High resolution EUV micro-exposures at the ALS

Patrick Naulleau

Kenneth A. Goldberg, Erik Anderson, Jason P. Cain, Paul Denham, Brian Hoef, Keith Jackson, Anne-Sophie Morlens, Seno Rekawa

Lawrence Berkeley National Laboratory

Robert L. Brainard

Rohm and Haas

Kim Dean

SEMATECH

MET printing station at Berkeley enables advanced EUV learning at 0.3 NA and low k_1

- **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

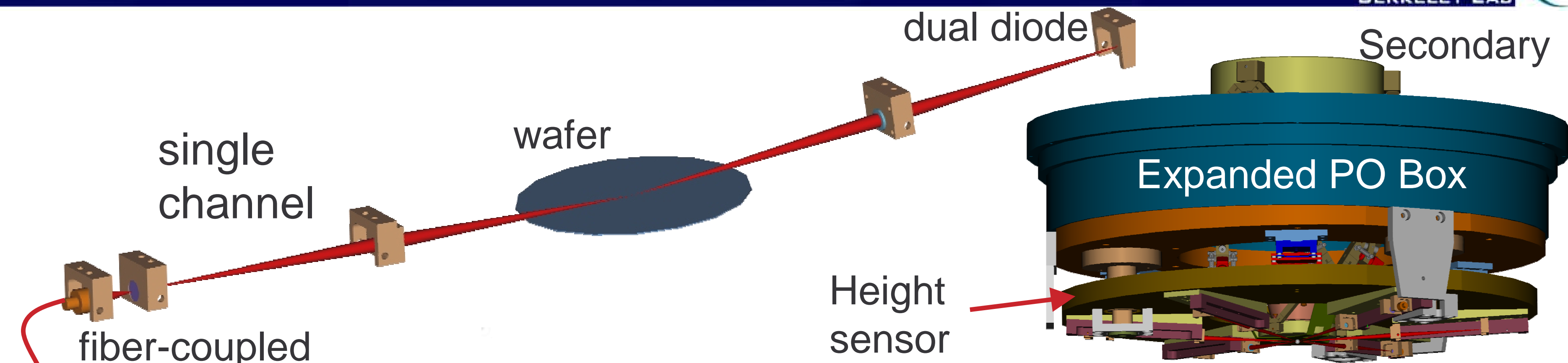
Reticle stage

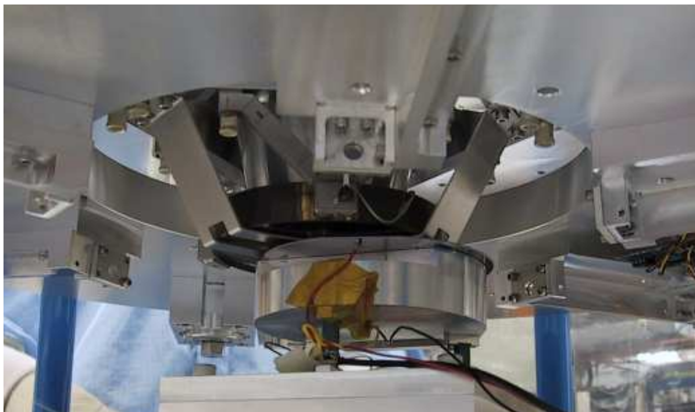
MET

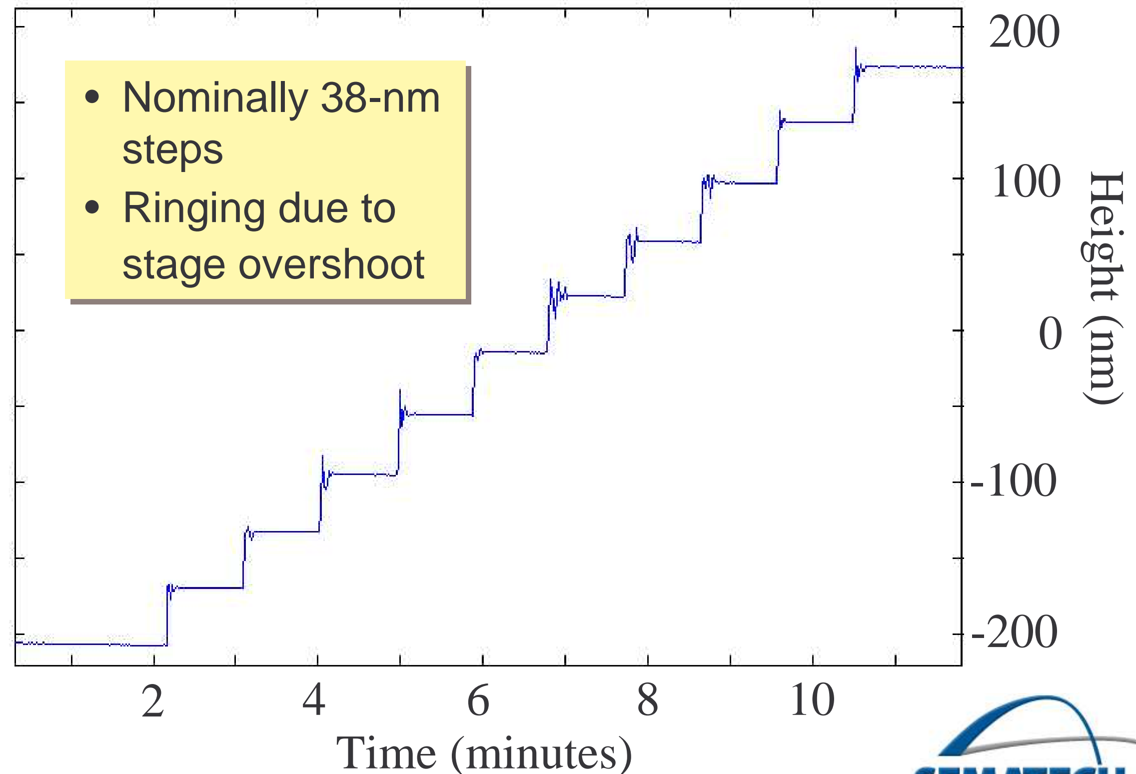
Wafer stage and height sensor

Pupil-fill monitor

Print-site grazing wafer height sensor provides sub-10-nm focus resolution







MET programmable illuminator supports $0 < \sigma < 1.2$

From synchrotron

High-speed dual-axis pupil-fill scanner

Y

X

Cylindrical scanners provide stationarity over large FOV

Low-speed field uniformity scanner

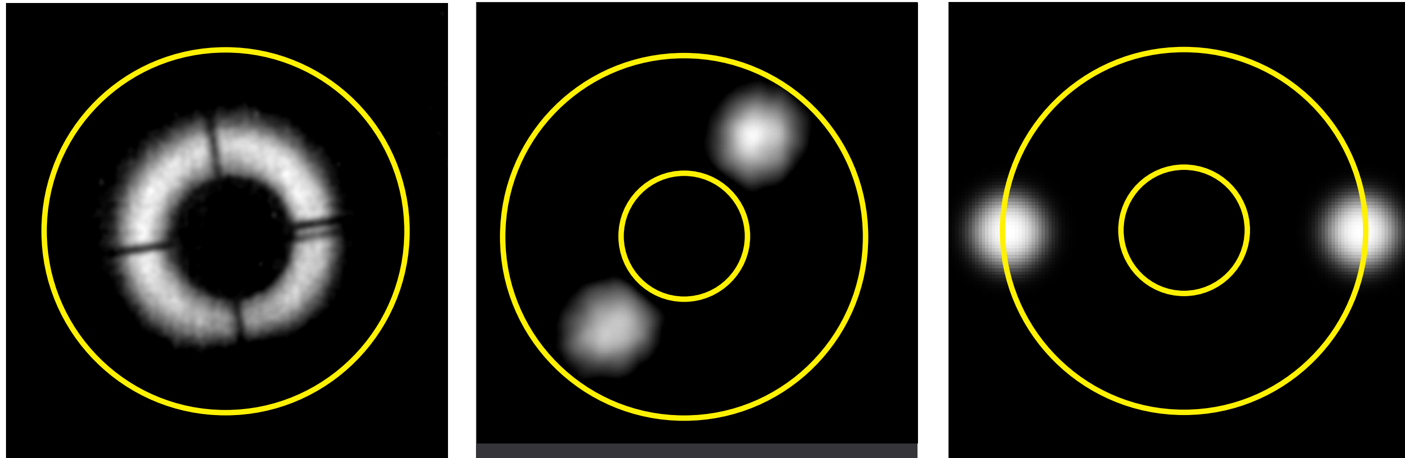
2D scanner

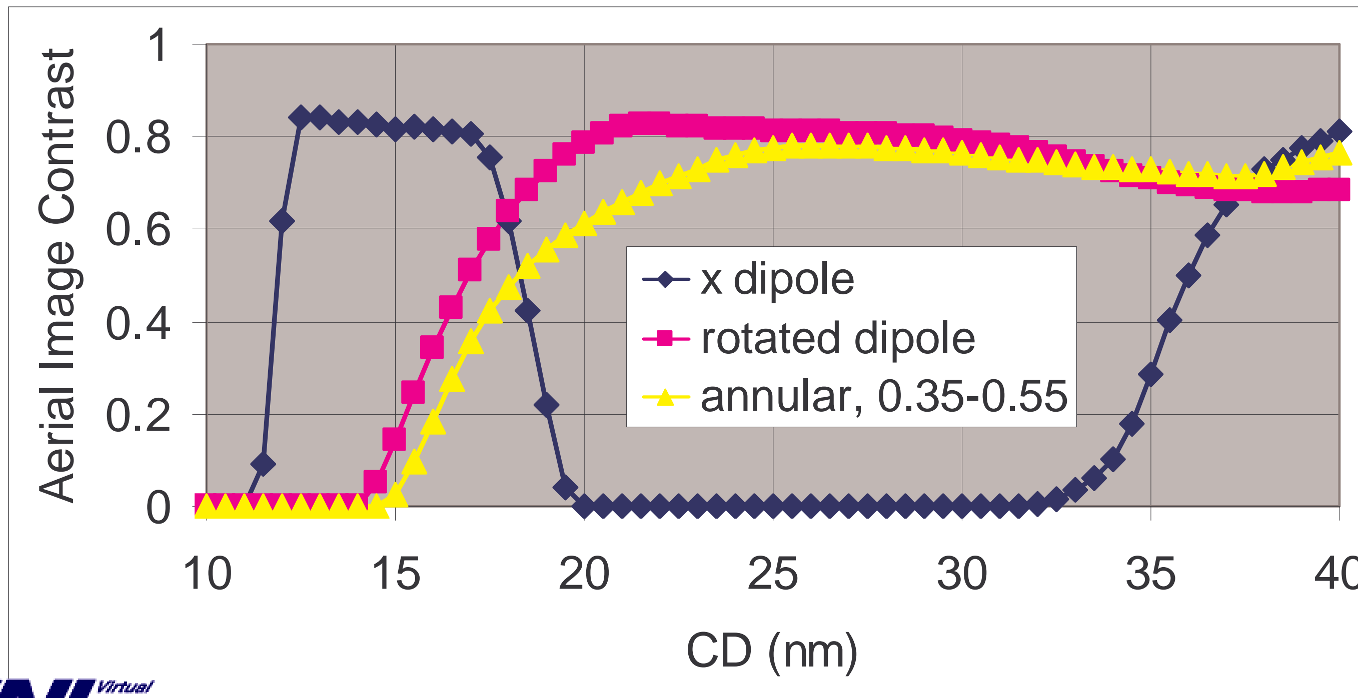
Toroid, scanner re-imaging optic

Reticle

- Fully programmable pupil fill
- Supports 200x600 µm field
  - Stationarity and uniformity
- Supports 10-ms exposures

Dipole capabilities enable ultra-high resolution printing





- *Prolith* modeling results including EUV-measured wavefront.

Printing operations began 2/20/04

- Main vacuum chamber installed in temperature-controlled room. Optic held to ±0.01 °C
- Transfer systems installed in amine-filtered clean room with PEB hot plate
- Wafer and reticle vacuum load locks
- Throughput:
  6-12 wafers per day
- Reticle exchange time:
  30 minutes

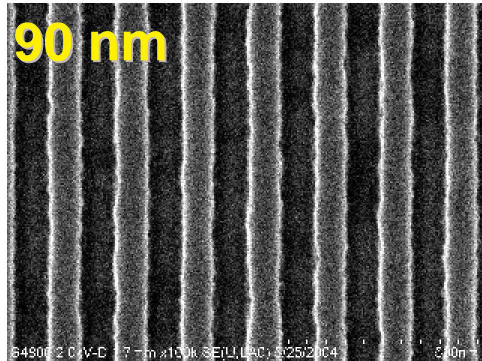
Reticle access port

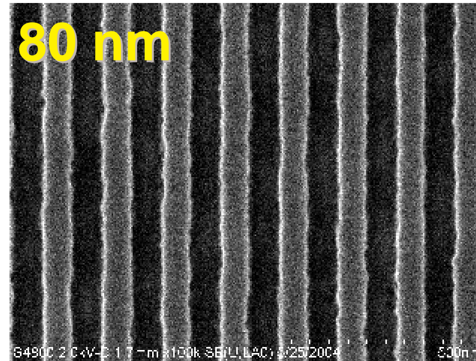
Wafer load-lock transfer

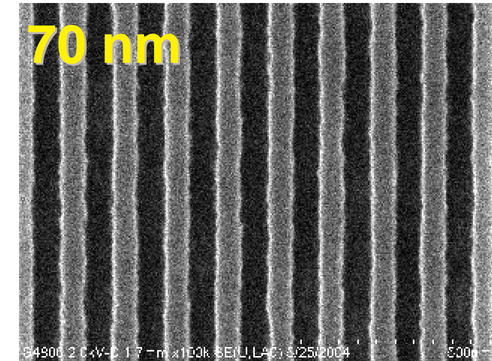
PEB hot plate

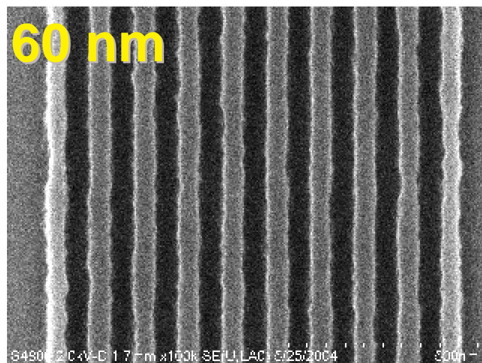
Amine-filtered clean room

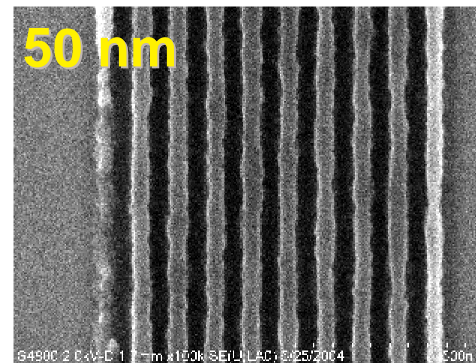
EUV-2D resist demonstrated to have a resolution cut-off of ~45 nm

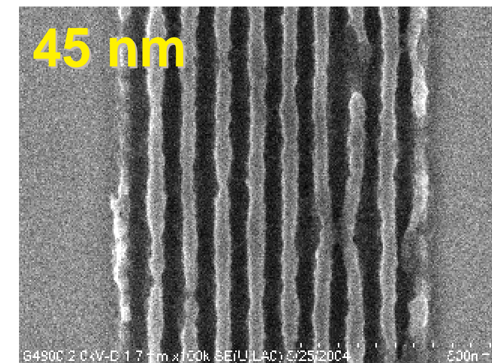


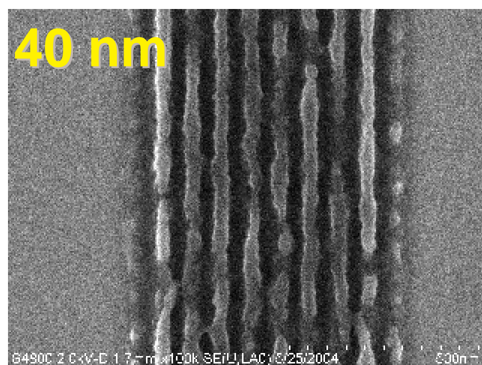








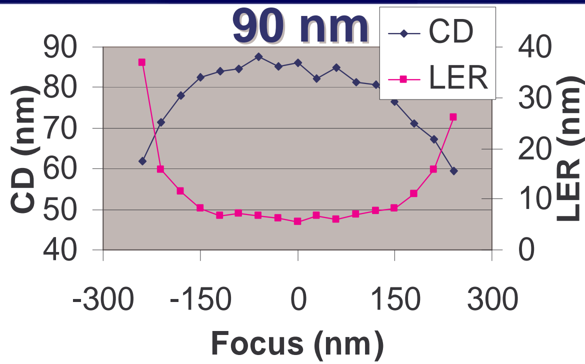


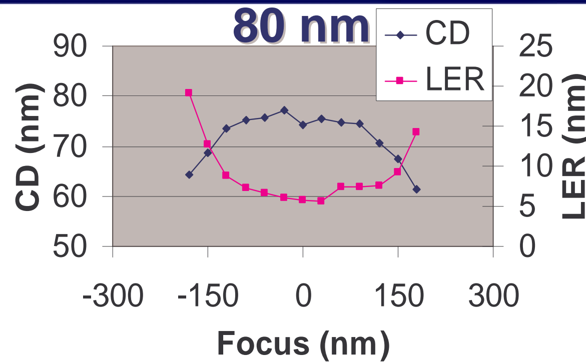


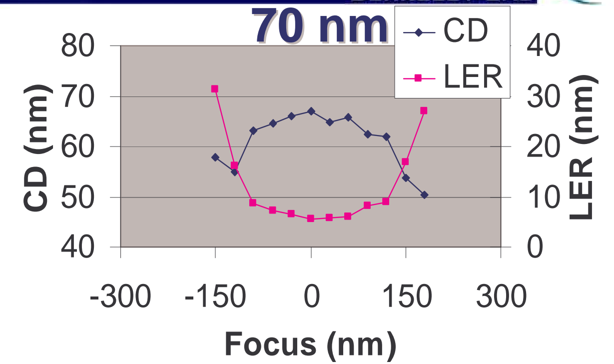
Processing Conditions:

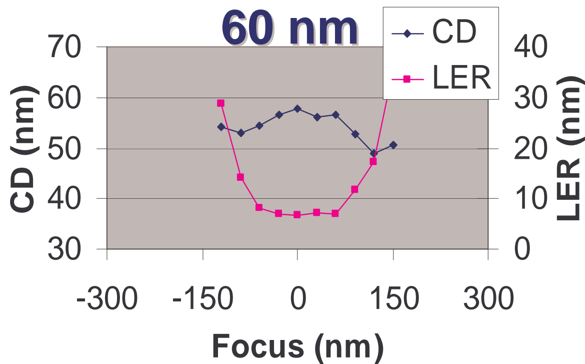
- Thickness 125-nm
- PEB 130 °C 90 Sec
- Develop 45 Sec
- Sensitivity 6.8 mJ/cm^2

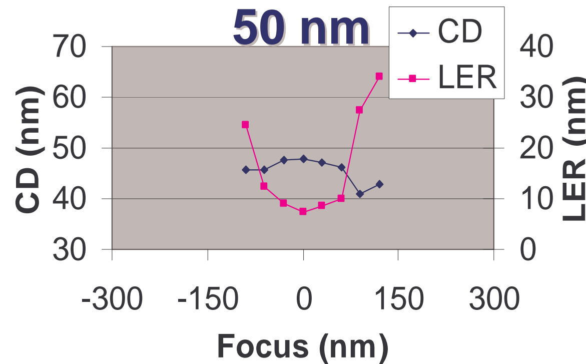
EUV-2D through-focus data (brightfield mask)

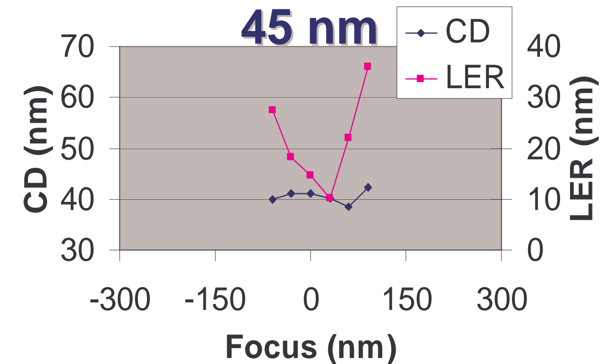


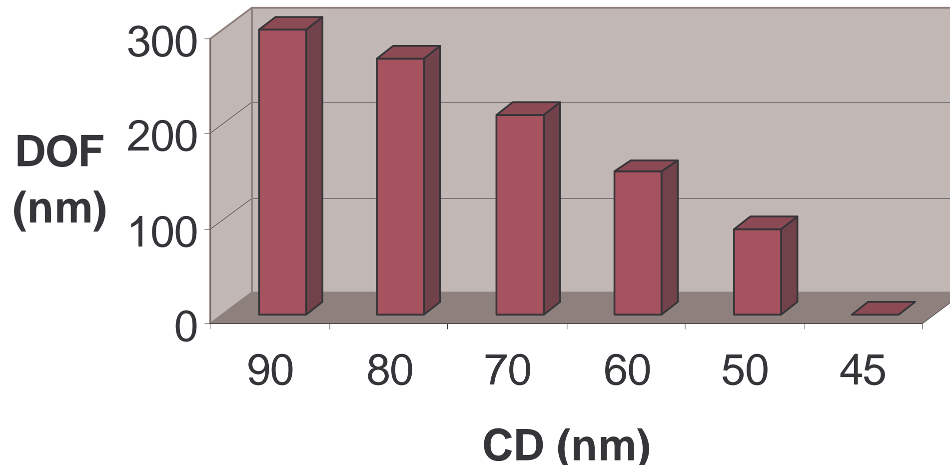








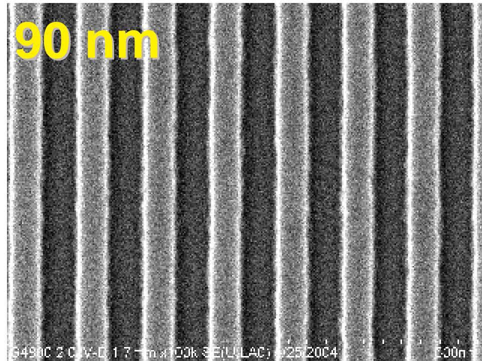


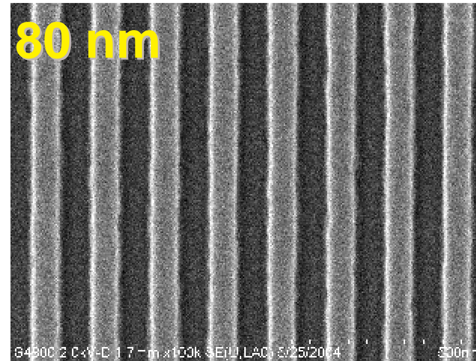


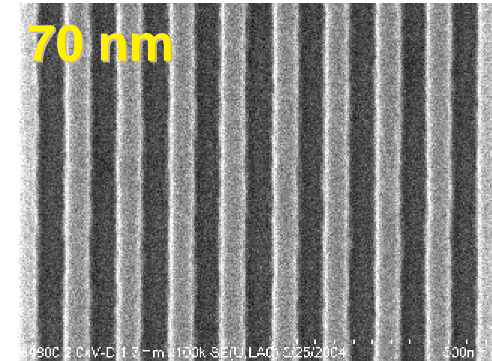
DOF determined from LER through-focus

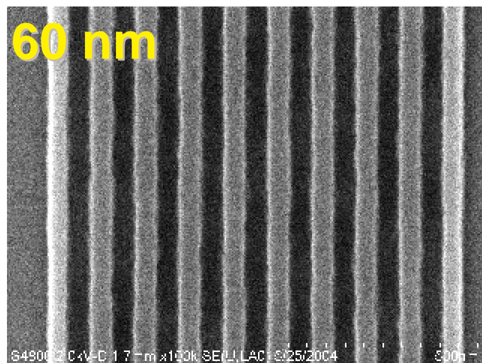
VNL Virtual National Laboratory

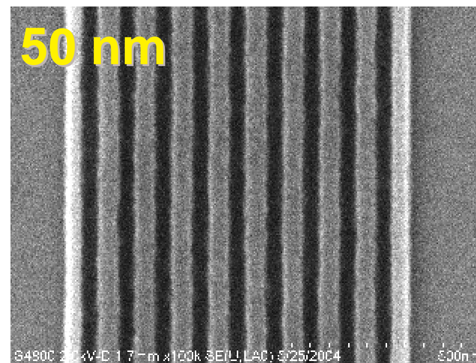
Rohm and Haas MET 1K resist shows 10-15 nm resolution improvement over EUV 2D

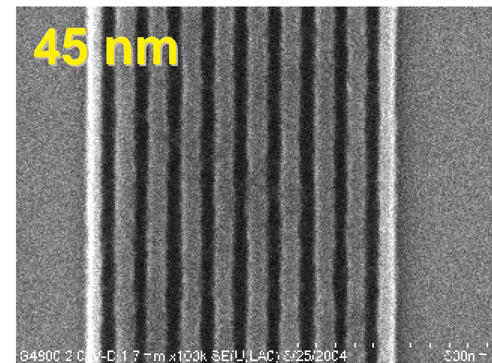


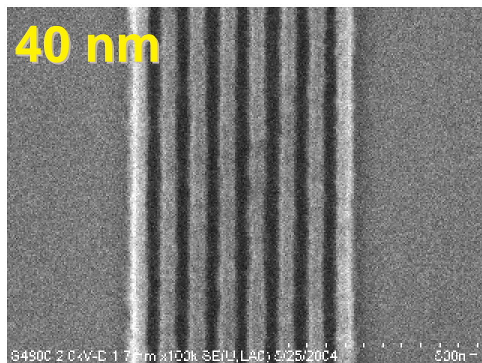


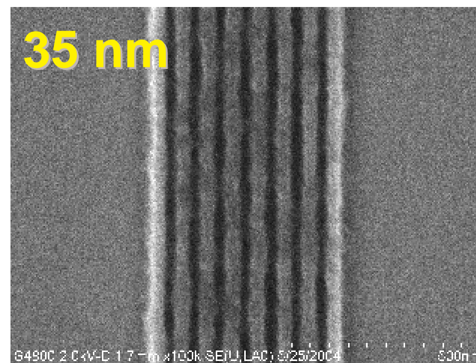








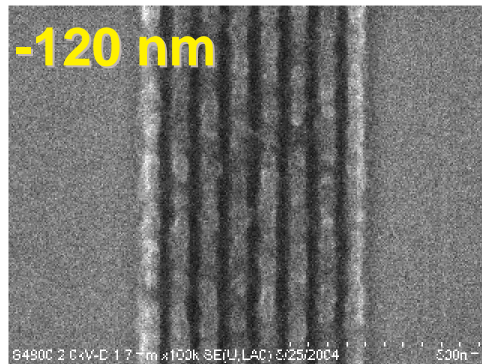


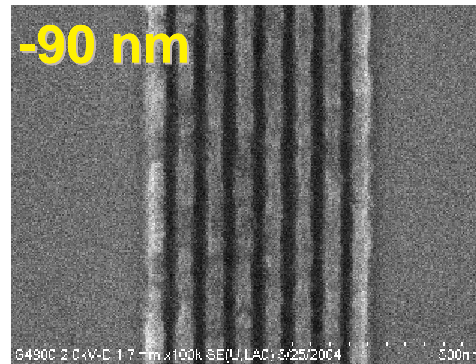


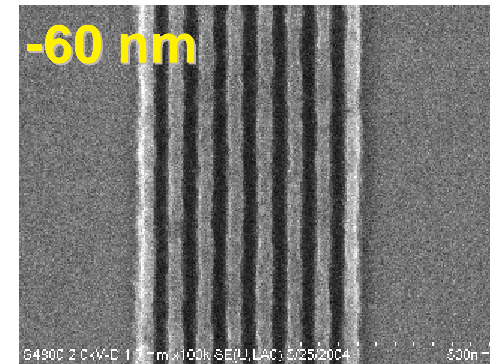
Processing Conditions:

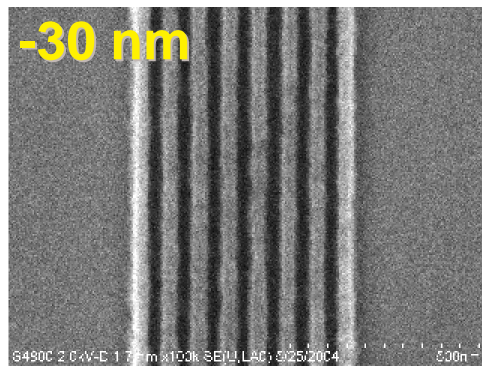
- Thickness 125-nm
- PEB 130 °C 90 Sec
- Develop 45 Sec
- Sensitivity 27 mJ/cm^2

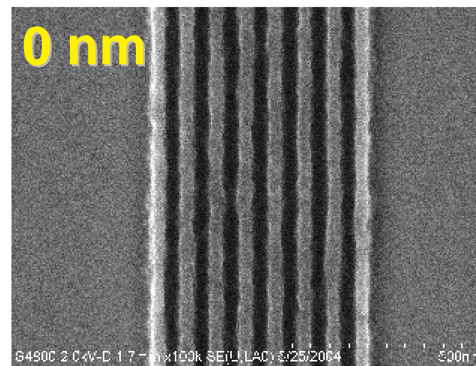
40-nm lines and spaces through focus in MET 1K (30-nm focus steps)

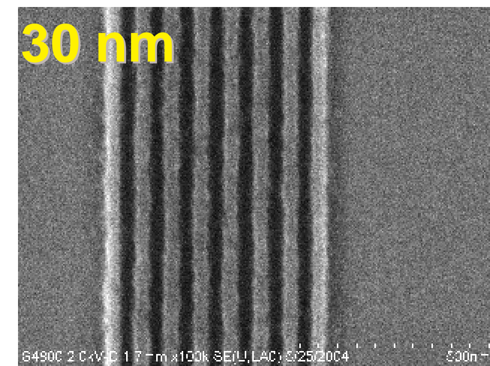


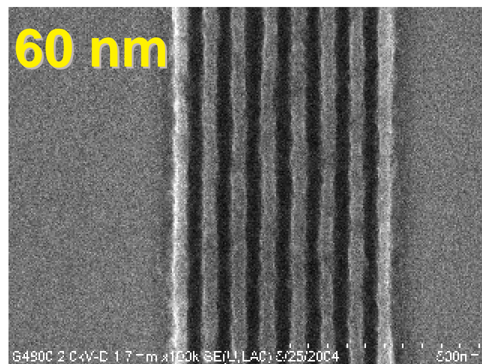


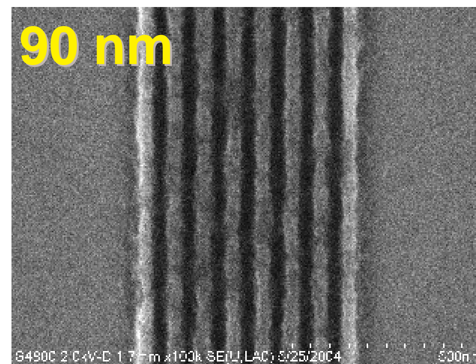


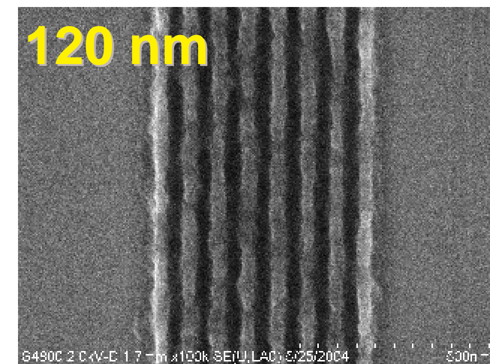












MET 1K through-focus data (brightfield mask)

90 nm
CD (nm) / LER (nm) vs. Focus (nm) — CD, LER

80 nm
CD (nm) / LER (nm) vs. Focus (nm) — CD, LER

70 nm
CD (nm) / LER (nm) vs. Focus (nm) — CD, LER

60 nm
CD (nm) / LER (nm) vs. Focus (nm) — CD, LER

50 nm
CD (nm) / LER (nm) vs. Focus (nm) — CD, LER

45 nm
CD (nm) / LER (nm) vs. Focus (nm) — CD, LER

40 nm
CD (nm) / LER (nm) vs. Focus (nm) — CD, LER

35 nm
CD (nm) / LER (nm) vs. Focus (nm) — CD, LER

MET 1K provides large increase in depth-of-focus compared to EUV 2D

DOF (nm)

500
400
300
200
100
0

MET 1K
EUV 2D

90 80 70 60 50 45 40 35

CD (nm)

Observed performance still resist limited

DOF constraints for Aerial-image data:

- Contrast > 60%
- NILS > 2
- ±10% CD change

DOF (nm)

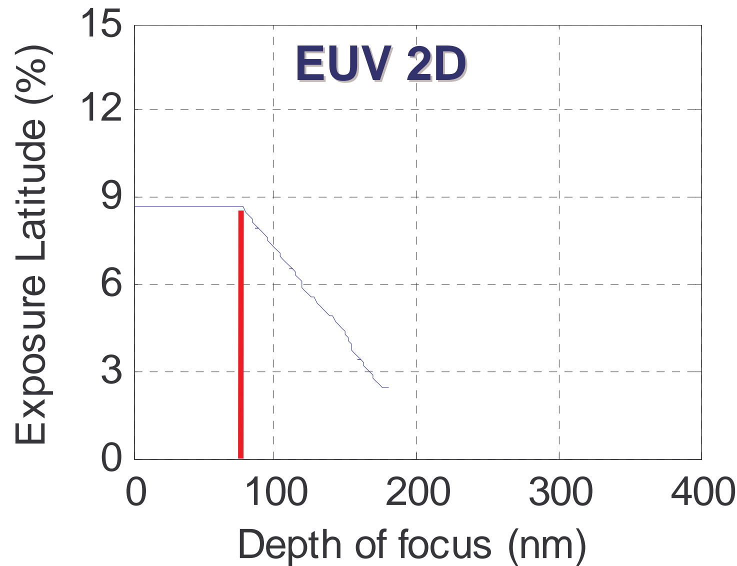
300
200
100
0

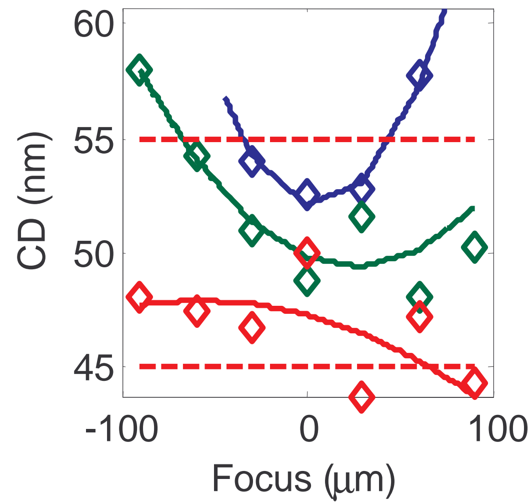
MET 1K
Aerial Image

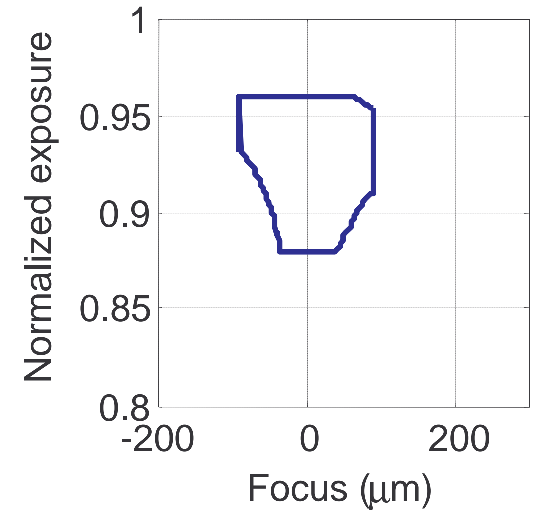
50 45 40 35 30 25 20

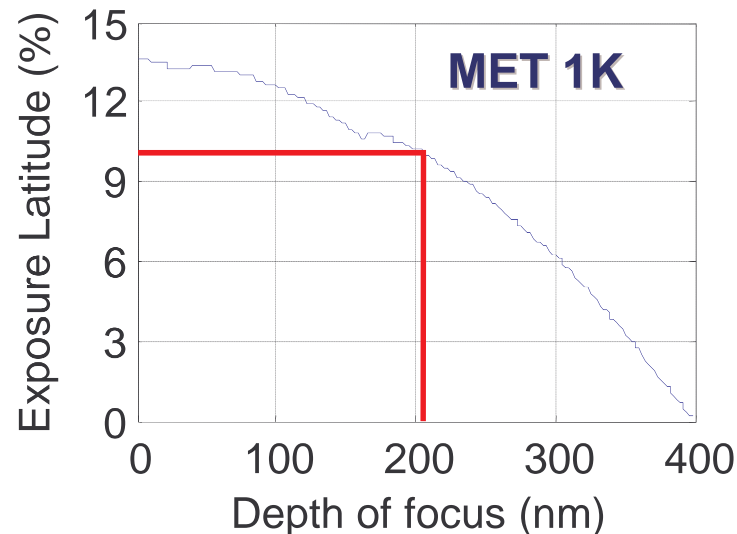
CD (nm)

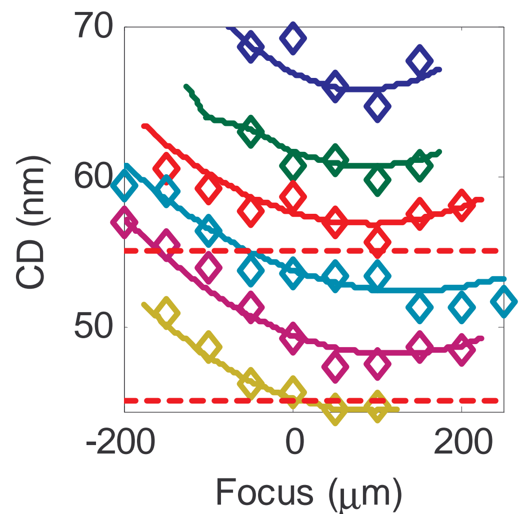
MET 1K provides large improvement in 50-nm dense line process window

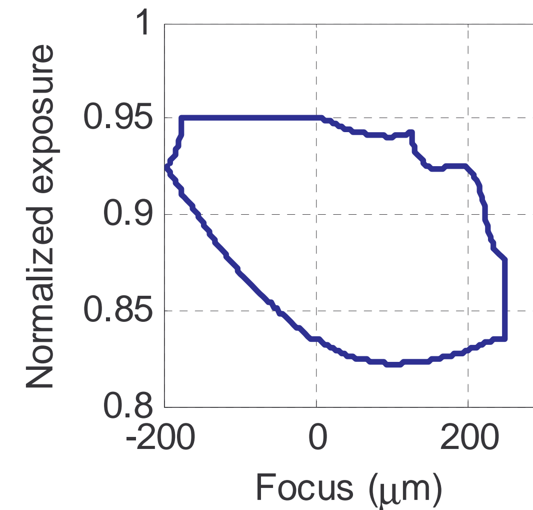




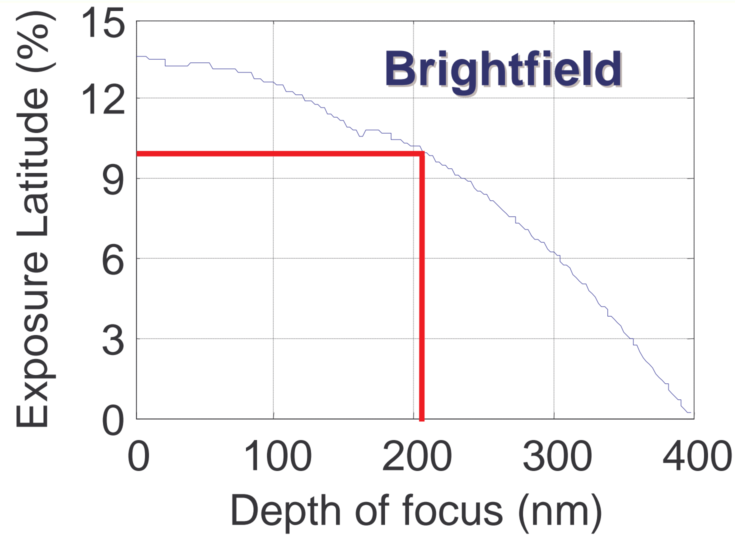


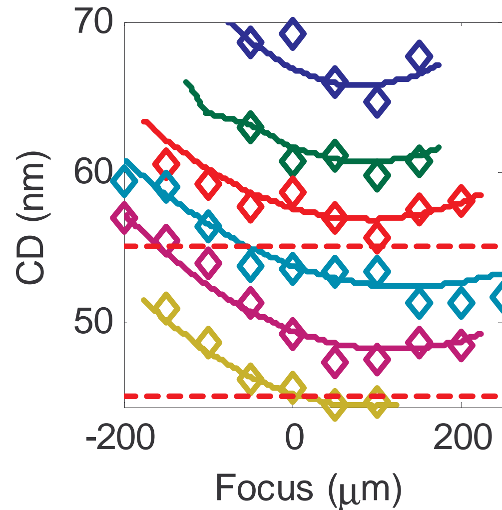


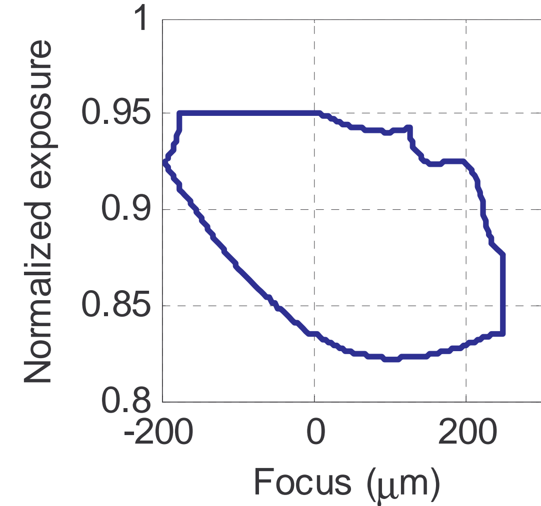


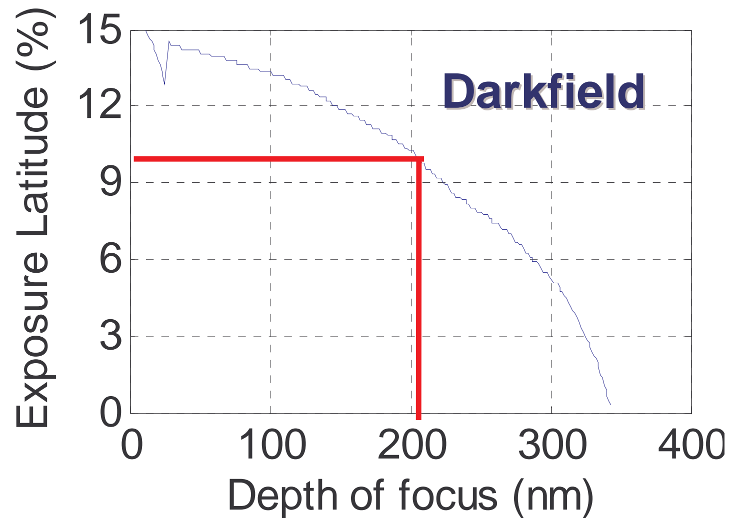


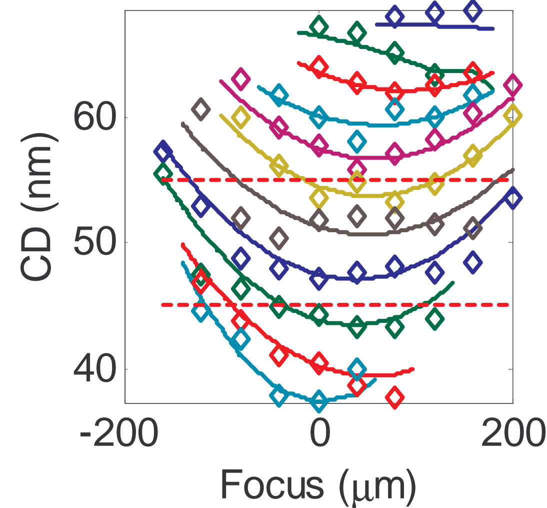
Brighfield to darkfield comparison shows that mid-range flare is not a concern

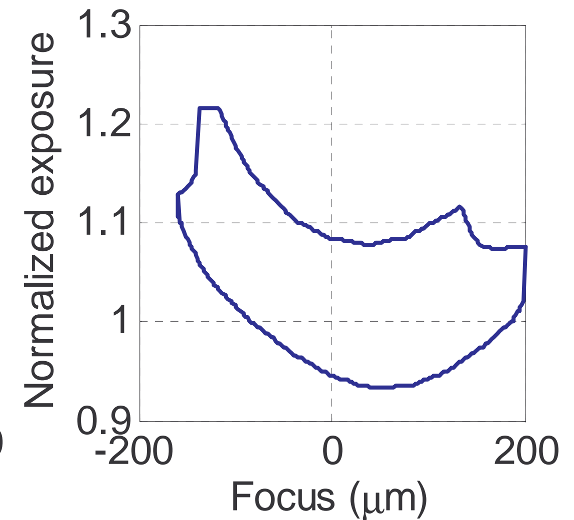






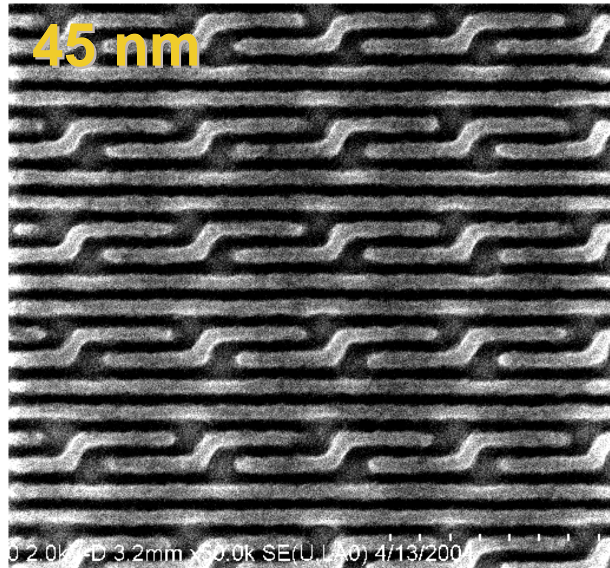


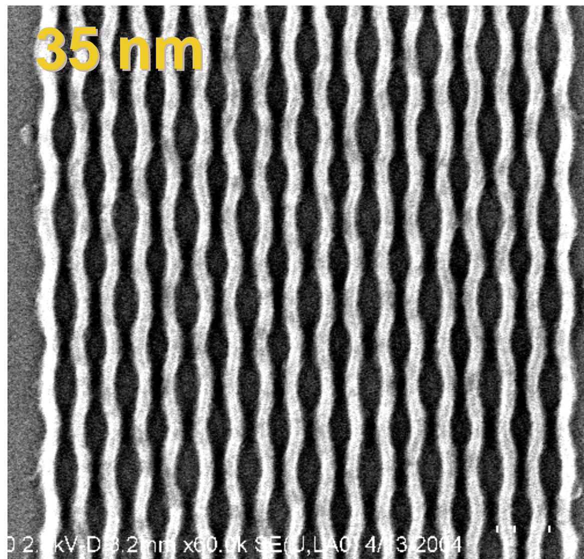


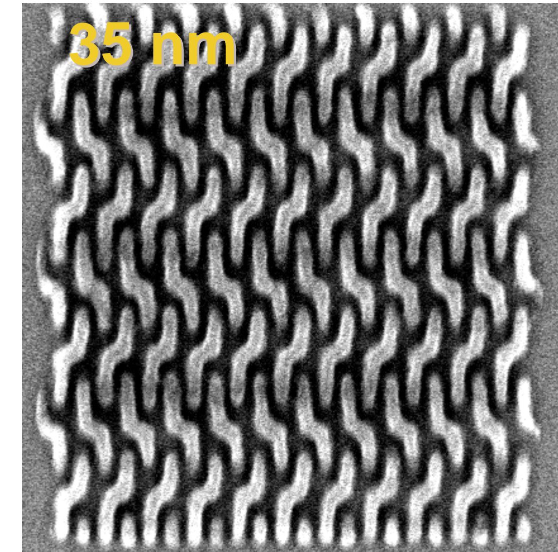


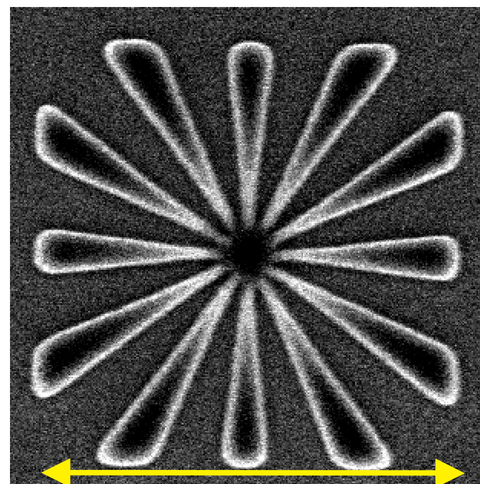
1 μm < Mid-range flare < 100 μm

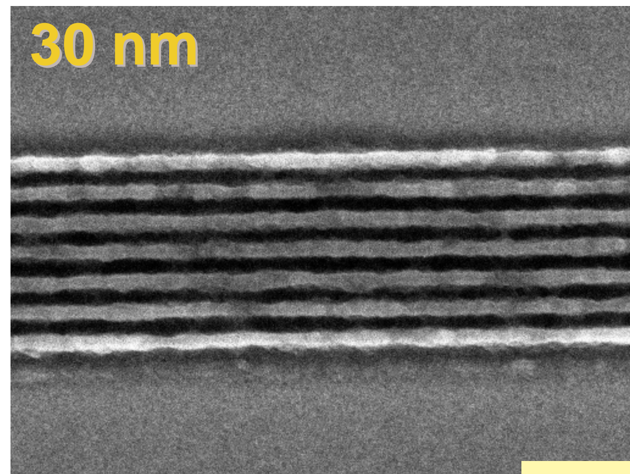
MET 1K resist shows modulation down to the 25-nm level

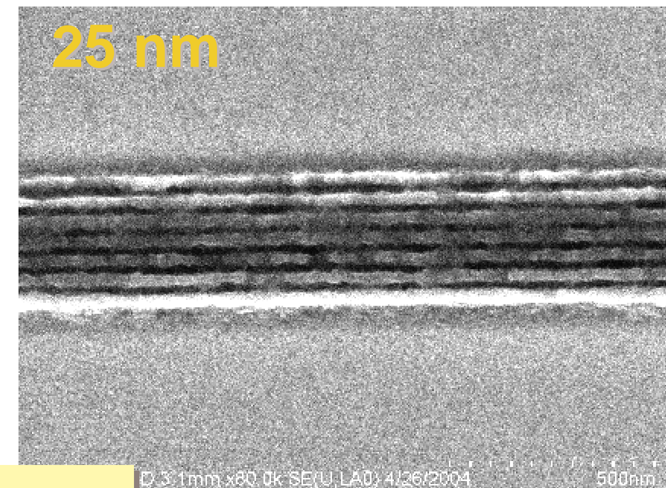












Monopole

Cross Sections of Resist MET 1K (through dose)

	70 nm	60 nm	50 nm	45 nm
21.6 mJ/cm^2				
23.0 mJ/cm^2				
24.3 mJ/cm^2				

Cross-sections obtained at SEMATECH

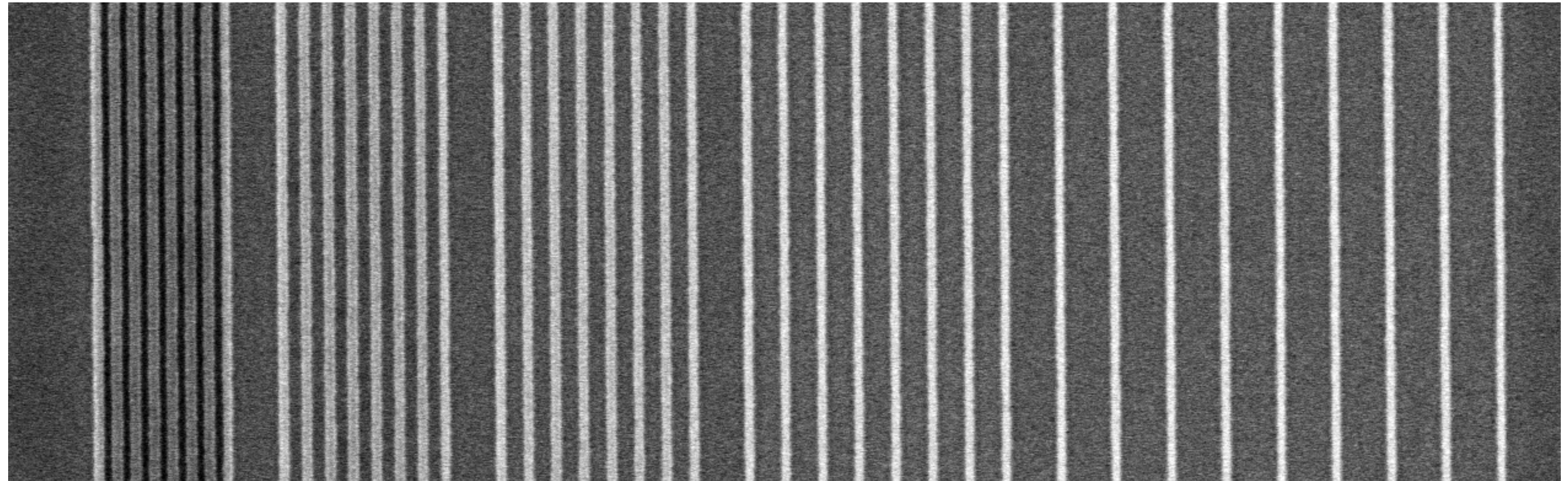
MET 1K process optimization still underway

BERKELEY LAB

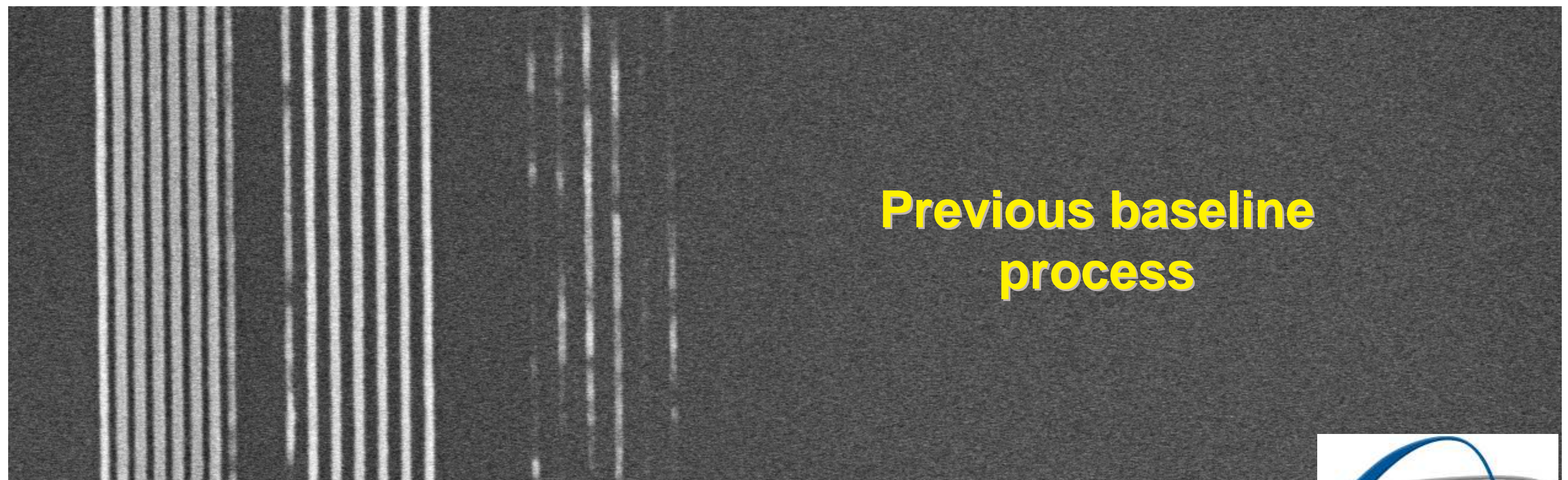
50-nm lines through pitch

1:1 1:1.5 1:2 1:3 1:5

SB=120°
PEB=120°

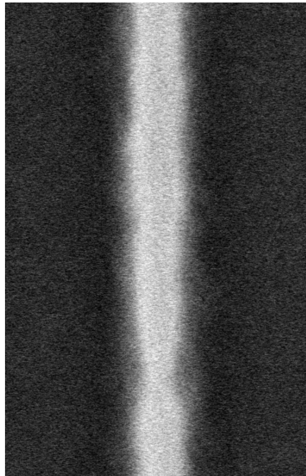


SB=130°
PEB=130°



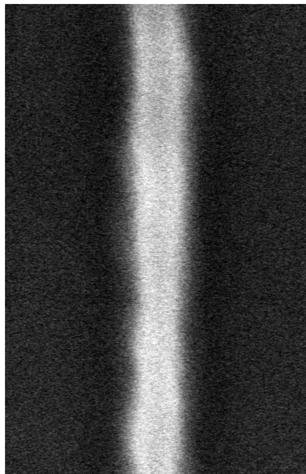
New process enables low-LER sub-30-nm isolated lines in MET 1K resist

LER values are single sided 3σ including periods up to 4x the CD



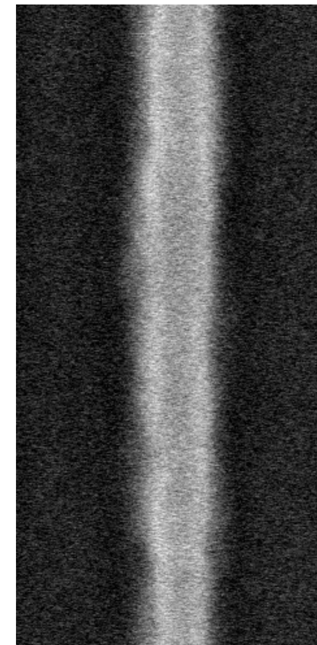
SB = 130°
PEB = 120°

CD = 28.3 nm
LER = 4.2 nm



SB = 120°
PEB = 120°

CD = 28.8 nm
LER = 3.2 nm



SB = 130°
PEB = 130°

CD = 38.6 nm
LER = 4.2 nm

Phase defect printability of isolated 2.5-nm bumps at multilayer surface

Substrate defects fabricated by D. Olynick, LBNL, Multilayer smoothing deposition provided by E. Spiller, LLNL

Summary

- MET at Berkeley operational since February 2004
- System includes programmable coherence illuminator
- Approximately 100 resists and 9 reticles tested to date
- Hypothesized resolution limit of EUV 2D verified
- 25-nm nested and isolated printing demonstrated in chemically-amplified resist
- Full process window characterization of printing in new MET 1K resist completed
- Brightfield to darkfield process window comparison verifies that mid-range flare is not an issue
- Cross-field aberration studies underway
- Defect printability studies underway