Benchmarking Commercial EUVL Resists at SEMATECH

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Outline

- Introduction
- Objective
- Methodology
- Benchmarking Data
- Summary

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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.

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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.

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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)

→ Database

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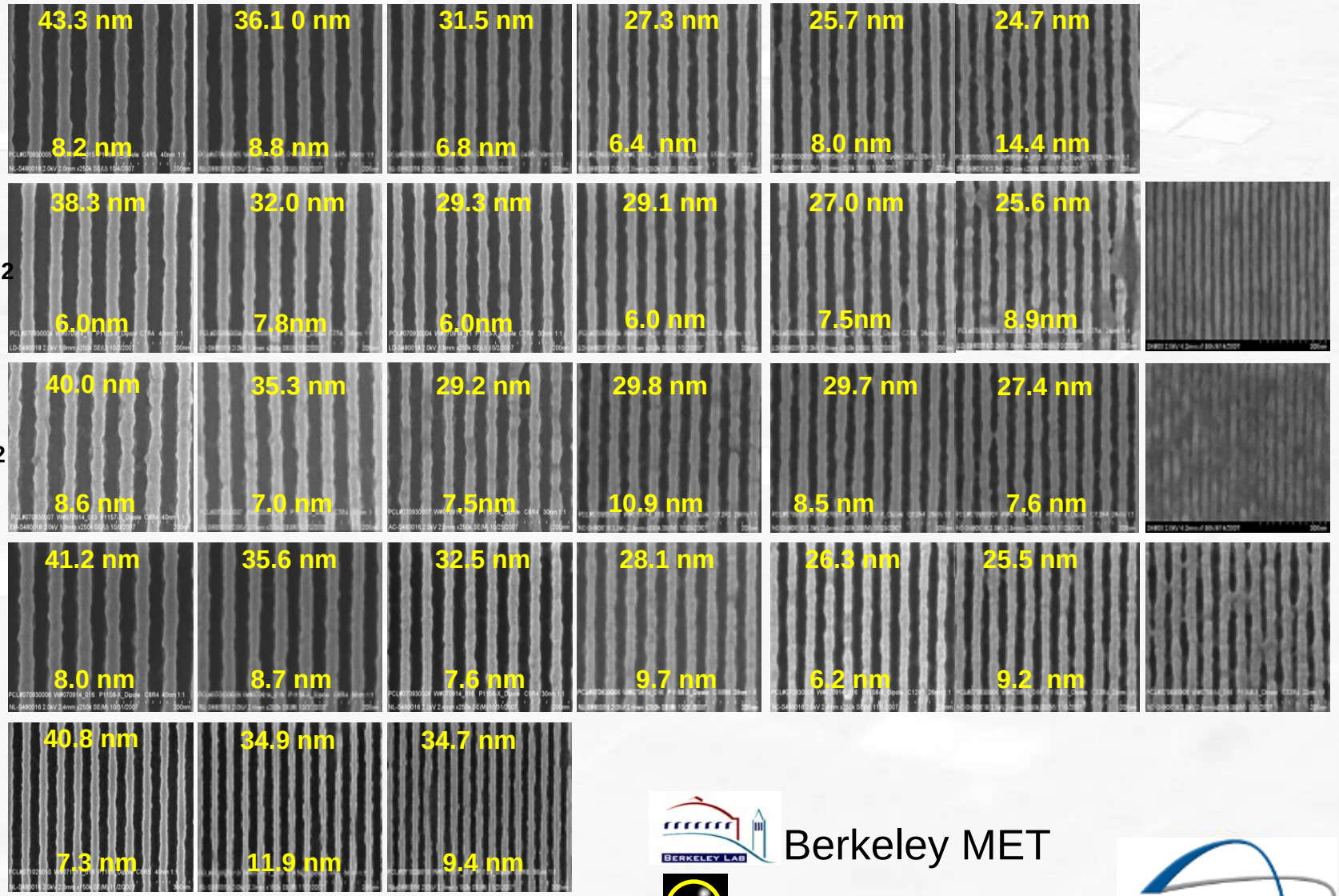
SEM Top View

	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/cm^2	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/cm^2	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/cm^2	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/cm^2	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/cm^2	40.8 nm / 7.3 nm	34.9 nm / 11.9 nm	34.7 nm / 9.4 nm				



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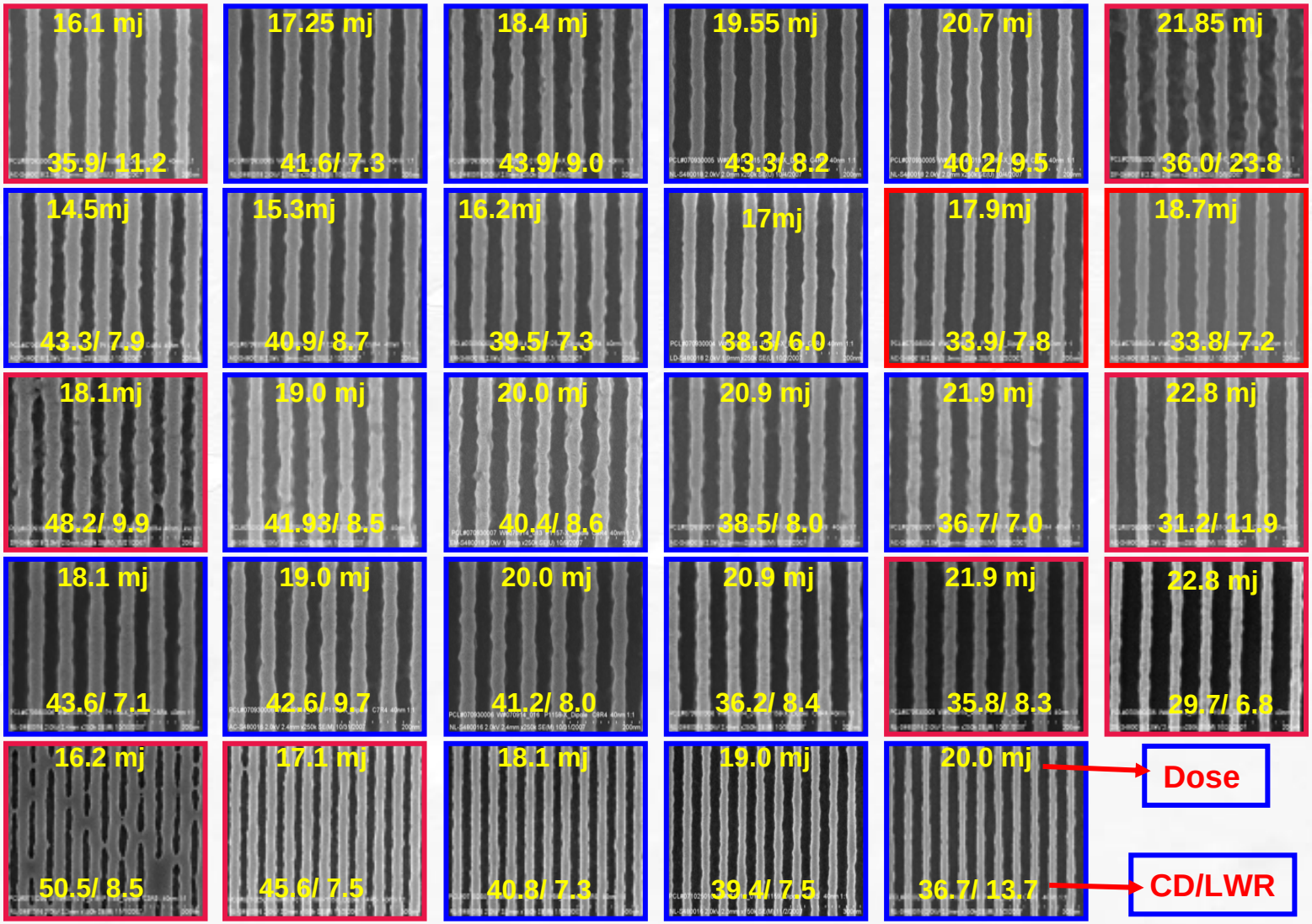
Exposure Latitude (EL) @ 40 nm HP



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

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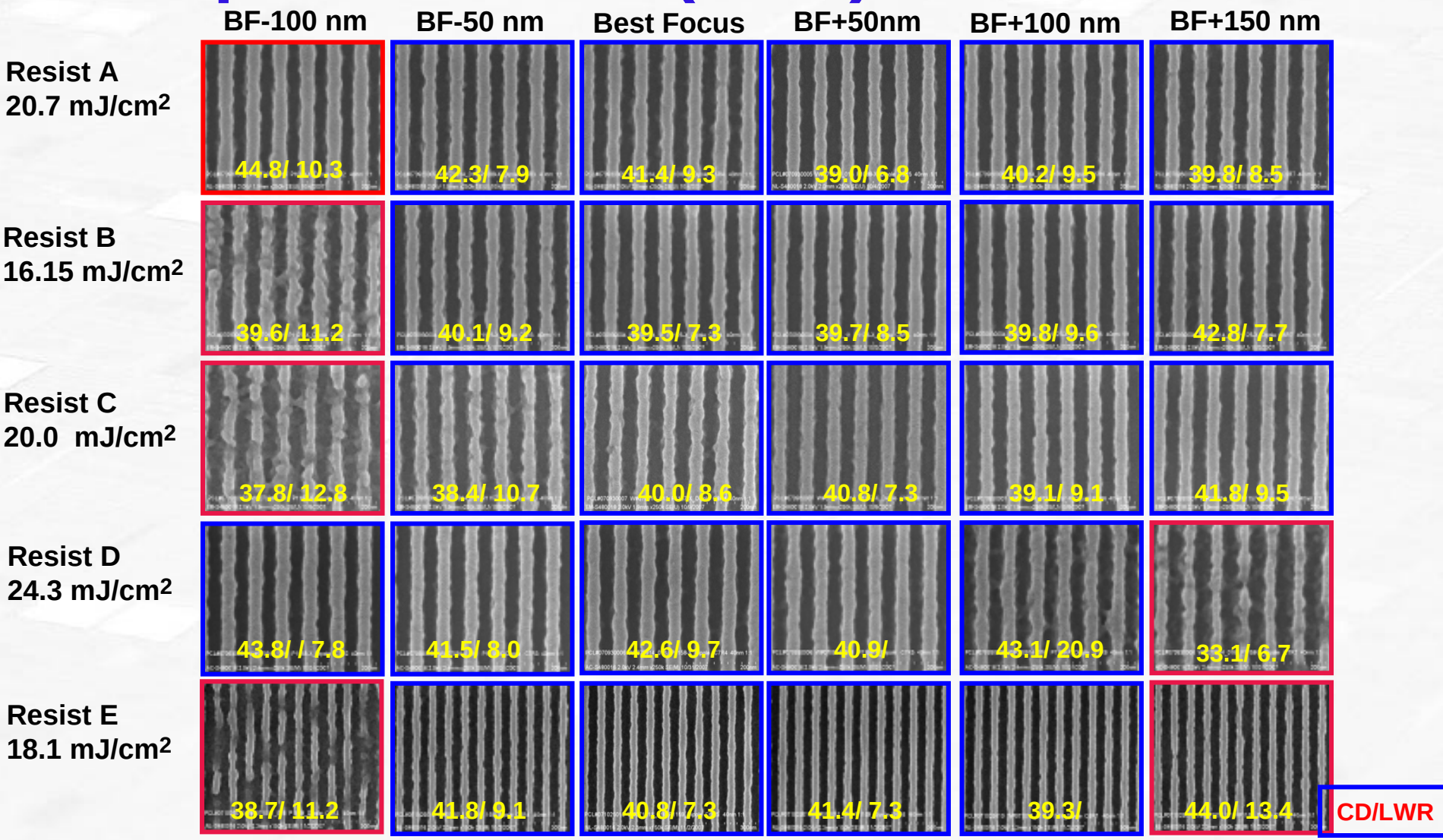
Depth of Focus (DOF) at 40 nm HP



- **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.**

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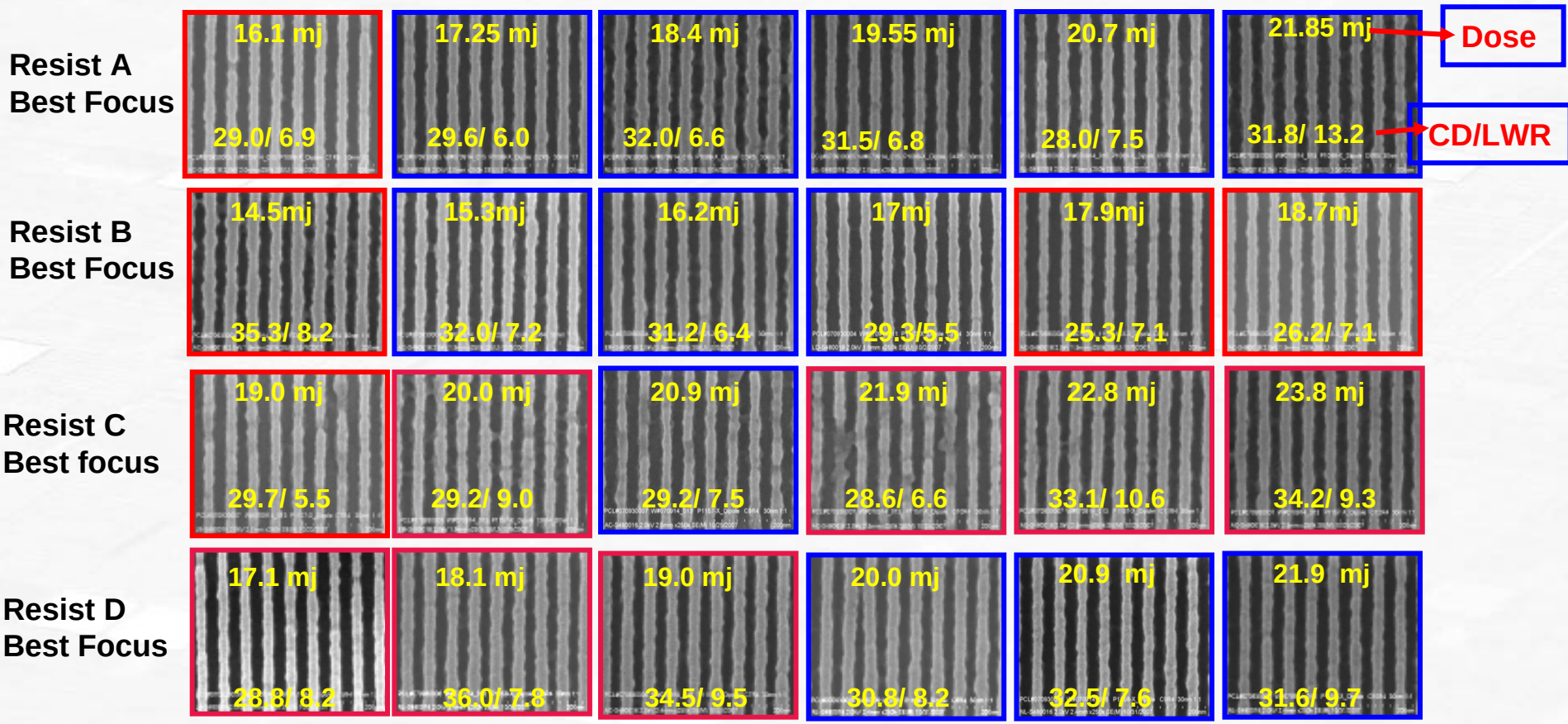
Exposure Latitude (EL) at 30 nm HP



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

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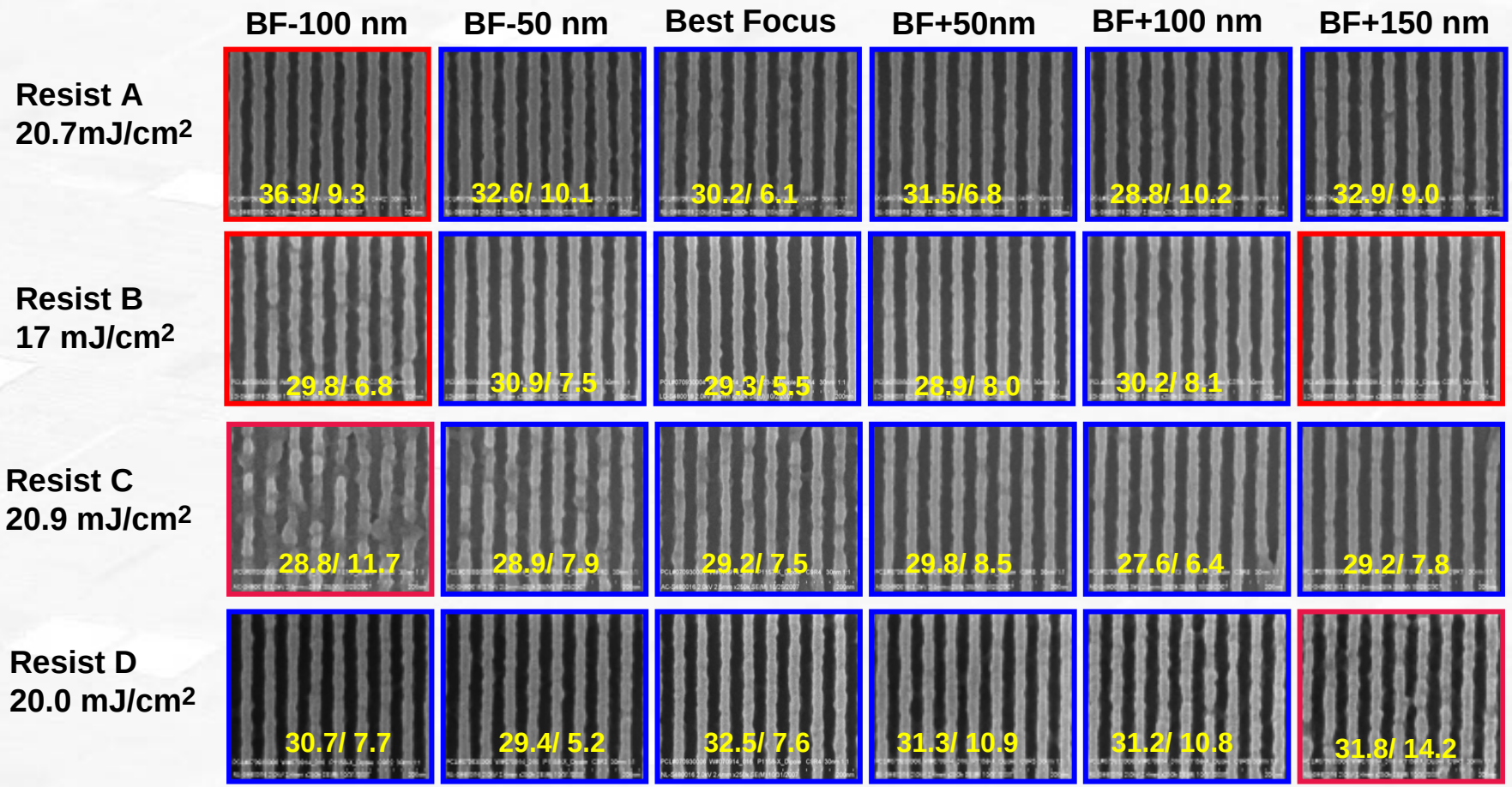
Depth of Focus (DOF) at 30 nm HP



- **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.**

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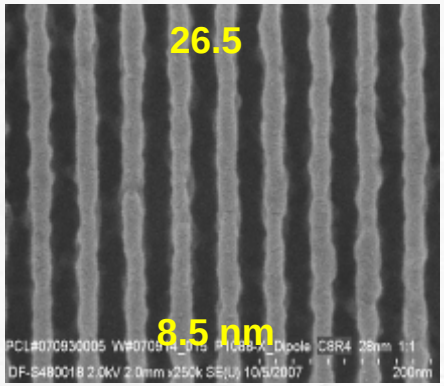
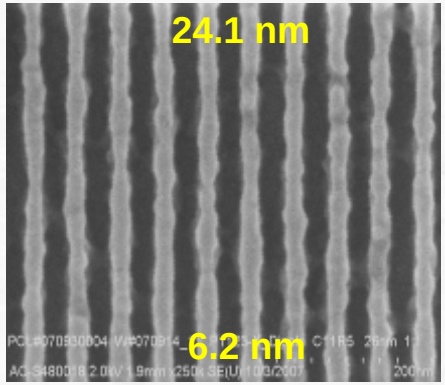
Top View Images of Lines/Spaces

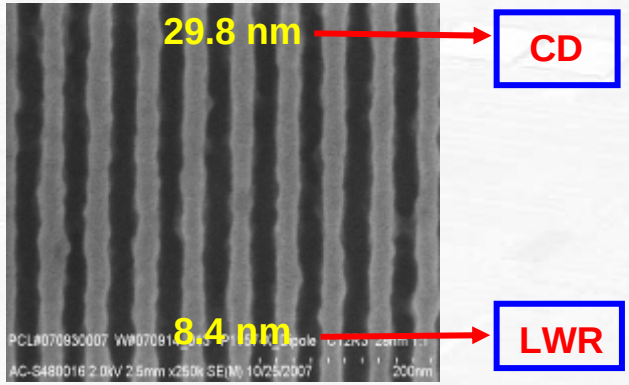
Resist A
28 nm HP



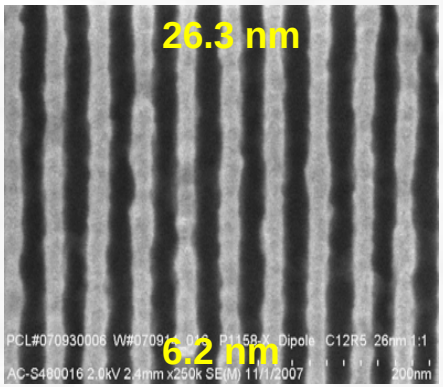
Resist B
26 nm HP



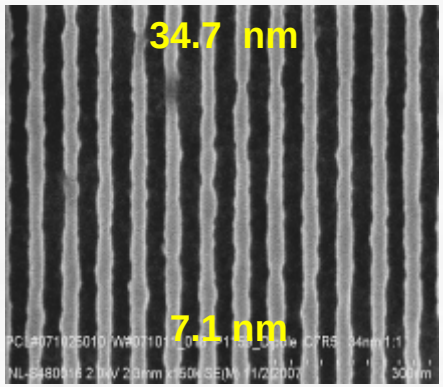
Resist C
28 nm HP



Resist D
26 nm HP



Resist E
34 nm HP



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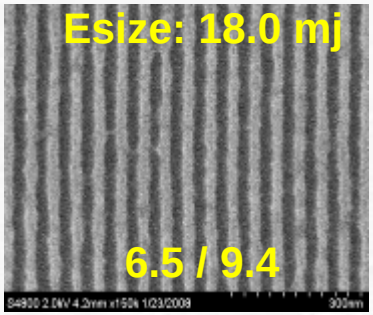
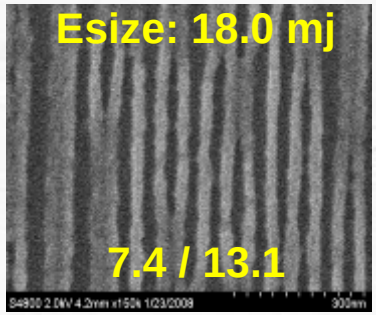
Resist B with under-layer materials resolution image comparison @ 26nm HP

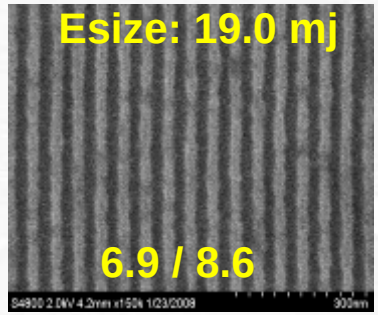
Resist B w/ HMDS



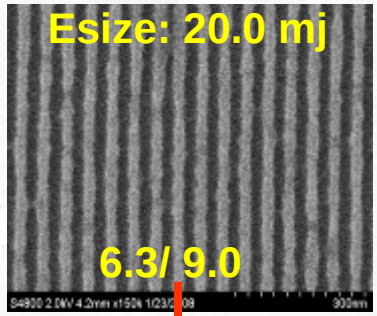
Resist B w/ under-layer A



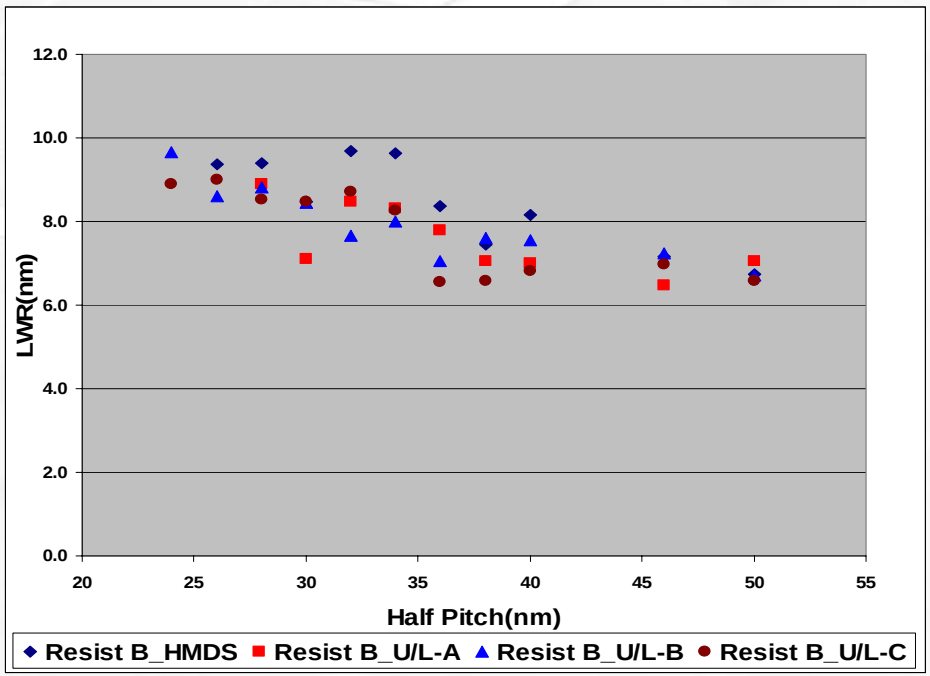
Resist B w/ under-layer B



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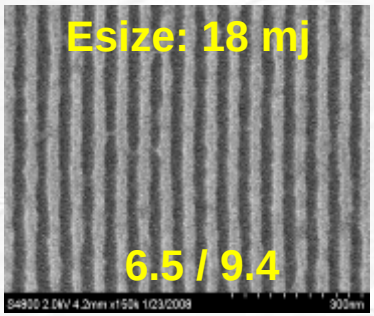
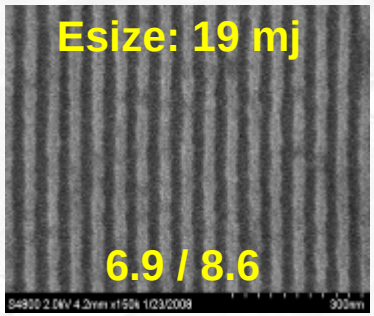
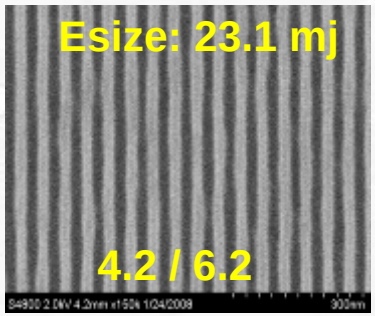
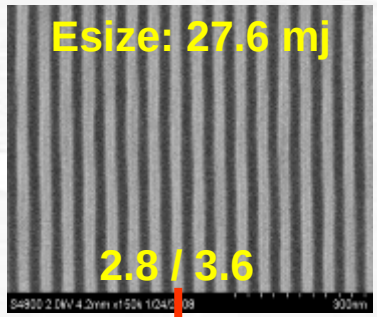
Achieved 3.6 nm of LWR @ 26 nm resolution with PAB/PEB optimization and under-layer material

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
Esize: 18 mj	Esize: 19 mj	Esize: 23.1 mj	Esize: 27.6 mj
6.5 / 9.4	6.9 / 8.6	4.2 / 6.2	2.8 / 3.6

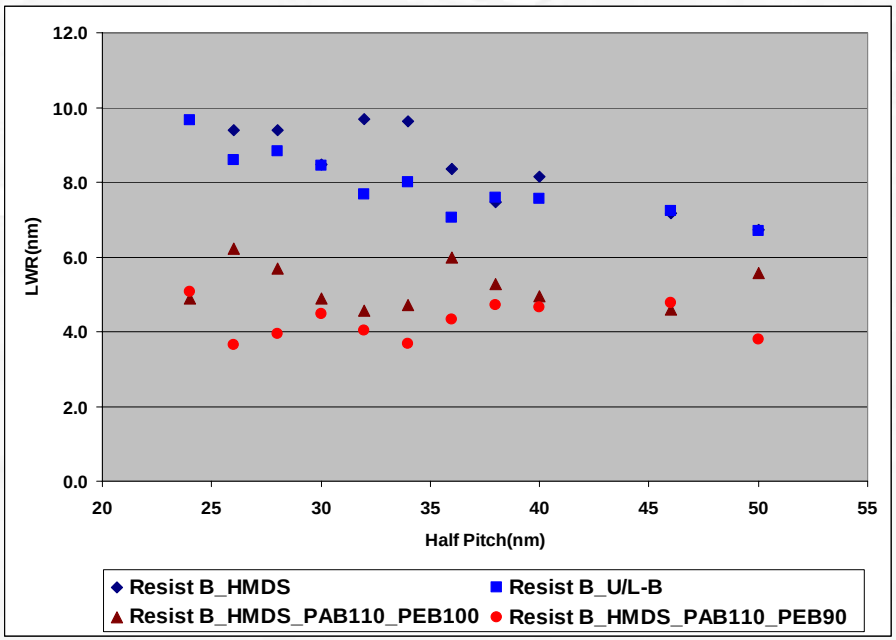








LER / LWR



- **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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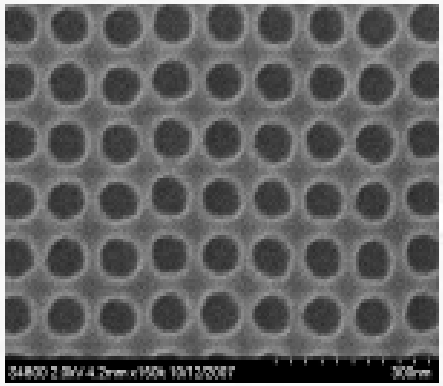
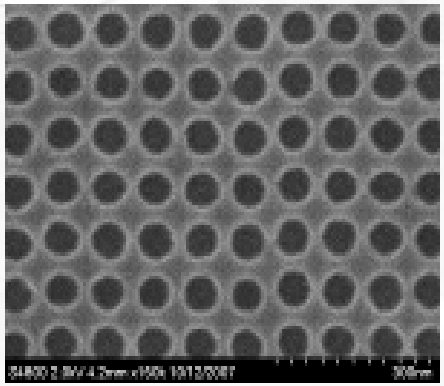
SEM Top-View Images for Contact Holes in Resist B

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

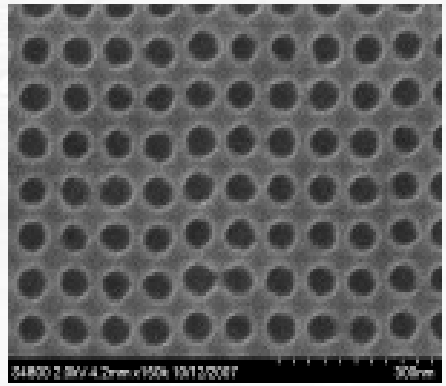
50 nm HP



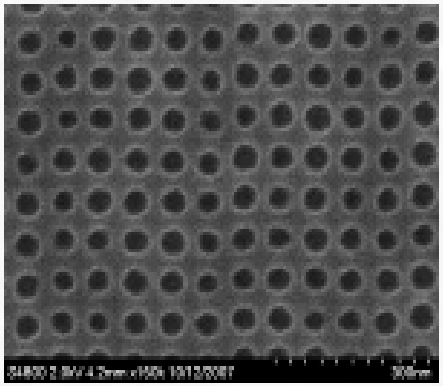
45 nm HP



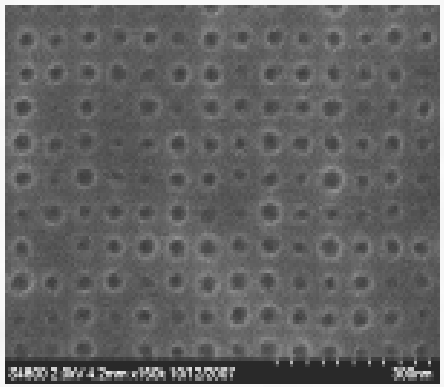
40 nm HP



35 nm HP



30 nm HP



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Annular 0.35-0.55

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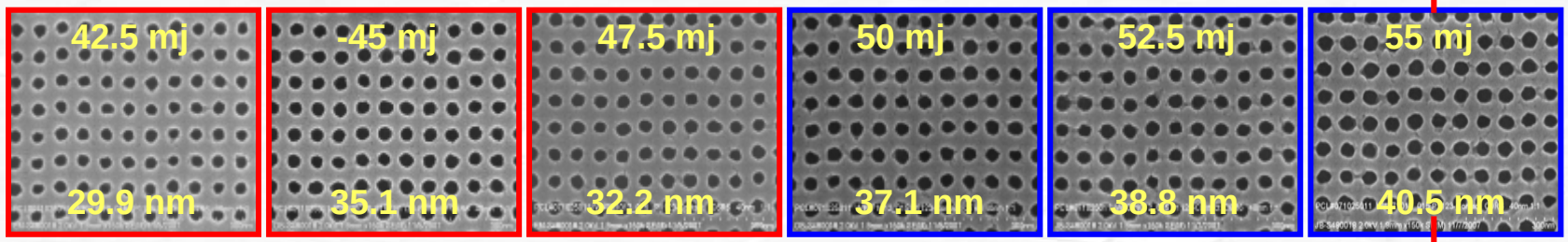
Contact Hole Exposure Latitude (EL) and Focus Process Latitude (DOF) at 40 nm HP

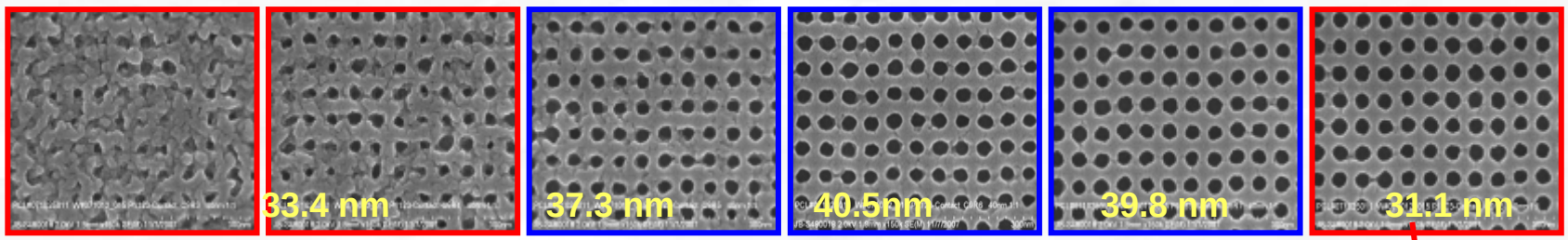
Dose

Resist B Best Focus EL



CD

Resist B DOF



CD

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

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Annular 0.35-0.55

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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

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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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