Improved EUV Resist Performance through Processing Refinements

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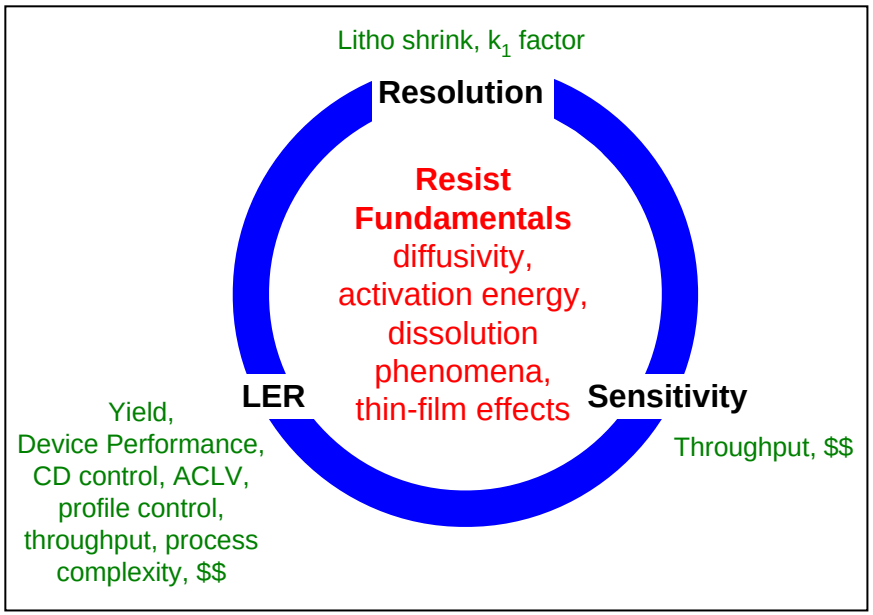
October 17, 2006

Outline

- EUV resist status and challenges
- New resist platform improvements
- Resist performance summary
  - Resolution
  - LWR/LER
  - Failure mechanisms
- Improvements from process refinements
  - PEB optimization
  - LER reduction
- Metrics for performance improvements
  - Process window
  - MTF and resist blur
  - Image-log-slope metrics (RELS)
- Summary and acknowledgments

Resist Performance Status and Challenges



*Current status **	**Resolution (nm)**	**LER (nm)**	**Sensitivity (mJ/cm^2)**
Best Resolution	**~ 30 nm half-pitch**	~ 7 nm	25 mJ/cm^2
Best LER	30 nm isolated	**3 nm**	Overdosed > 30mJ/cm^2
Best Sensitivity	45 nm half-pitch	>10 nm	**6 mJ/cm^2**

** Public status prior to 2006 EUVL Symposium*

- Current status of chemically amplified resists: best performance is not achieved simultaneously for all critical parameters
- Critical parameters and agents are interrelated

What Limits Resolution?

- Chemical amplification
  - Solubility switching (deprotection) of resist polymers occurs by a catalytic reaction-diffusion process

Higher resolution **Higher dose**	Less diffusion Less blur Less reaction	⟷	More diffusion More blur More reaction	**Lower resolution** **Lower dose**

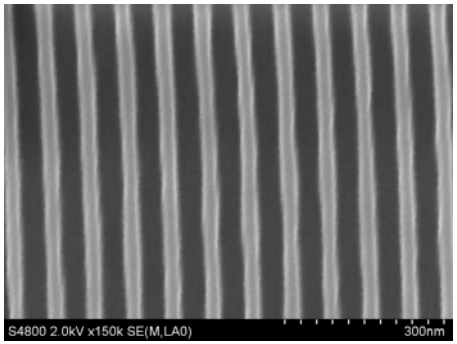
  - For 32nm node and below, 'low diffusivity' resists are required

- Development process
  - Failure mechanisms
    - Top loss, 'crumbling'
    - Pattern collapse
      - Interfacial properties (resist and liquid)
      - Yield stress; elastic vs. elastoplastic deformation
      - Aspect ratio scaling

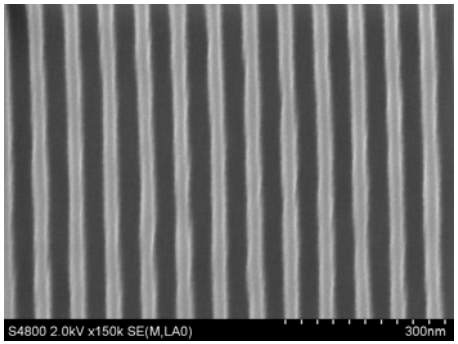
- Fundamental materials properties- ultrathin film behavior

- Component miscibility and morphology (aggregation)

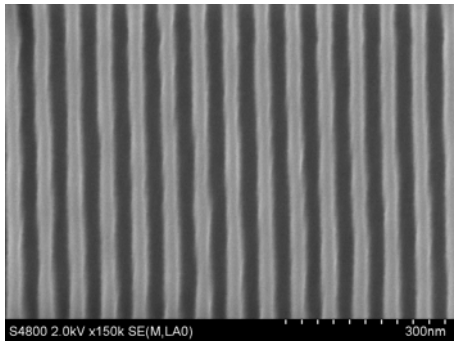
XP-6627-Q Platform with Improved Performance LBNL MET, Y-monopole illumination, FT = 50 nm



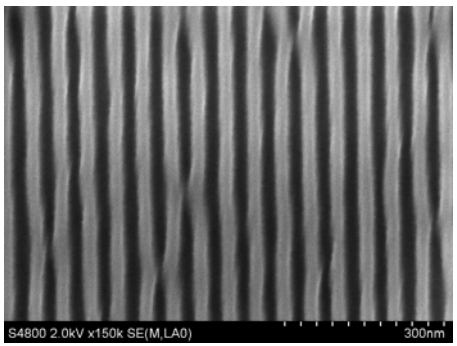
36L80P 27 mJ/cm^2
LER/LWR = 3.2/5.3 nm



32.4L72P 27 mJ/cm^2
LER/LWR = 2.9/4.4 nm



28.8L64P 27 mJ/cm^2
LER/LWR = 3.2/4.8 nm



25.2L56P 27 mJ/cm^2

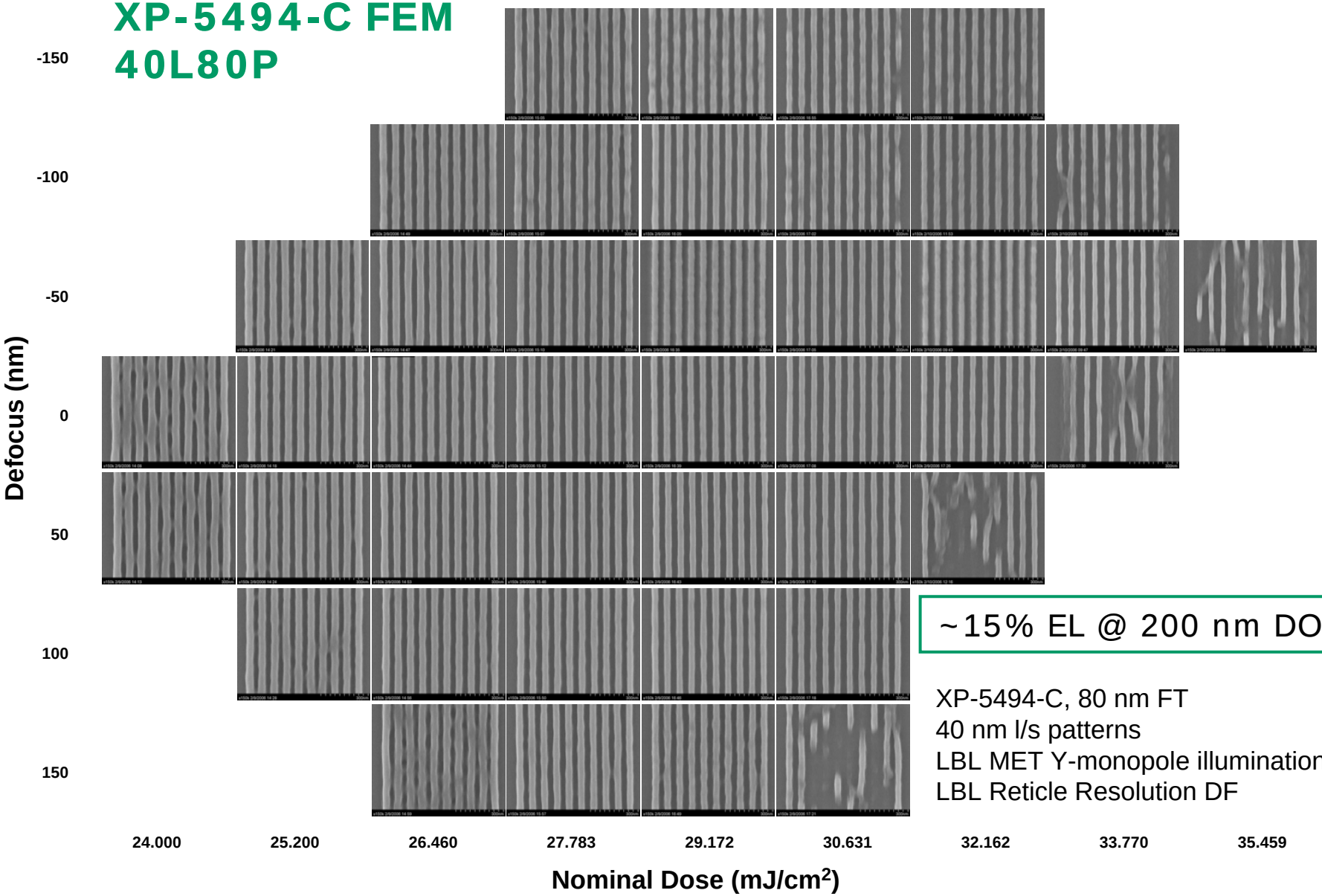
- Improved resolution, LER, and thin-film performance
- XP-6627 resist family uses ‘new generation’ materials

Rohm&Haas EUV Resists- Process Refinement

- XP-5494 and XP-6305 resist families contain both high activation energy (E_a) and low E_a blocking groups
- Very good resolution with process windows at 40 and 35 nm 1:1 l/s (Y-monopole illumination)
- Performance can be systematically varied with formulation refinement

- Goals:
  - Examine impact of process refinement on resist performance
  - Assess metrics for showing process improvement
  - Link metrics with materials fundamentals

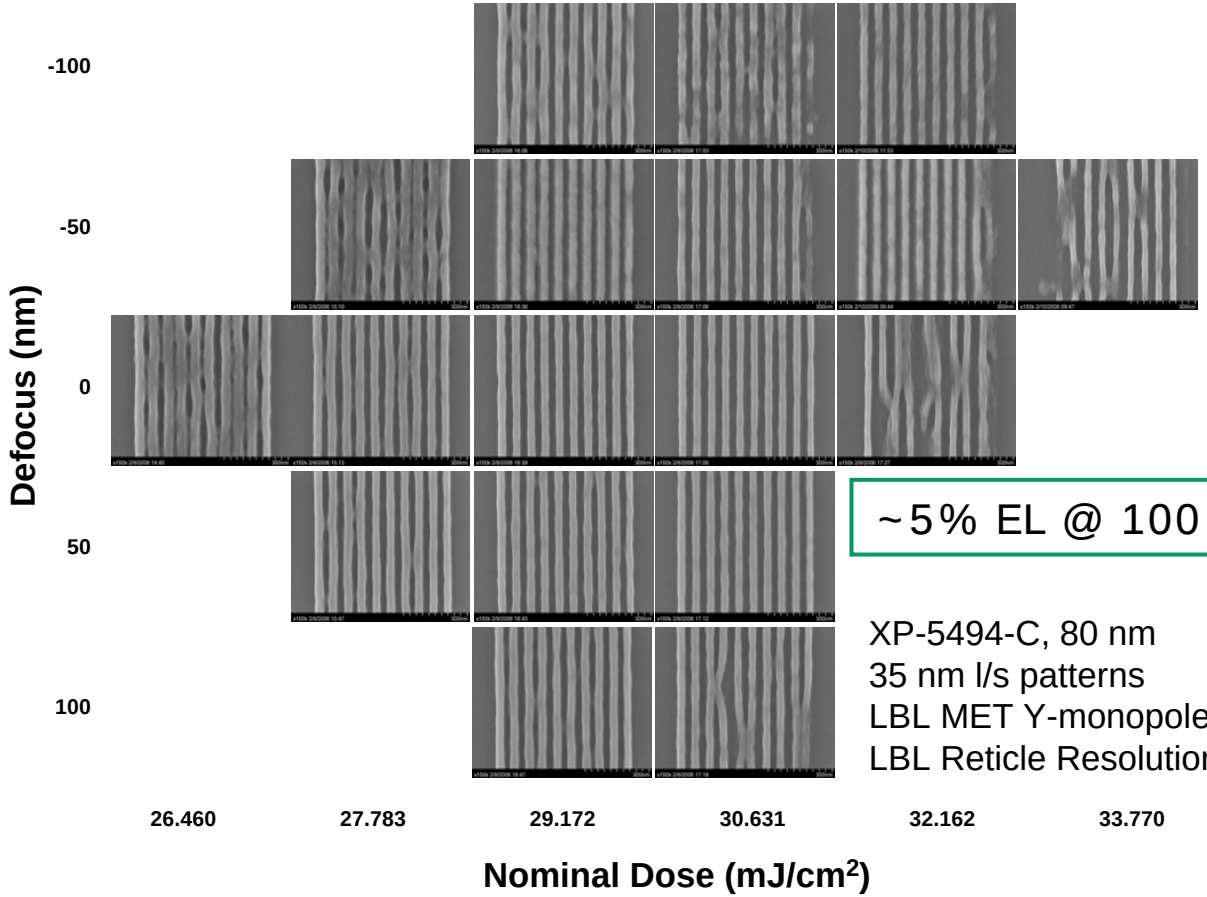
XP-5494-C FEM 40L80P



~15% EL @ 200 nm DOF

XP-5494-C, 80 nm FT
40 nm l/s patterns
LBL MET Y-monopole illumination
LBL Reticle Resolution DF

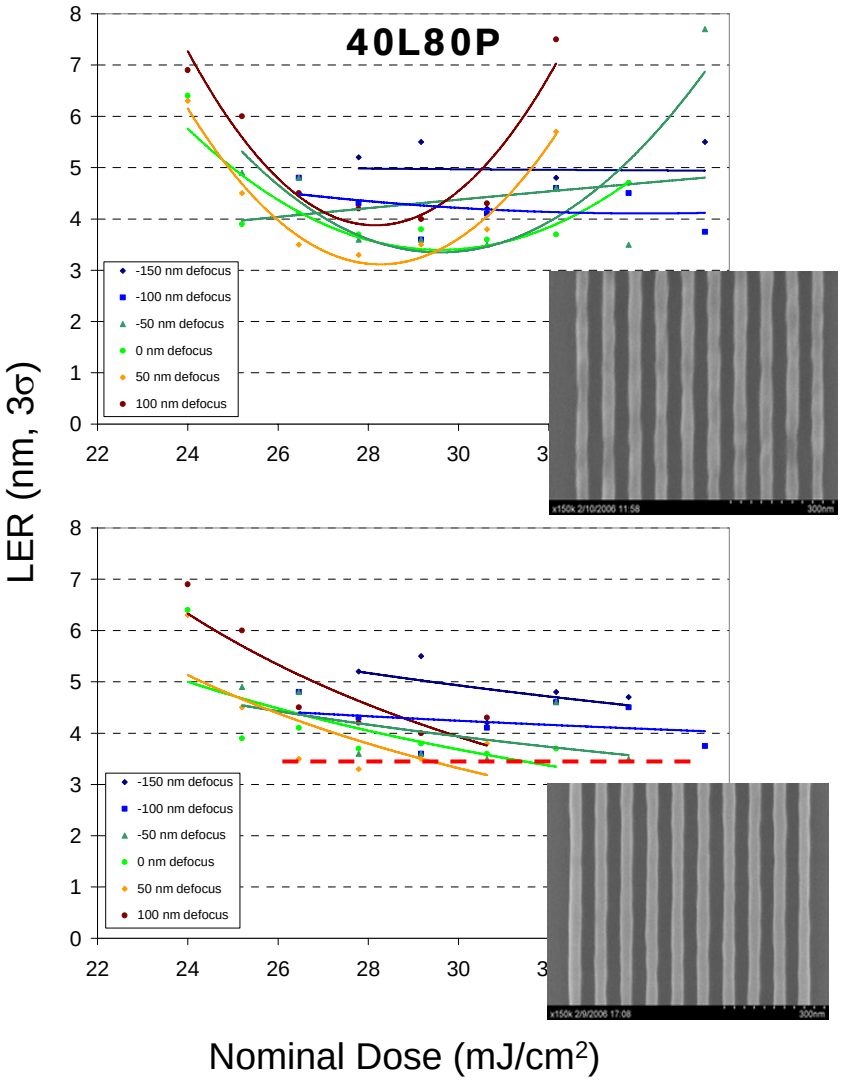
XP-5494-C FEM
35L/70P

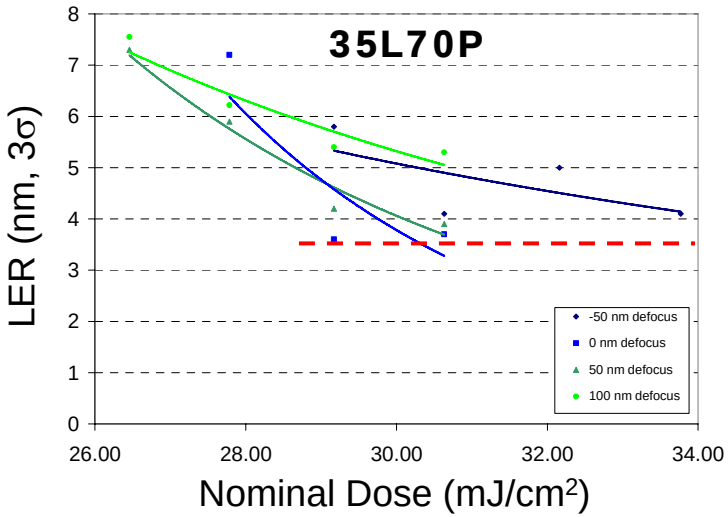


~5% EL @ 100 nm DOF

XP-5494-C, 80 nm
35 nm l/s patterns
LBL MET Y-monopole illumination
LBL Reticle Resolution DF

XP-5494-C LER Trends





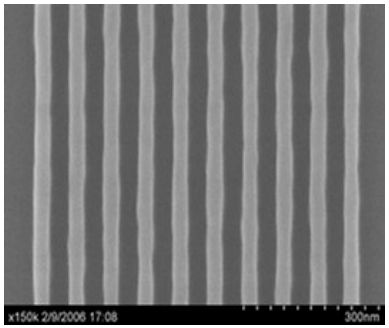
- Limiting LER ~3.5 nm
- Expected dose/focus trends are observed
- Topography complicates LER analysis

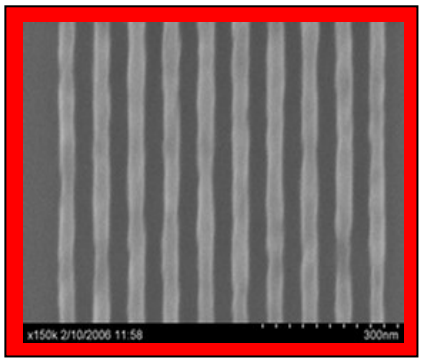
Failure Mechanisms

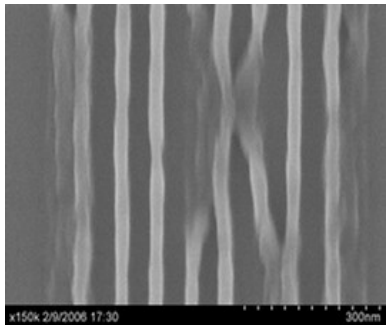
40L80P

Top Loss

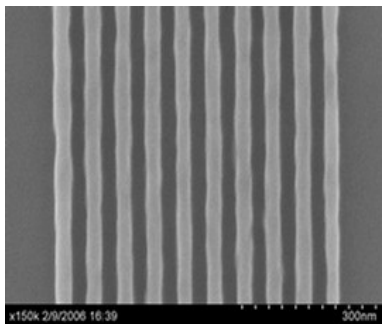
Pattern Collapse

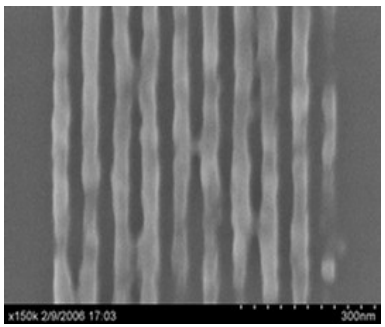


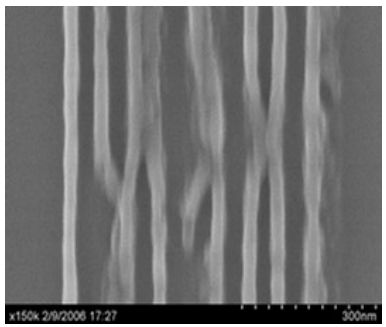




35L70P

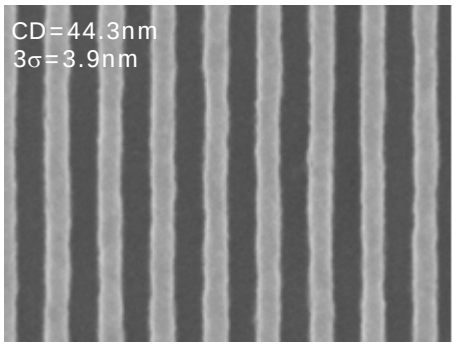




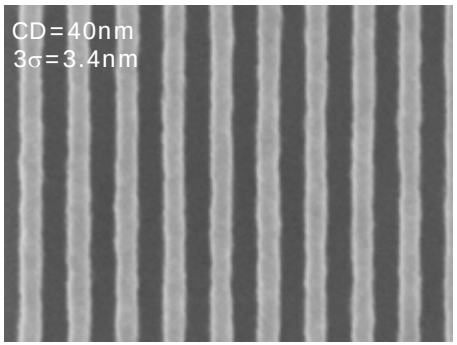


- Feature-size dependent continuum of top-loss and pattern collapse
- LER measurement effects can be seen prior to CD measurement effects

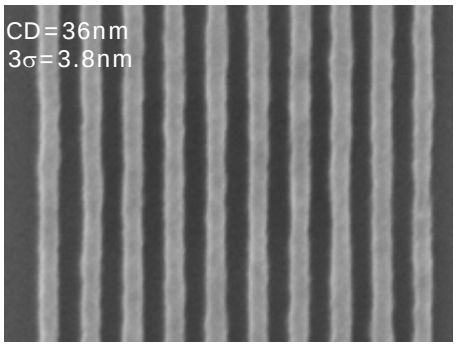
Top-Loss Failure SEM Comparison: MET-1K



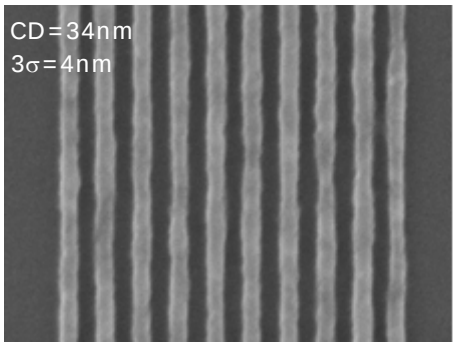
50 nm 1:1



45 nm 1:1

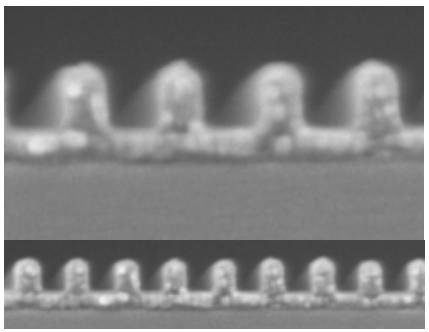


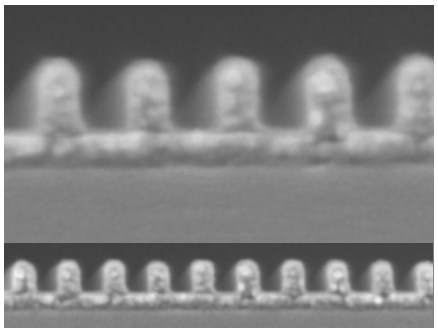
40 nm 1:1

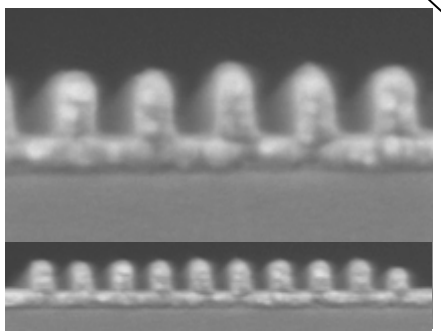


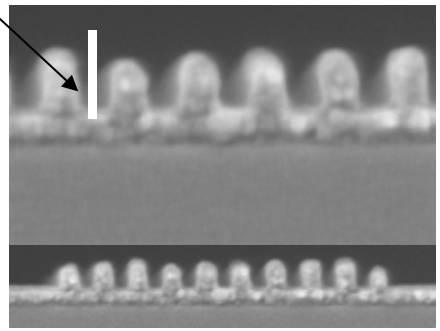
35 nm 1:1

This bar represents full thickness (80nm)



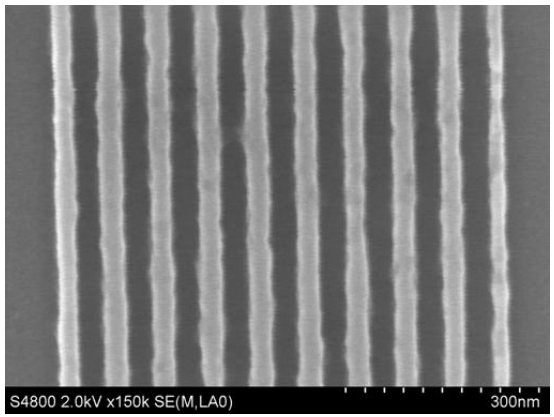






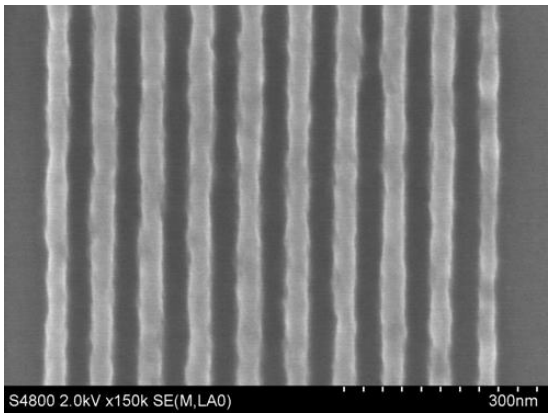
Film Thickness Effects: XP-6305-G

FT = 80nm



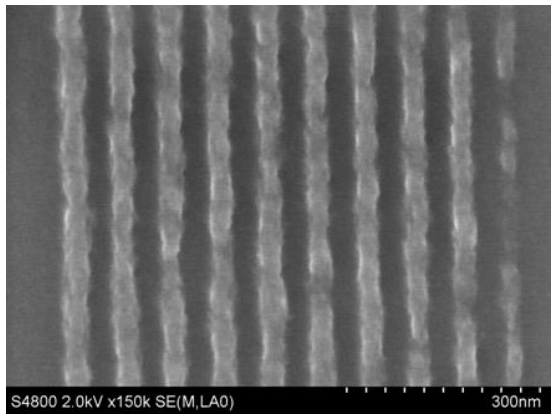
40L80P, 11.3mJ/cm^2
LER=3.7±0.7

FT = 62nm



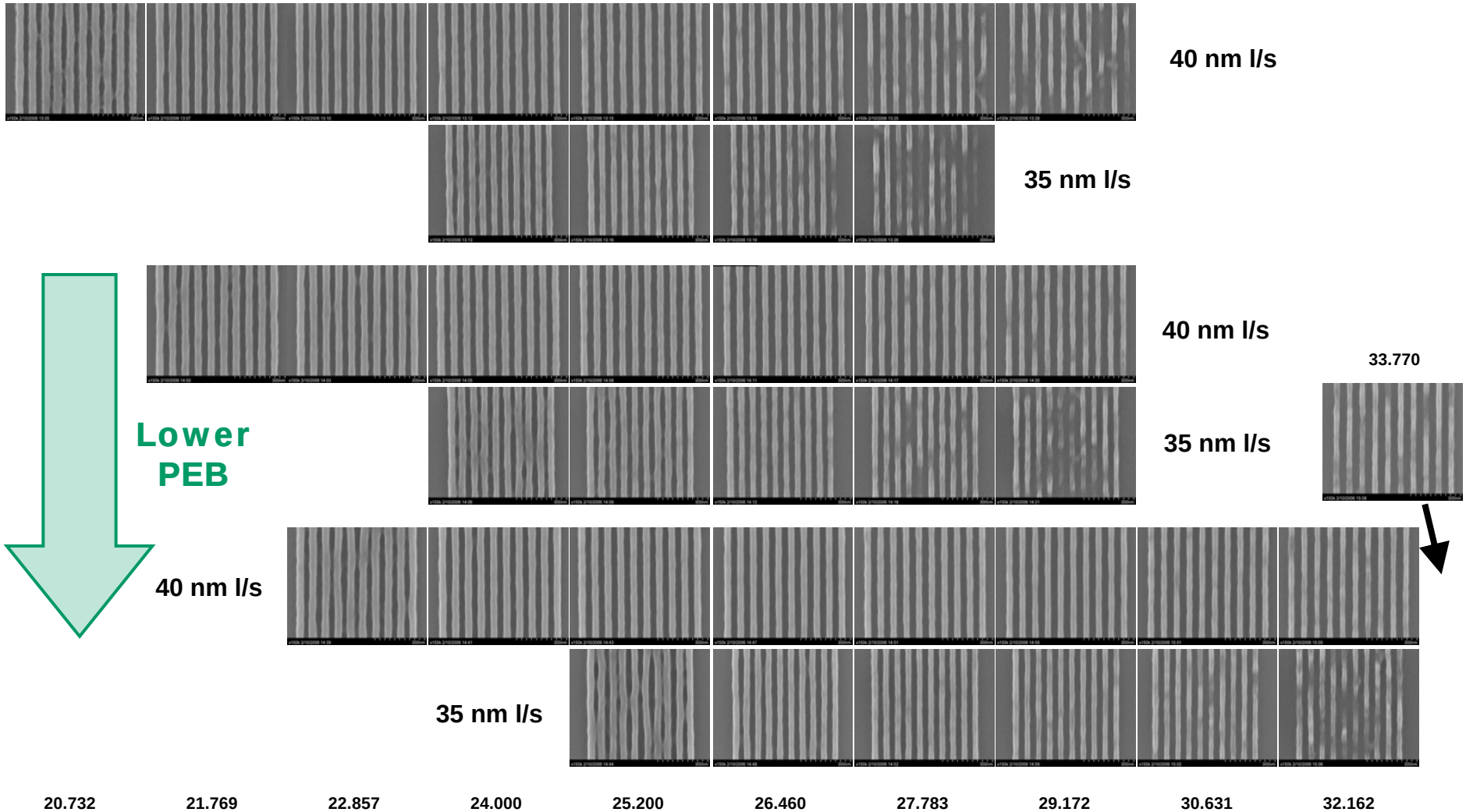
40L80P, 10.8mJ/cm^2
LER=4.2±0.9

FT = 40nm



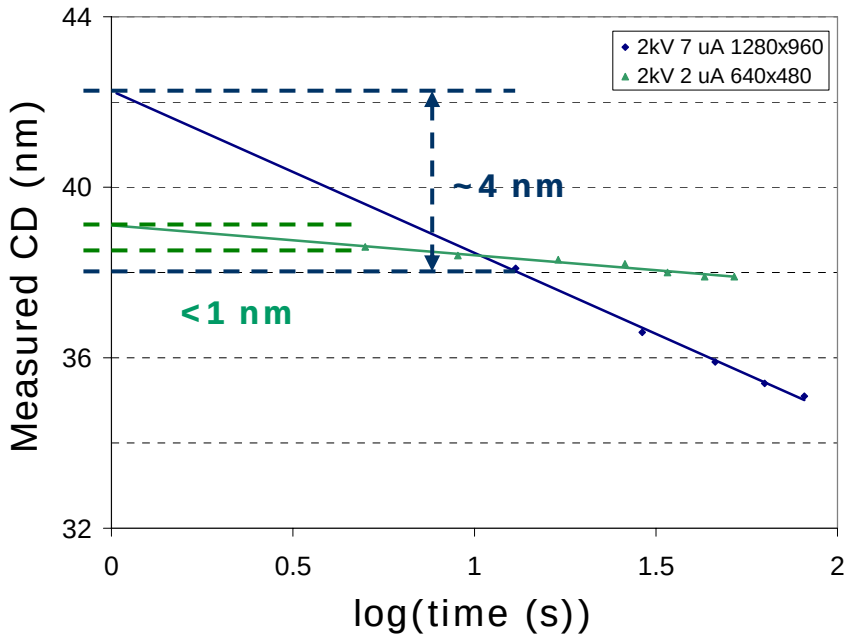
40L80P, 10.8mJ/cm^2
LER=7.1±1.1

- Top-loss and roughness become worse as thickness decreases
- Ultrathin film regime
- Sub-60 nm thicknesses are needed for 22 nm node



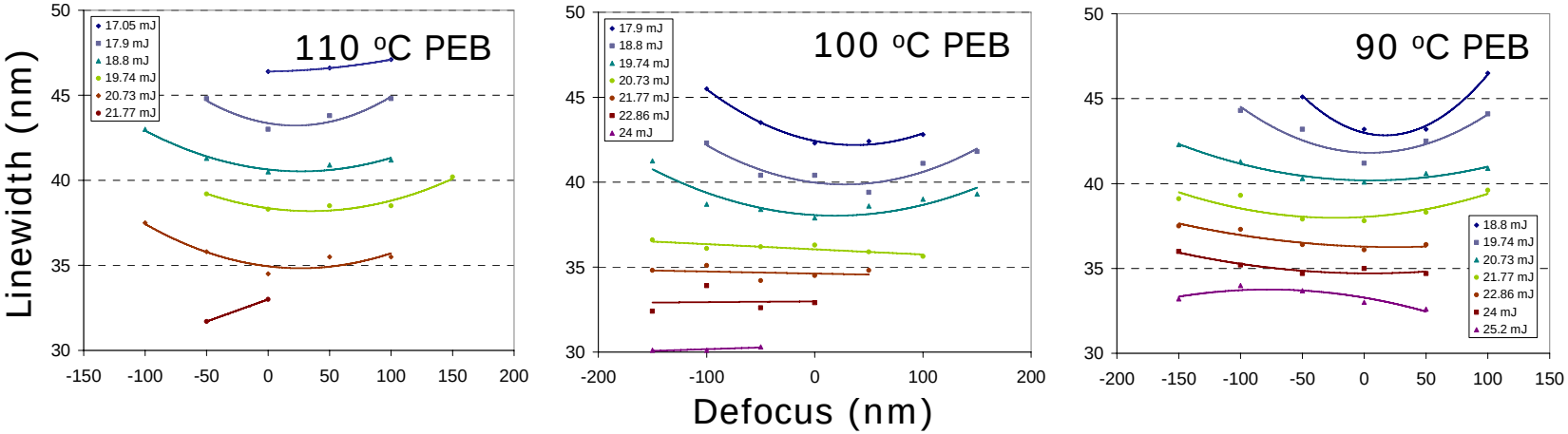
XP 6305-A, 80 nm thickness
40 nm l/s at best focus in first row; 35 nm l/s patterns at best focus in second row
LBL MET Y-monopole illumination; LBL Reticle Resolution DF

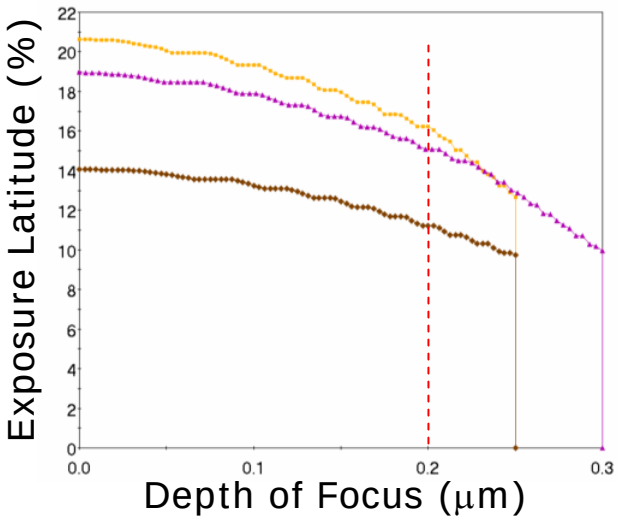
SEM line slimming- XP-5494-K
SEM Image Capture Modifications



- Lower beam current, fast image acquisition, consistent dwell time
- This is an enabling modification for lithographic analysis that follows

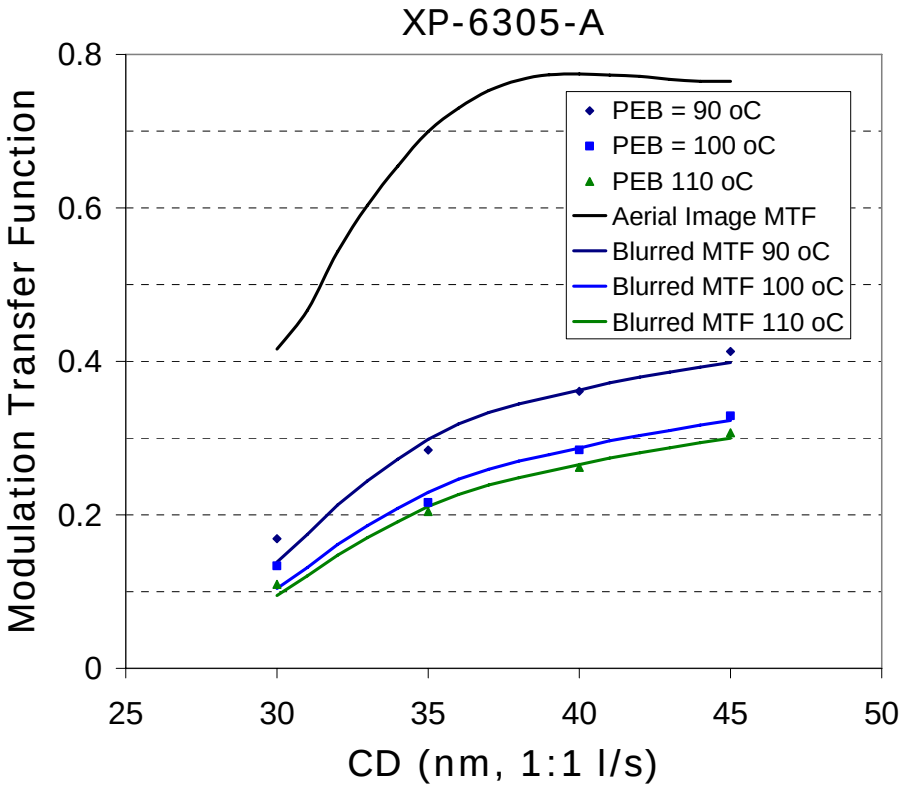
XP-6305-A 40L80P Process Window vs. PEB Temperature





PEB Temperature (°C)	EL (%) (at 200nm DOF) (+/- 10% CD)
90	16.2
100	15.1
110	11.2

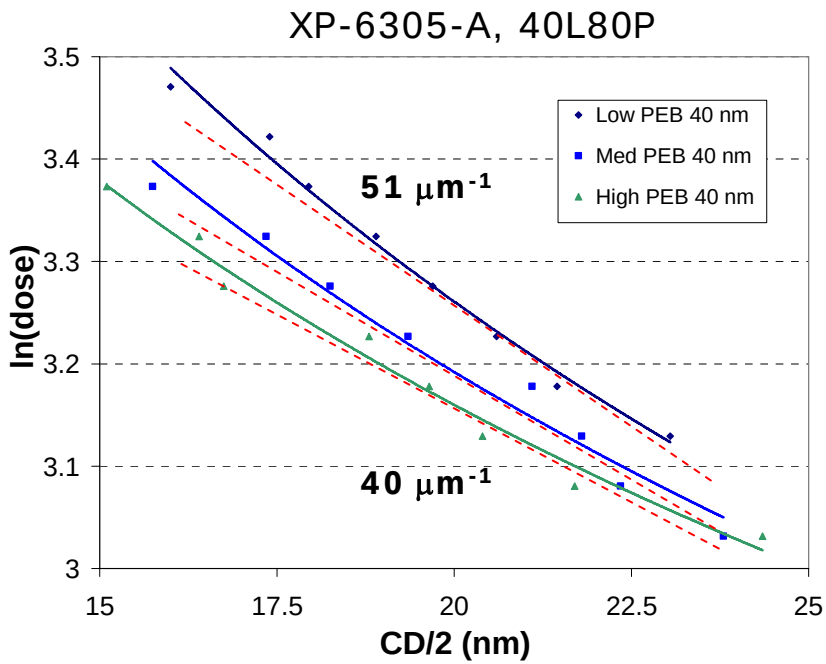
Effect of PEB Temperature on Effective Resist Blur

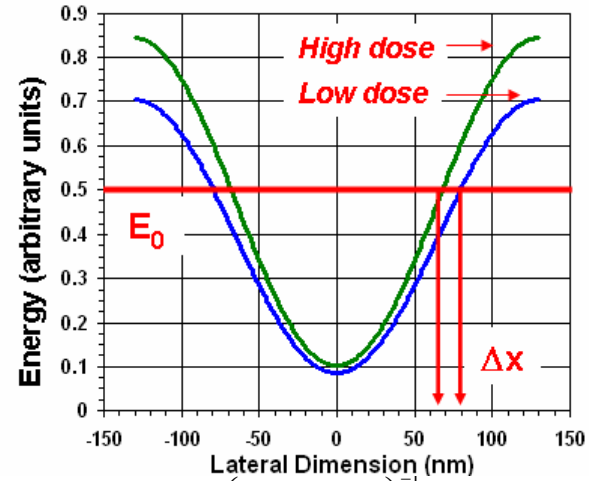


PEB Temperature (°C)	Effective Resist Blur (nm)
90	22
100	29
110	32

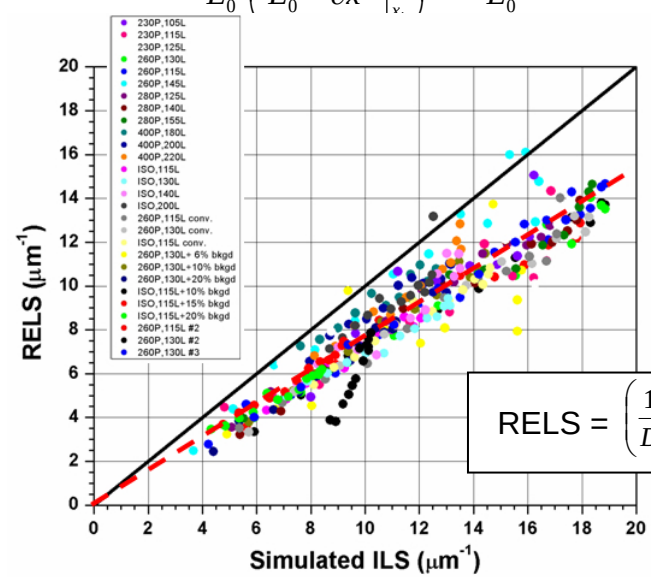
Blur simulation- thanks to Patrick Naulleau, LBNL

PEB Temperature Impact on Resist-Edge Log Slope





$$\Delta x_i \cong \frac{\Delta E}{E_0}\left(\frac{1}{E_0}\frac{\partial E(x)}{\partial x}\bigg|_{x_i}\right)^{-1} = \frac{\Delta E}{E_0}(ILS)^{-1}$$

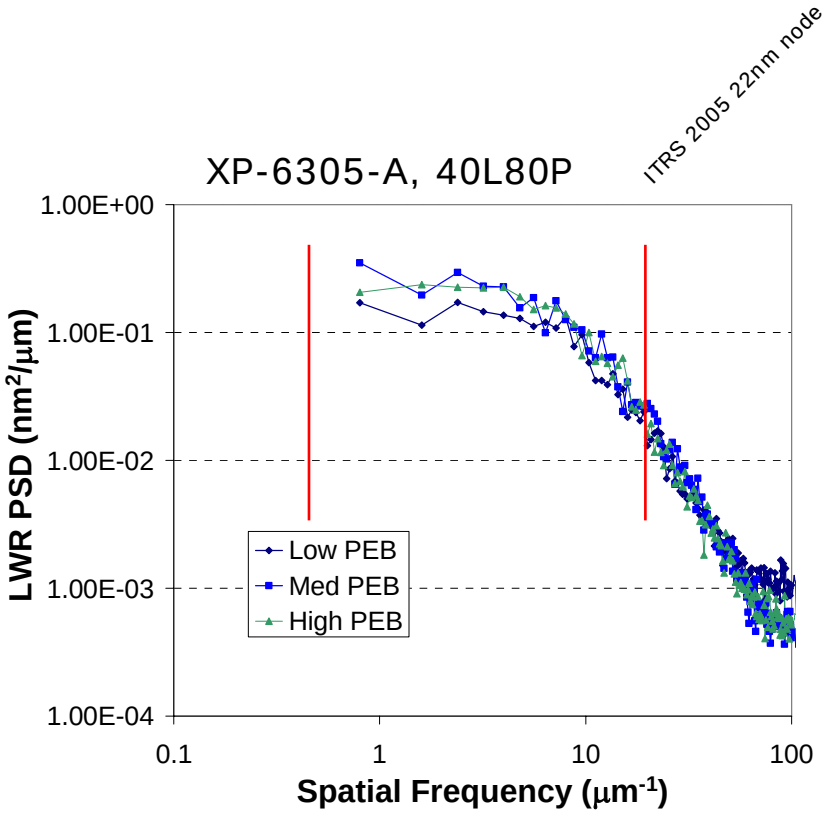


$$\text{RELS} = \left(\frac{1}{D}\frac{\partial D(x)}{\partial x}\bigg|_{x_i}\right)$$

- At constant E_{size}, RELS increases as PEB decreases
- Link between simulation and experiment
- RELS, ILS strongly correlated with process window, LER, etc.

-A. Pawloski et al. Proc. SPIE 2004, 5376, 414

PEB Temperature Impact on LER and LWR



LWR α (integrated PSD)$^{1/2}$

ITRS specifies low-frequency LWR as
$0.5 < f(x) < 1/\text{MPU Pitch}$ (μm^{-1})

PEB Temperature (°C)	LER (nm 3σ)	LWR (nm 3σ)
90	3.6 (0.2)	5.5 (0.3)
100	4.2 (0.2)	7.0 (0.3)
110	4.3 (0.2)	6.8 (0.3)

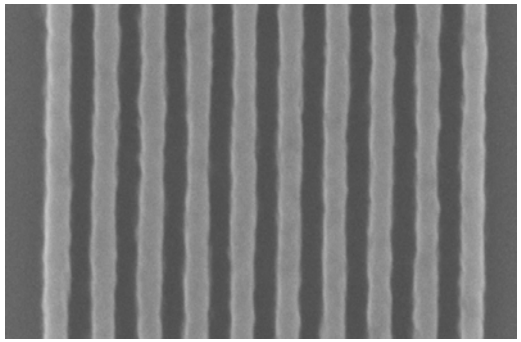
- Lower LER at 90 °C PEB temperature
- PSD from averaged measurement of 40 lines at equivalent E_{size}

Summary Table- PEB Variation for XP-6305-A

PEB (^oC)	EL (at 200 nm DOF) (40L80P)	MTF (40L80P)	Effective Resist Blur (nm)	RELS (μm^{-1} at E_{size})	LER/LWR (nm 3σ at E_{size}) (~ITRS 22 nm node)
90	16.2	0.36	22	51	3.6/5.5
100	15.1	0.28	29	43	4.2/7.0
110	11.2	0.26	32	40	4.3/6.8

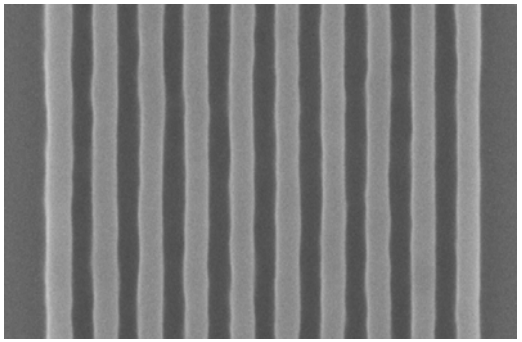
- By all metrics, lower PEB temperature appears superior-
  - MTF increases as PEB temperature decreases
  - Resist blur decreases as PEB temperature decreases
  - At constant E_{size}, RELS increases as PEB decreases
  - Possible trend to lower LER/LWR at lower bake temperature

Surface Conditioners for LER/LWR Reduction XP-5494-C



Baseline Process

CD = 41.7 +/- 0.8 nm
LER = 4.3 +/- 0.4 nm
LWR = 6.6 +/- 0.7 nm

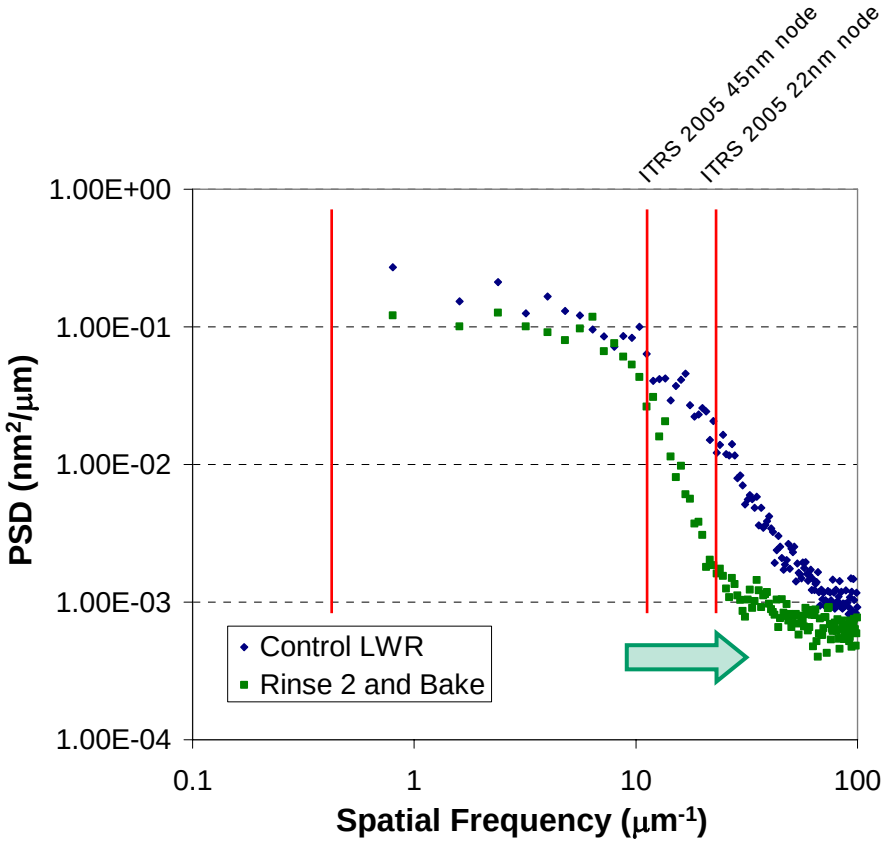


Surface Conditioner Process

CD = 40.6 +/- 0.6 nm
LER = 3.2 +/- 0.4 nm
LWR = 5.0 +/- 0.9 nm

- Surface conditioners are known to improve LER, pattern collapse, and defectivity for 248 and 193 nm lithography
- Process-
  - apply surface conditioner rinse at end of development
  - optional bake following drying
- ~1 nm LER reduction from surface conditioner alone; bake effect unclear
- No change in resolution capabilities; effects on CD are minor or negligible

Resist Process LWR PSD Comparison vs. ITRS 2005



ITRS MPU ½ pitch (nm)	ITRS LWR Spec (nm 3σ)	LWR Control (nm 3σ)	LWR Rinse + Bake (nm 3σ)	Improve-ment (nm 3σ)
Filtered $0.8 < f(x) < 100\ \mu m^{-1}$		5.8	4.3	1.5
45	2.4	4.9	4.0	0.9
32	1.7	5.2	4.1	1.1
22	1.2	5.5	4.2	1.3

LWR α (integrated PSD)$^{1/2}$

ITRS specifies low-frequency LWR as $0.5 < f(x) < 1/\text{MPU Pitch}\ (\mu m^{-1})$

- Example process includes surface conditioner rinse and post-rinse bake
- Rinse reagent LWR reduction is substantial even at low frequency
- Net LWR reduction from rinse treatment increases for smaller nodes
- ITRS LWR targets remain a challenge

Summary

- EUV resist performance can be significantly improved through process refinement
- Performance improvements from PEB optimization may include improved process window and lower LER/LWR
- Performance improvement metrics appear to fundamentally link PEB improvements to resist blur and development contrast
- Surface conditioners may be an effective method to help bridge the gap between observed LER/LWR trends and industry needs
- New materials with improved resolution, LER/LWR, and ultrathin film performance have been successfully developed

Acknowledgments

Sematech: Kim Dean

LBNL: Patrick Naulleau, Brian Hoef, Paul Denham, Gideon Jones, Jerrin Chiu

AMD: Berni Phillips, Harry Levinson