Title
Benchmarking commercial EUVL resists at SEMATECH

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Publication Date
2008-03-31

Benchmarking Commercial EUVL Resists at SEMATECH

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SPIE-2008
Feb. 28, 2008

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Outline

- Introduction
- Objective
- Methodology
- Benchmarking Data
- Summary

Introduction

- Extreme ultraviolet lithography (EUVL) is one of the leading candidates for next generation lithography technology for the 32 nm HP and beyond.
- The availability of EUV resists is one of the most significant challenges facing its commercialization.
- To accelerate EUV resist development, SEMATECH provides access to two exposure tools:
    - The EUV Resist Test Center (RTC) at SEMATECH at the University at Albany, SUNY, NY.
    - The SEMATECH microexposure tool (ALS-MET) at Lawrence Berkeley National Laboratory (LBNL).
- The results presented here were collected on the SEMATECH Berkeley MET with the same illumination and resist thickness.

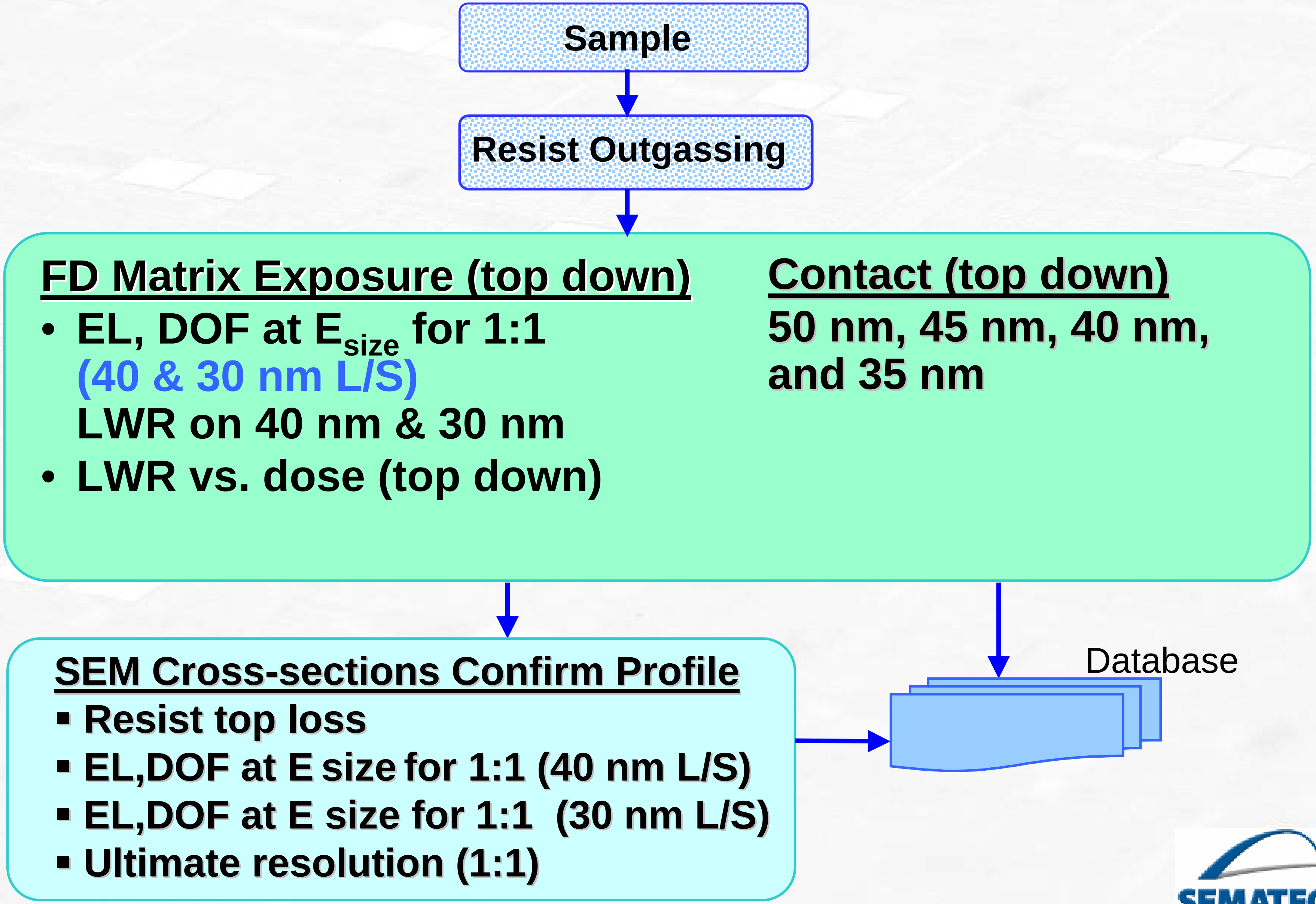
Objective

- Evaluate resist samples from commercial suppliers with well defined protocols and specification targets.
  - Provide suppliers with a benchmarking data package using a consistent protocol for feedback and improvement.
  - Focus on resolution, LWR, and photospeed.

Specifications	2007 Goals
Resolution lines1:1 (nm)	32
Resolution lines 1:5 (nm)	25
Resolution contact holes 1:1 (nm)	45
Resolution contact holes 1:5 (nm)	45
Low frequency LWR (nm, 3 σ)	<2.5
Photospeed, EUV (mJ/cm^2)	10
Outgassing (molecules/cm^2)	6.5E+14

Assumptions: Resolution results confirmed with cross-sectional SEM. Resolution targets can be met with Y-monopole illumination. Photospeed target is for 1:1 lines. Outgassing spec is for 35-200 AMU excluding 44 AMU.

Resist Benchmarking Protocol Procedure



Sample

Resist Outgassing

FD Matrix Exposure (top down)

- **EL, DOF at E_{size} for 1:1 (40 & 30 nm L/S) LWR on 40 nm & 30 nm**
- **LWR vs. dose (top down)**

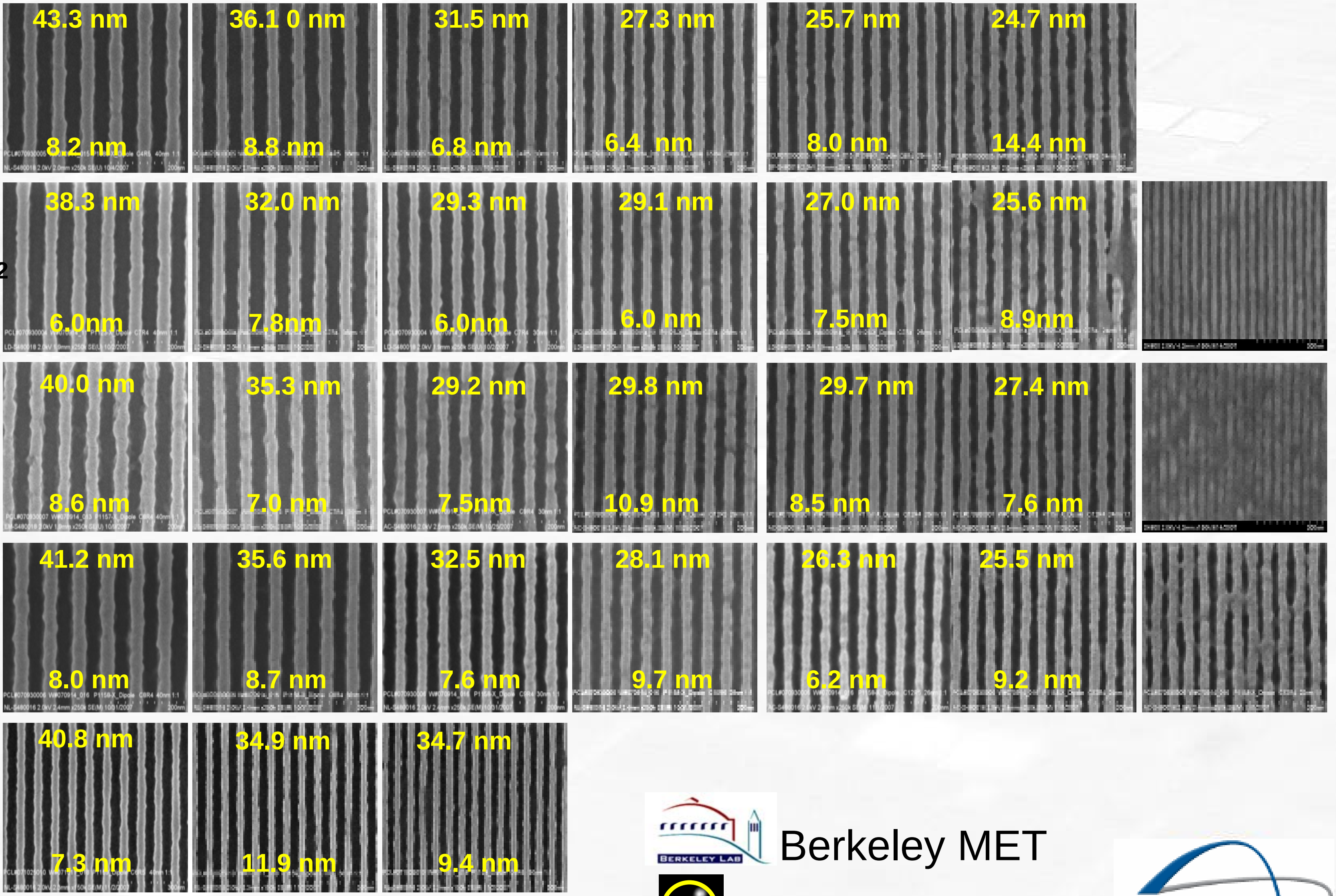
Contact (top down)

50 nm, 45 nm, 40 nm, and 35 nm

SEM Cross-sections Confirm Profile

- **Resist top loss**
- **EL,DOF at E size for 1:1 (40 nm L/S)**
- **EL,DOF at E size for 1:1 (30 nm L/S)**
- **Ultimate resolution (1:1)**

SEM Top View



	40 nm HP	36 nm HP	30 nm HP	28 nm HP	26 nm HP	24 nm HP	22 nm HP
Resist A **20.7 mJ/cm²**	43.3 nm 8.2 nm	36.1 0 nm 8.8 nm	31.5 nm 6.8 nm	27.3 nm 6.4 nm	25.7 nm 8.0 nm	24.7 nm 14.4 nm	
Resist B **16.15 mJ/cm²**	38.3 nm 6.0nm	32.0 nm 7.8nm	29.3 nm 6.0nm	29.1 nm 6.0 nm	27.0 nm 7.5nm	25.6 nm 8.9nm	
Resist C **20.0 mJ/cm²**	40.0 nm 8.6 nm	35.3 nm 7.0 nm	29.2 nm 7.5nm	29.8 nm 10.9 nm	29.7 nm 8.5 nm	27.4 nm 7.6 nm	
Resist D **24.3 mJ/cm²**	41.2 nm 8.0 nm	35.6 nm 8.7 nm	32.5 nm 7.6 nm	28.1 nm 9.7 nm	26.3 nm 6.2 nm	25.5 nm 9.2 nm	
Resist E **18.1 mJ/cm²**	40.8 nm 7.3 nm	34.9 nm 11.9 nm	34.7 nm 9.4 nm				

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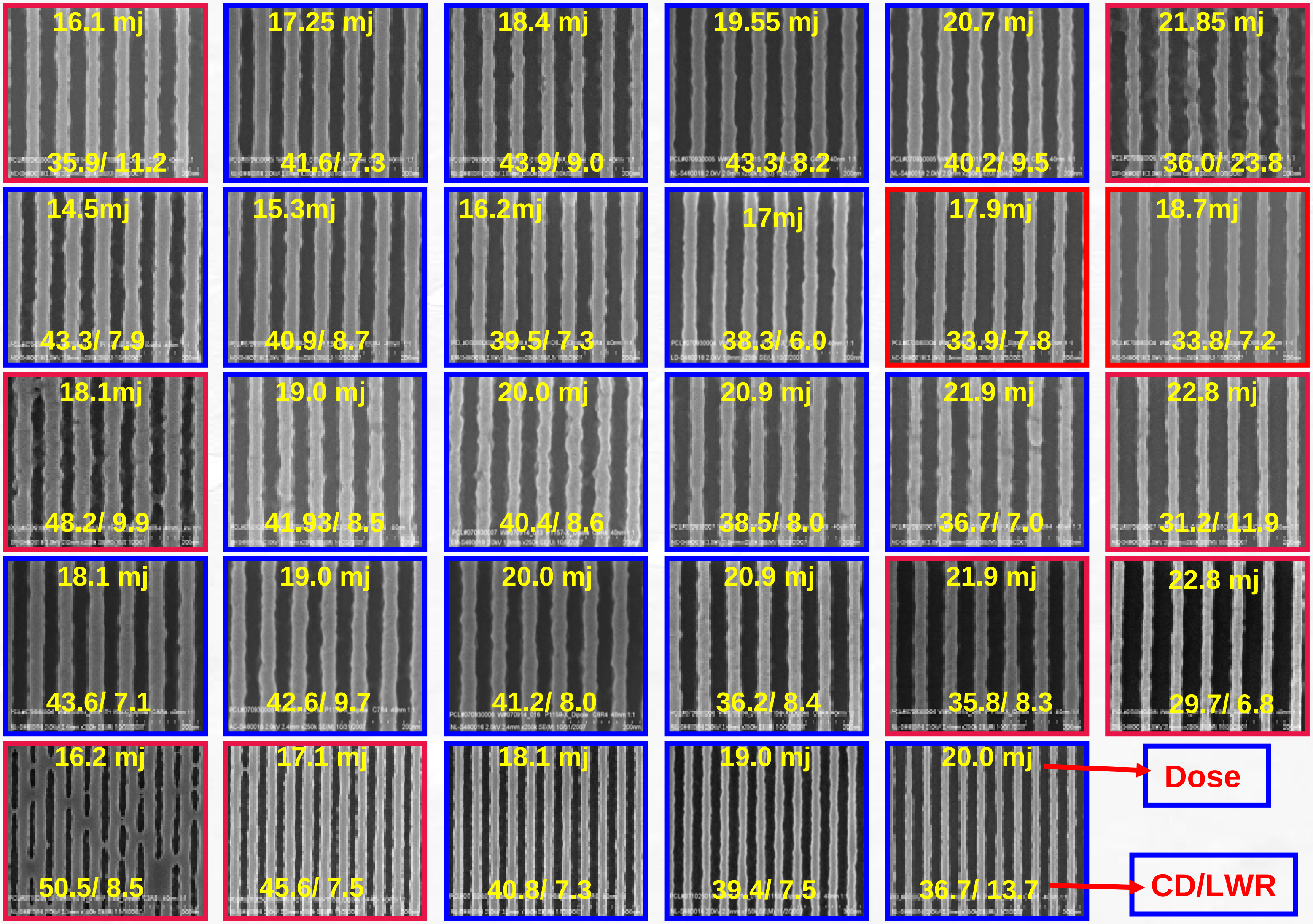
Exposure Latitude (EL) @ 40 nm HP



Resist A Best Focus	16.1 mj 35.9/ 11.2	17.25 mj 41.6/ 7.3	18.4 mj 43.9/ 9.0	19.55 mj 43.3/ 8.2	20.7 mj 40.2/ 9.5	21.85 mj 36.0/ 23.8
Resist B Best Focus	14.5mj 43.3/ 7.9	15.3mj 40.9/ 8.7	16.2mj 39.5/ 7.3	17mj 38.3/ 6.0	17.9mj 33.9/ 7.8	18.7mj 33.8/ 7.2
Resist C Best Focus	18.1mj 48.2/ 9.9	19.0 mj 41.93/ 8.5	20.0 mj 40.4/ 8.6	20.9 mj 38.5/ 8.0	21.9 mj 36.7/ 7.0	22.8 mj 31.2/ 11.9
Resist D Best Focus	18.1 mj 43.6/ 7.1	19.0 mj 42.6/ 9.7	20.0 mj 41.2/ 8.0	20.9 mj 36.2/ 8.4	21.9 mj 35.8/ 8.3	22.8 mj 29.7/ 6.8
Resist E Best Focus	16.2 mj 50.5/ 8.5	17.1 mj 45.6/ 7.5	18.1 mj 40.8/ 7.3	19.0 mj 39.4/ 7.5	20.0 mj 36.7/ 13.7	

Dose

CD/LWR

- Resist A and C demonstrated 15% of EL at 40 nm HP

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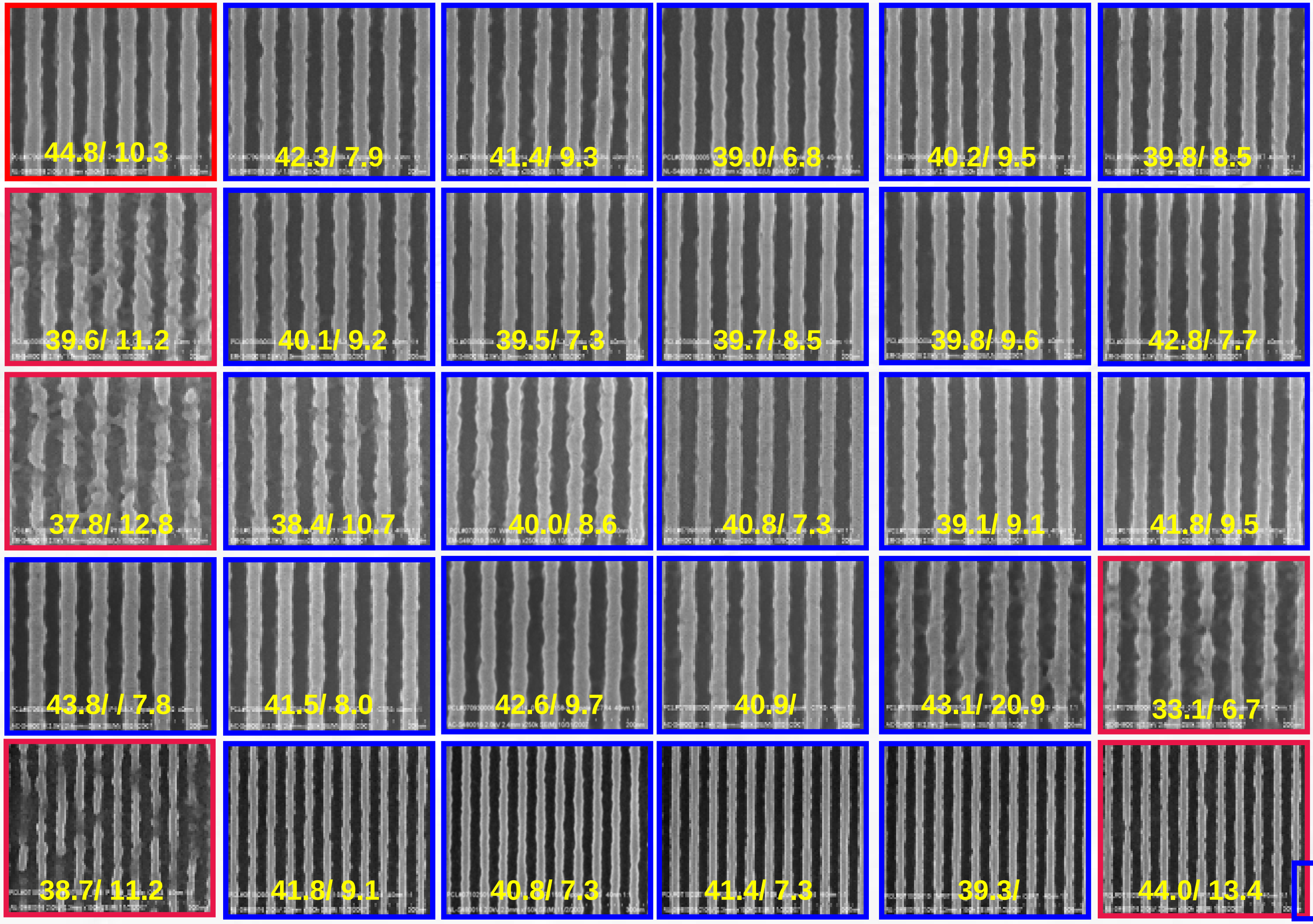
Depth of Focus (DOF) at 40 nm HP



	BF-100 nm	BF-50 nm	Best Focus	BF+50nm	BF+100 nm	BF+150 nm
Resist A **20.7 mJ/cm^2**	44.8/ 10.3	42.3/ 7.9	41.4/ 9.3	39.0/ 6.8	40.2/ 9.5	39.8/ 8.5
Resist B **16.15 mJ/cm^2**	39.6/ 11.2	40.1/ 9.2	39.5/ 7.3	39.7/ 8.5	39.8/ 9.6	42.8/ 7.7
Resist C **20.0 mJ/cm^2**	37.8/ 12.8	38.4/ 10.7	40.0/ 8.6	40.8/ 7.3	39.1/ 9.1	41.8/ 9.5
Resist D **24.3 mJ/cm^2**	43.8/ / 7.8	41.5/ 8.0	42.6/ 9.7	40.9/	43.1/ 20.9	33.1/ 6.7
Resist E **18.1 mJ/cm^2**	38.7/ 11.2	41.8/ 9.1	40.8/ 7.3	41.4/ 7.3	39.3/	44.0/ 13.4

CD/LWR

- **Resist A demonstrated 200 nm of DOF on 40 nm HP**

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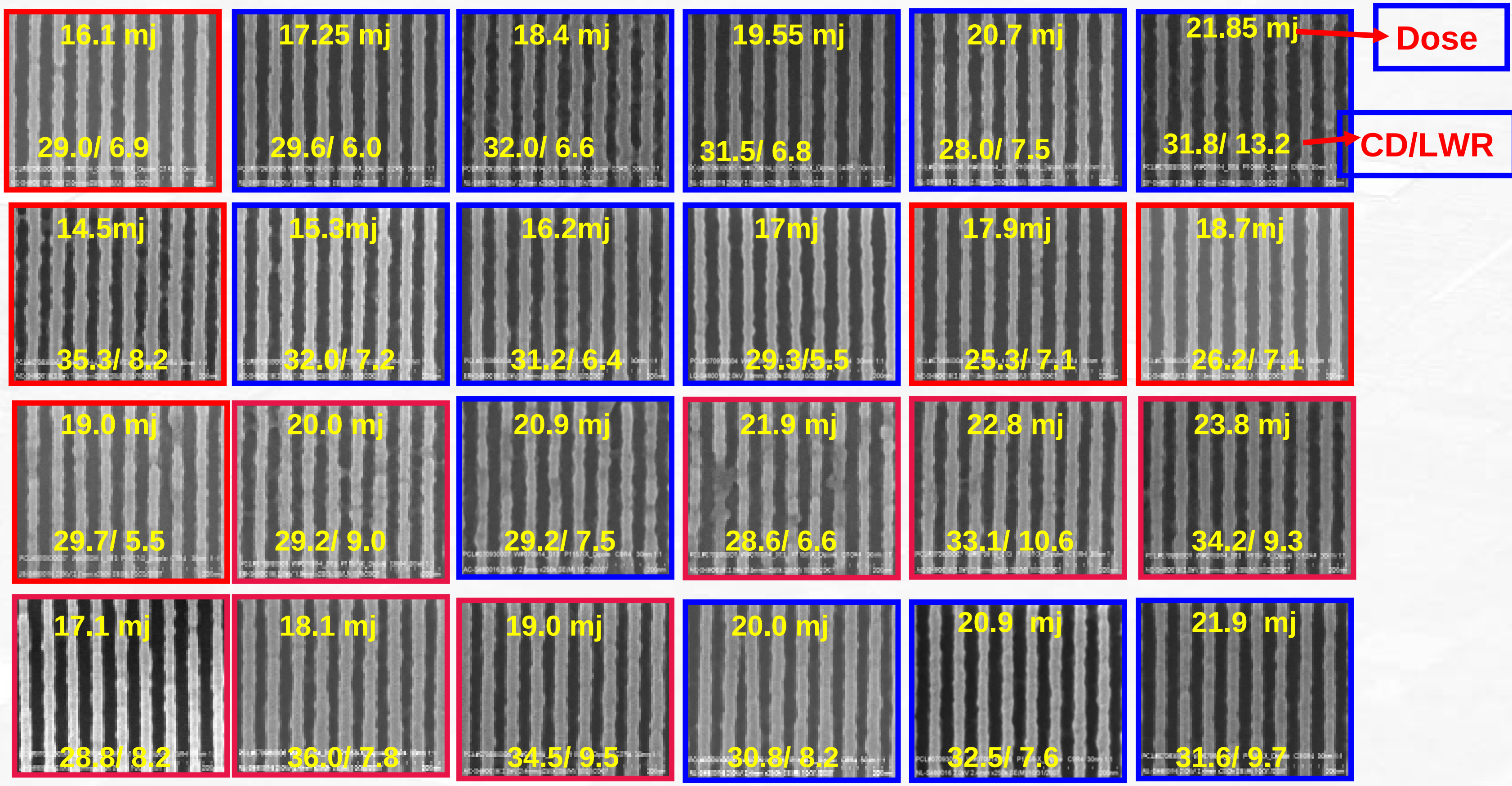
Summary of Dose/Focus Process Latitude at 40 nm HP

Resist Name	Resist THK (nm)	Illumination	Mask	Esize (mJ/cm2)	Exposure Latitude(%)	DoF (nm)	Ultimate Imaging (CD/LWR)
Resist A	50	Rot-Dipole	Horizontal Cleave	20.7	20.0	200	26.5/ 8.5
Resist B	50	Rot-Dipole	Horizontal Cleave	16.15	20.0	200	24.1/ 6.2
Resist C	50	Rot-Dipole	Horizontal Cleave	20.0	20.0	200	29.8/ 8.4
Resist D	50	Rot-Dipole	Horizontal Cleave	19.0	20.0	200	26.3/ 6.2
Resist E	50	Rot-Dipole	Horizontal Cleave	18.1	15.0	150	34.1/ 7.1

- Resist B demonstrated 20% of EL and 200nm of DOF @ 40nm HP with Esize 16.15 mJ/cm^2.

Exposure Latitude (EL) at 30 nm HP



Resist A Best Focus	16.1 mj 29.0/ 6.9	17.25 mj 29.6/ 6.0	18.4 mj 32.0/ 6.6	19.55 mj 31.5/ 6.8	20.7 mj 28.0/ 7.5	21.85 mj 31.8/ 13.2
Resist B Best Focus	14.5mj 35.3/ 8.2	15.3mj 32.0/ 7.2	16.2mj 31.2/ 6.4	17mj 29.3/5.5	17.9mj 25.3/ 7.1	18.7mj 26.2/ 7.1
Resist C Best focus	19.0 mj 29.7/ 5.5	20.0 mj 29.2/ 9.0	20.9 mj 29.2/ 7.5	21.9 mj 28.6/ 6.6	22.8 mj 33.1/ 10.6	23.8 mj 34.2/ 9.3
Resist D Best Focus	17.1 mj 28.8/ 8.2	18.1 mj 36.0/ 7.8	19.0 mj 34.5/ 9.5	20.0 mj 30.8/ 8.2	20.9 mj 32.5/ 7.6	21.9 mj 31.6/ 9.7

- Resist A demonstrated 20.0% of EL at 30 nm HP

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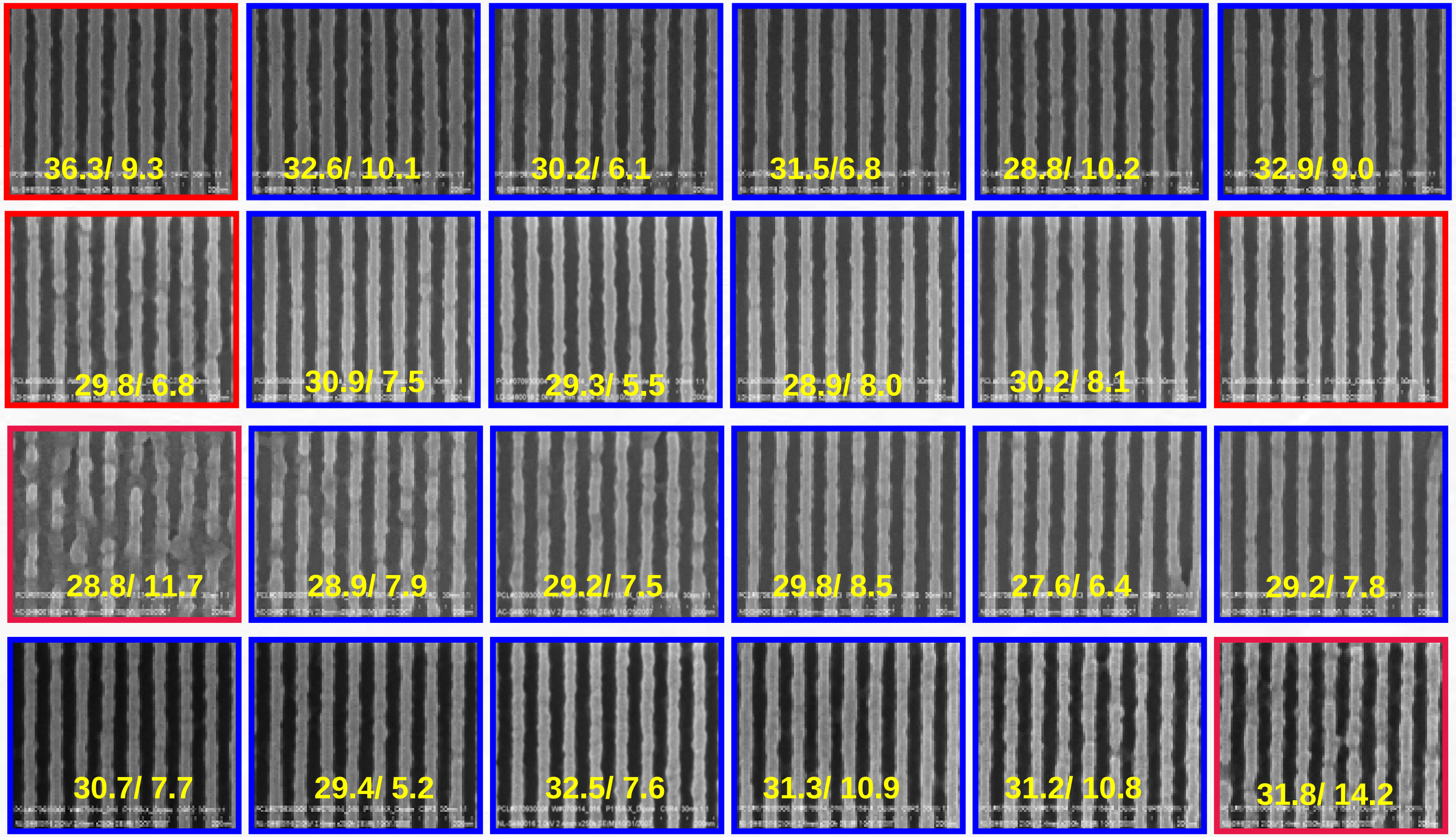
Depth of Focus (DOF) at 30 nm HP



	BF-100 nm	BF-50 nm	Best Focus	BF+50nm	BF+100 nm	BF+150 nm
Resist A **20.7mJ/cm^2**	36.3/ 9.3	32.6/ 10.1	30.2/ 6.1	31.5/6.8	28.8/ 10.2	32.9/ 9.0
Resist B **17 mJ/cm^2**	29.8/ 6.8	30.9/ 7.5	29.3/ 5.5	28.9/ 8.0	30.2/ 8.1	
Resist C **20.9 mJ/cm^2**	28.8/ 11.7	28.9/ 7.9	29.2/ 7.5	29.8/ 8.5	27.6/ 6.4	29.2/ 7.8
Resist D **20.0 mJ/cm^2**	30.7/ 7.7	29.4/ 5.2	32.5/ 7.6	31.3/ 10.9	31.2/ 10.8	31.8/ 14.2

- **Resists A and D demonstrated 200 nm of DOF at 30 nm HP**

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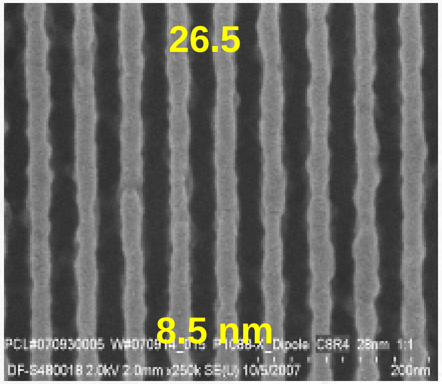
Summary of Dose/Focus Process Latitude at 30 nm HP

Resist Name	Resist THK (nm)	Illumination	Mask	Esize (mJ/cm2)	Exposure Latitude(%)	DoF (nm)	Ultimate Imaging (CD/LWR)
Resist A	50	Rot-Dipole	Horizontal Cleave	20.7	20	200	26.5/ 8.5
Resist B	50	Rot-Dipole	Horizontal Cleave	17.0	10	150	24.1/6.2
Resist C	50	Rot-Dipole	Horizontal Cleave	20.9	2.5	200	29.8/ 8.4
Resist D	50	Rot-Dipole	Horizontal Cleave	20.0	5	200	26.3/ 6.2

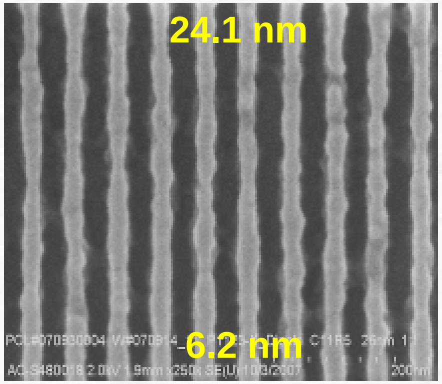
- Resist A demonstrated 20% of EL and 200nm of DOF @ 40nm HP with Esize 20.7 mJ/cm^2.

Top View Images of Lines/Spaces

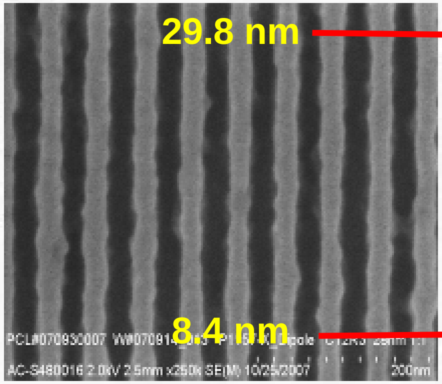
Resist A
28 nm HP



Resist B
26 nm HP



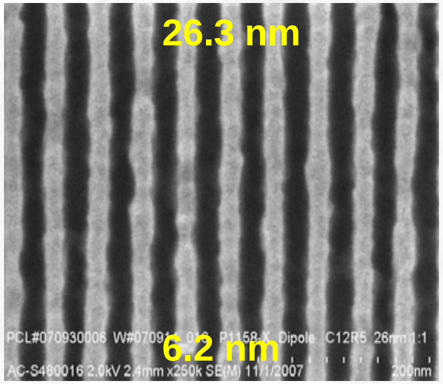
Resist C
28 nm HP



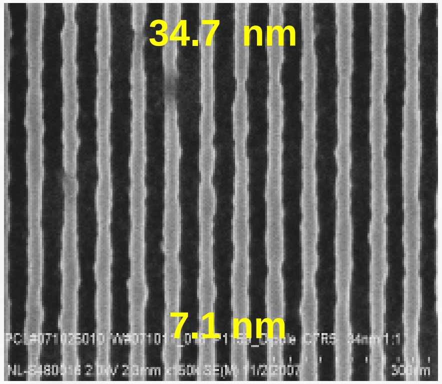
CD

LWR

Resist D
26 nm HP



Resist E
34 nm HP



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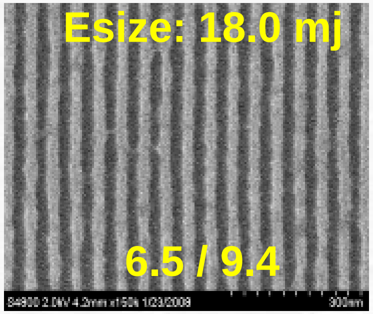
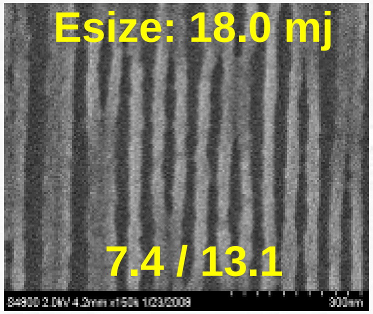
Resist B with under-layer materials resolution image comparison @ 26nm HP

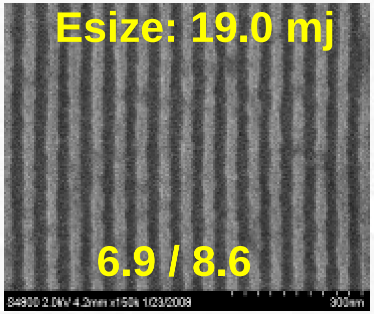
Resist B
w/ HMDS



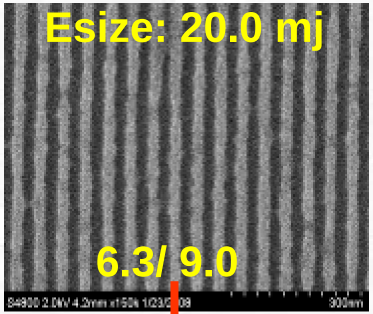
Resist B
w/ under-layer A



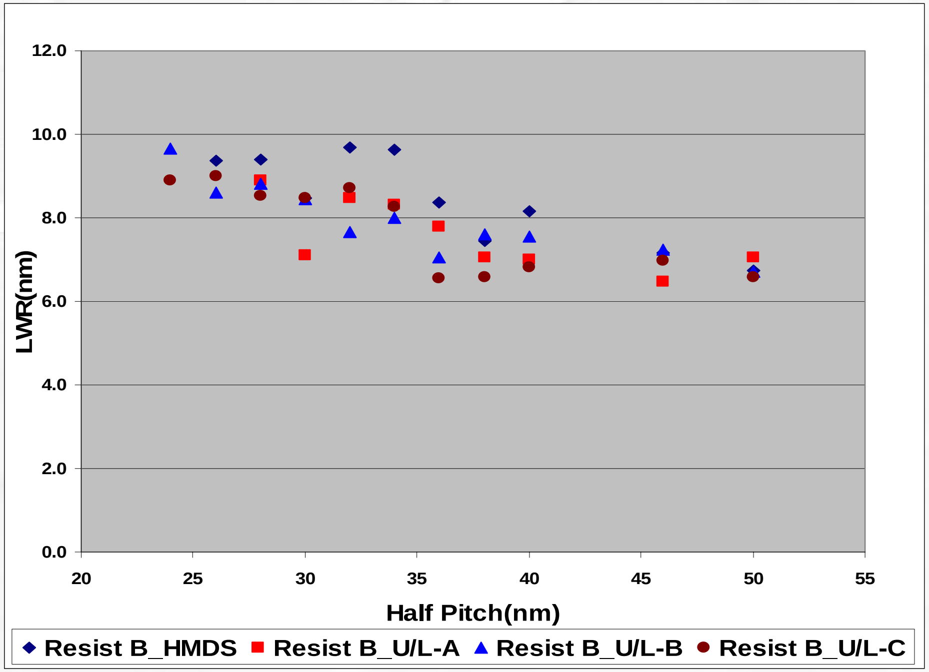
Resist B
w/ under-layer B



Resist B
w/ under-layer C



LER / LWR



- No visible LWR improvement from all under-layer materials, and slightly changed on photospeed.
- Observed resist collapse on under-layer A @26nm HP.

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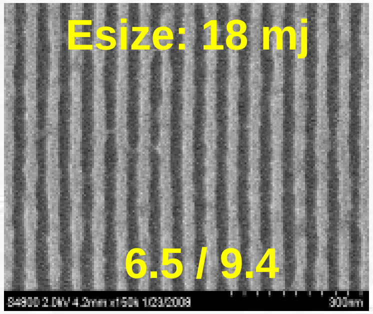
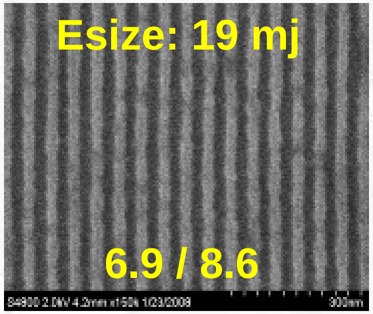
Achieved 3.6 nm of LWR @ 26 nm resolution with PAB/PEB optimization and under-layer material

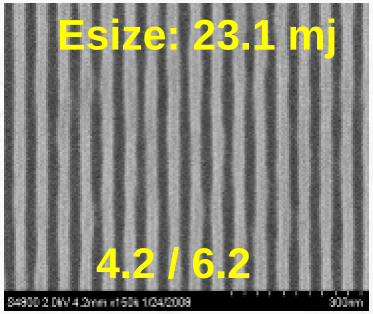
Resist B
w/ HMDS
120C/ 100C



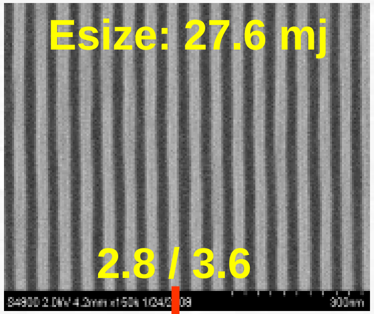
Resist B
w/ under-layer- B
120C/ 100C



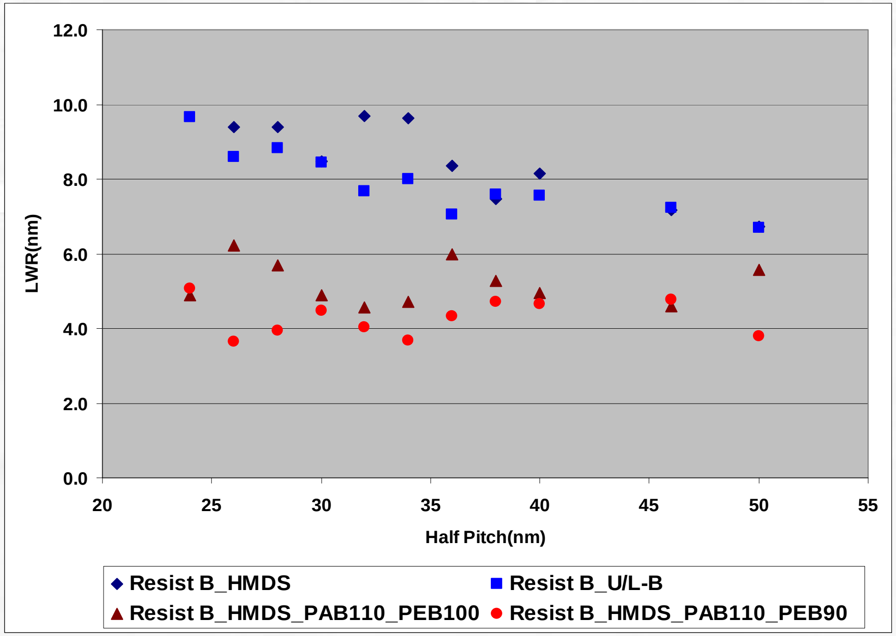
Resist B
w/ under-layer- B
110C/ 100



Resist B
w/ under-layer- B
110C/ 90C



LER / LWR



- **Optimized PAB/PEB temperature with underlayer material improved LWR performance significantly (from 9.4 nm → 3.6 nm) with trade-off lower photospeed which increase Esize by 20%~ 50%**

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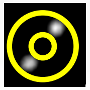

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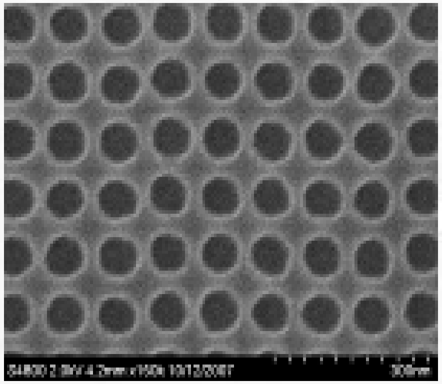
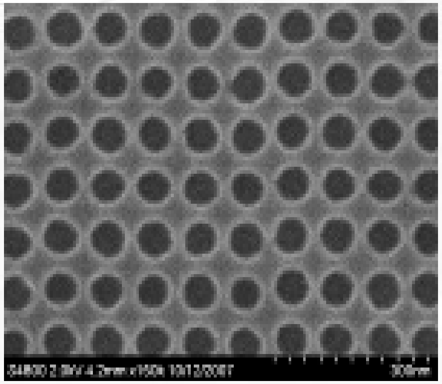
SEM Top-View Images for Contact Holes in Resist B

- Resist B 45 mJ/cm2
- Mask: LBNL mask 2007-02, contact cleave cell

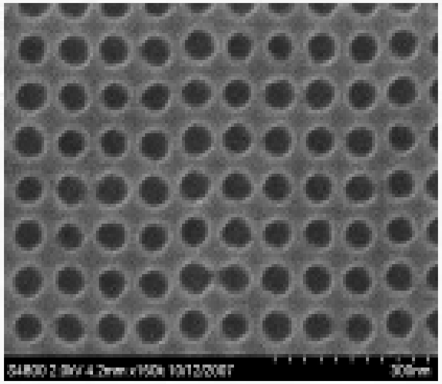
50 nm HP



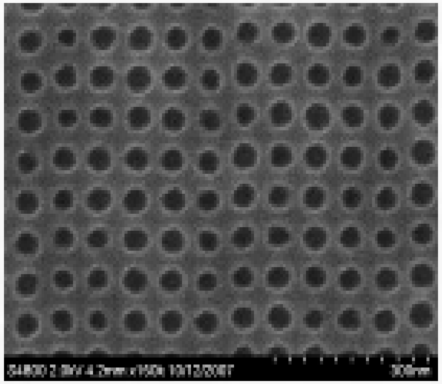
45 nm HP



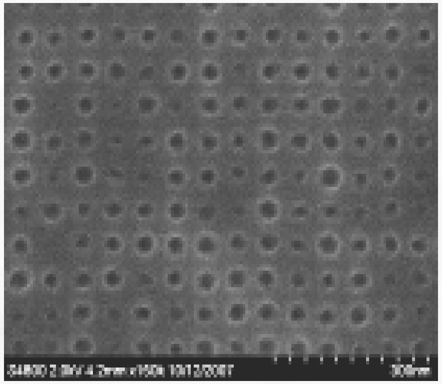
40 nm HP



35 nm HP



30 nm HP



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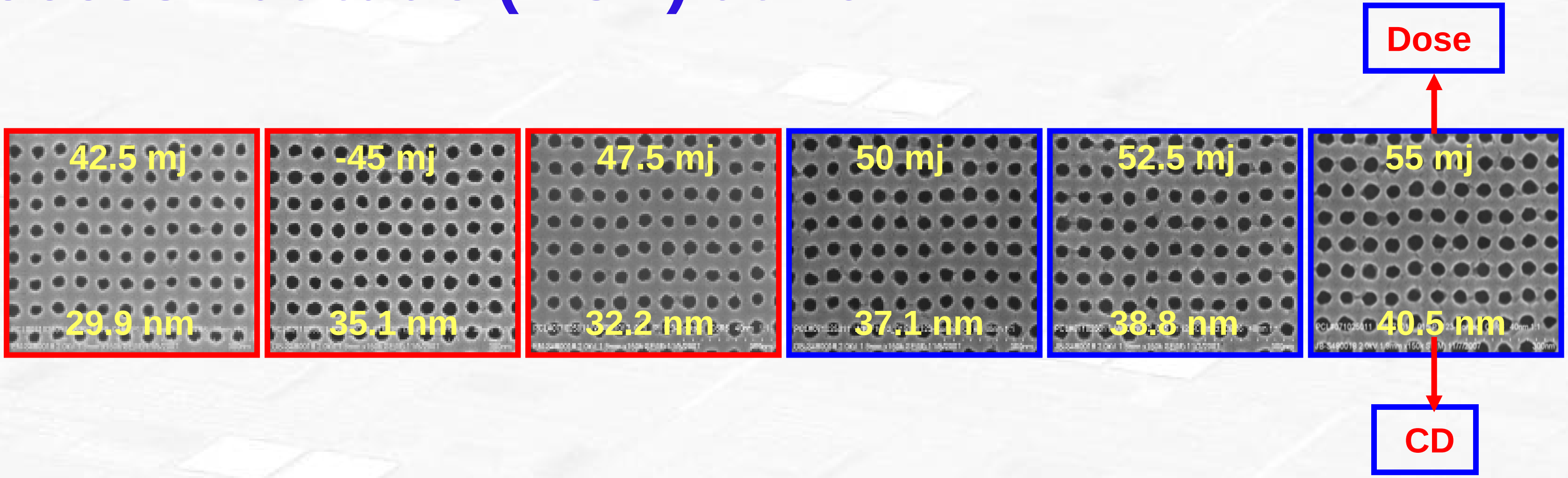
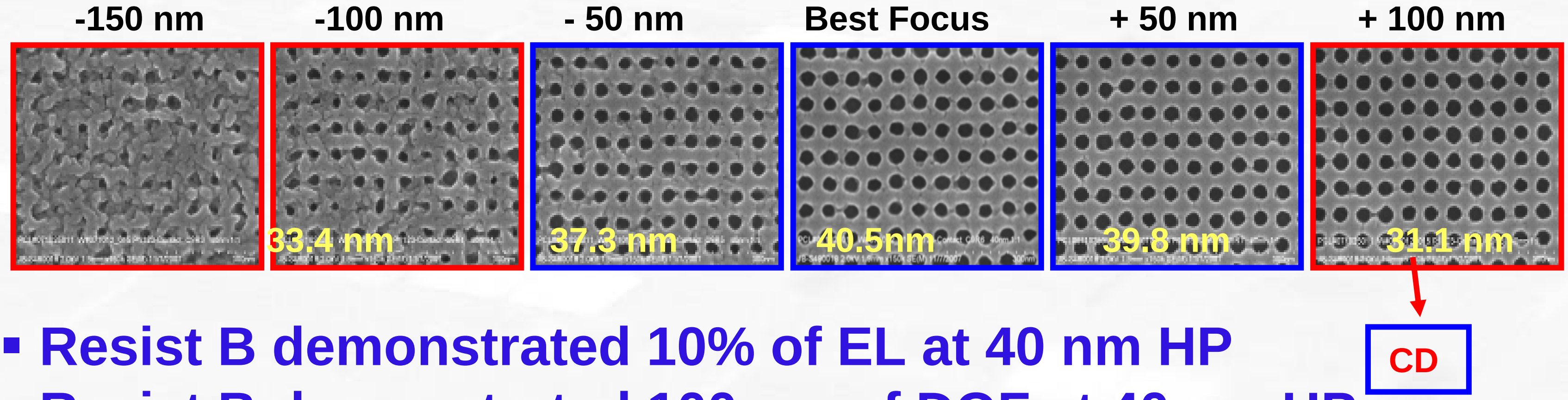
Annular 0.35-0.55

Contact Hole Exposure Latitude (EL) and Focus Process Latitude (DOF) at 40 nm HP

Resist B
Best Focus
EL



Resist B
DOF



- **Resist B demonstrated 10% of EL at 40 nm HP**
- **Resist B demonstrated 100 nm of DOF at 40 nm HP**

Berkeley MET

Annular 0.35-0.55

Benchmarking conclusion (I)

Specifications	2007 Goals	Resist A	Resist B	Resist C	Resist D	Resist E
Resolution lines1:1 (nm)	32	28	26	30	26	32
Low frequency LWR (nm, 3 σ)	<2.5	6.0 @30 nm	5.5 @30 nm	7.5 @30 nm	8.2 @30 nm	N/ A
Photospeed, EUV (mJ/cm2)	10	17.25 @30 nm	17.0 @30 nm	20.9 @30 nm	20.0 @30 nm	N/ A
Outgassing (molecules/cm^2)	6.5E+14	pass	pass	pass	pass	pass

- Best process latitude @ 30-nm HP
  - Resist A: 200 nm DOF @ 20.0% EL
- Best LWR
  - Resist B: 5.5 nm (still ~ 2.2X larger than requirement)
  - 3.6 nm achieved @ 26nm HP (optimized PAB/PEB/BARC)
- Fastest resist with reasonable process latitude @ 30-nm HP
  - Resist B: 17mJ/cm2
- Best resolution
  - Resist A and B: 22 nm printing with rotated-dipole

Benchmarking conclusion (II)

- Imaging resolution meets 30 nm HP goal
  - 200-nm DOF @ 20% EL with Resist A
- LER/LWR remains primary challenge to meet needs for 32 nm HP pilot lines.
- Reasonable process latitude demonstrated for 40-nm contact holes
- 35 nm contact hole printing demonstrated
  - High dose requirements (55 mJ/cm2) indicate major effort needed to meet 32 nm HP pilot line needs

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Acknowledgement:

SEMATECH: Matt Malloy and RTC staff for processing support.

ATDF: Don Frohock, Laurie Dennig, Emily Morales, and Arthur Calderon for their SEM support.

LBNL: Brian Hoef, Gideon Jones, Paul Denham, Chris Anderson, Jerrin Chiu, Ken Goldberg, and Dimitra Niakoula for MET support.