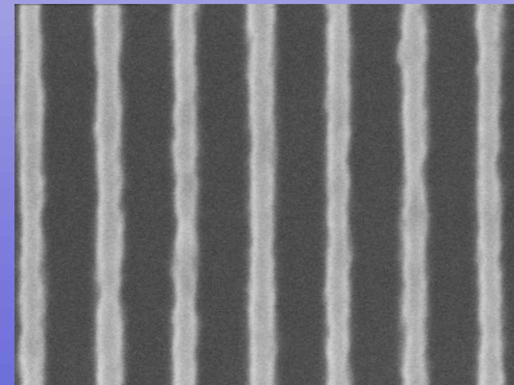


35 nm



45 nm 40 nm 35 nm





27 nm

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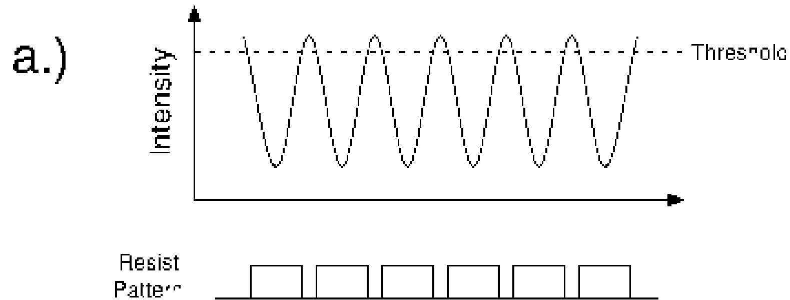
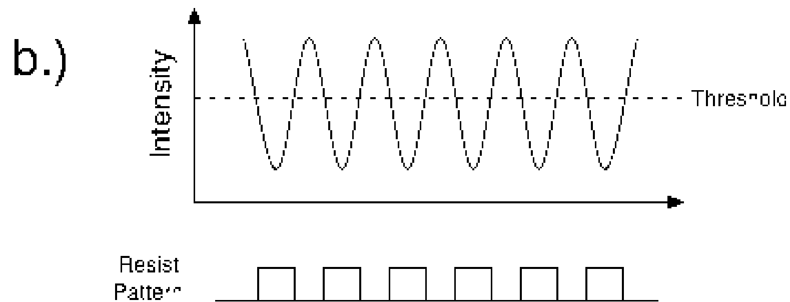
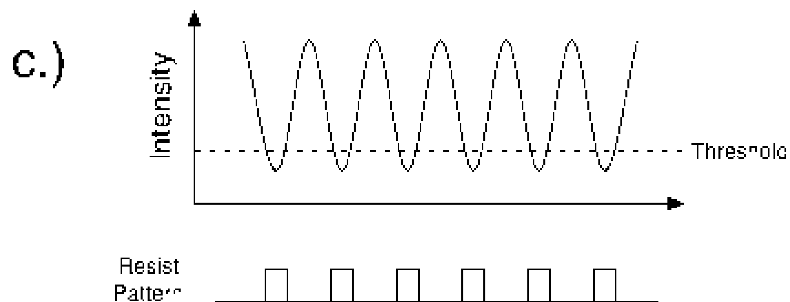
Resist based MTF measurements provide insight into resist and system properties

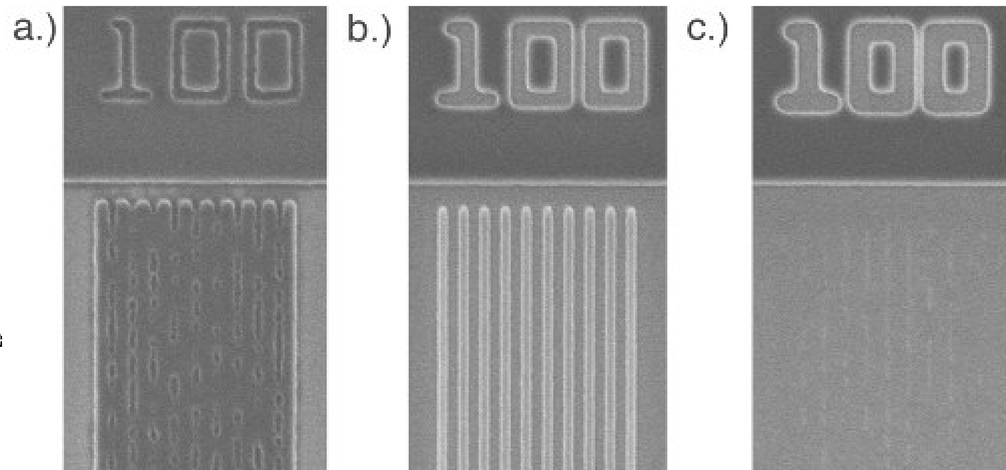






- MTF = pitch-dependent contrast
- Contrast determined from:
  - D_{max}, the dose at which resist lines first begin to clear
  - D_{min}, the dose at which resist lines disappear

$$Contrast = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{D_{max} - D_{min}}{D_{max} + D_{min}}$$



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Resist performance has strong impact on measured contrast

Contrast

0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

0 20 40 60 80 100 120

Feature Size (nm)

Modeling
EUV 2D
KRS
MET 1K
Supplier D
Supplier A
Supplier C

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AMD

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EUV Resist LER & Sensitivity

LER versus Sensitivity for selection of known EUV resists

Status: Line Edge Roughness (HVM Spec): < 1.6 nm
Line Edge Roughness (Best Current): 2.5 nm

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Summary

- EUV printing with state-of-the-art EUV tools is now resist limited
  - Limits on the order of 32-nm nested and 27-nm isolated observed
- MTF measurement in resist serves as good relative comparison metric for resist performance
- Simultaneously meeting resolution, LER, and speed requirements remains significant challenge

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