Imaging Capability of EUV Photoresists: Contact Holes, Lines and Spaces

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INVENT

Outline

I. Introduction

II. EUV resist line/space evaluations

III. EUV resist contact hole evaluations

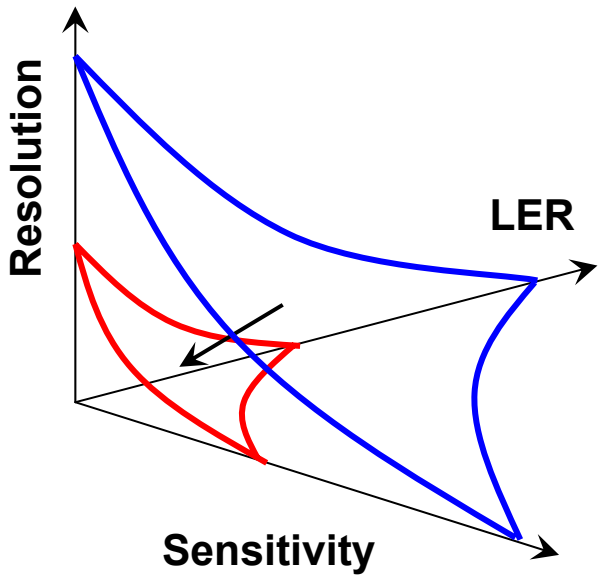
IV. CNSE/ASML alpha tool results

V. Summary

VI. Acknowledgements

I. Introduction

International Nanoelectronics VENTure (INVENT) is a program with IBM, AMD, Qimonda, Micron & CNSE that focuses on 193 nm immersion and EUV technology development.



INVENT EUV R&D Resist Goals

Lines/Spaces:

Resolution (nm)	LER (nm 3σ)	Sensitivity (mJ/cm^2)
32	<2.5	5-15

Contact Holes:

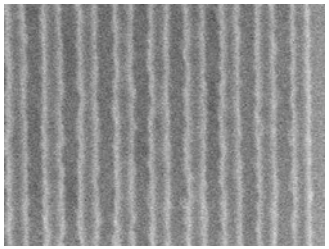
Resolution (nm)	Sensitivity (mJ/cm^2)
32	~2x L/S dose*

*For general L/S and CH resist

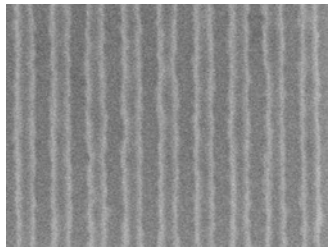
LWR values are converted to LER assuming

LER = LWR/√2 and shown in (parenthesis).

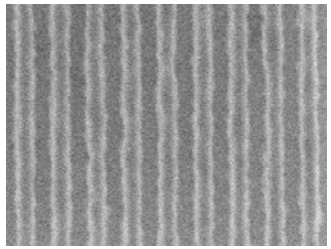
II. Resist A: 40 nm L/S Through Dose For Good Sensitivity Resist



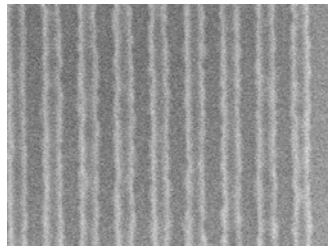
12.0 mJ/cm2



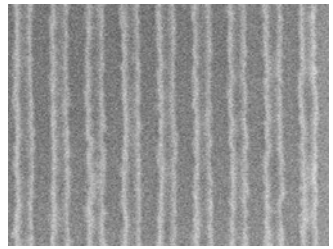
12.7 mJ/cm2



13.3 mJ/cm2

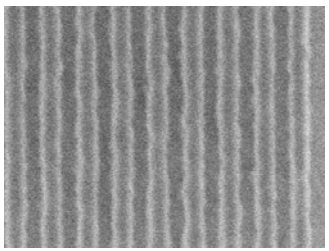


14.0 mJ/cm2

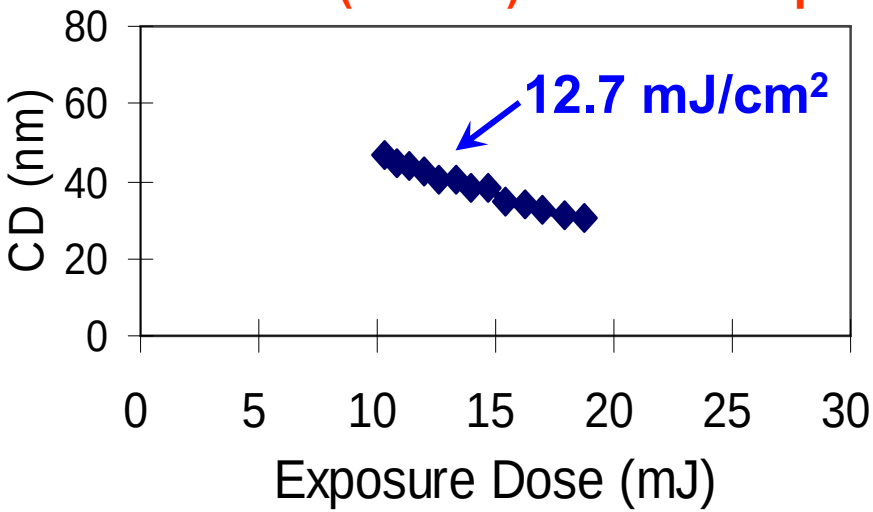


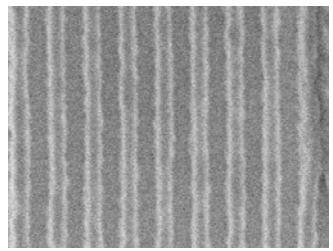
14.7 mJ/cm2

LER = (3.7 nm) – vendor reported

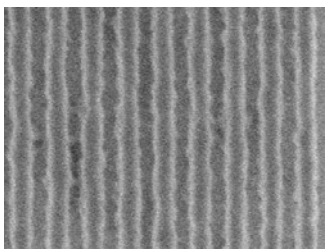


11.4 mJ/cm2





15.4 mJ/cm2

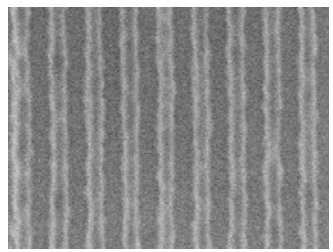


10.9 mJ/cm2

Film Thickness: 80nm

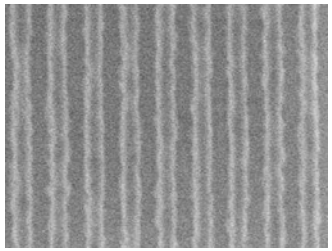
BMET y-monopole

PAB/PEB: 100˚C/100˚C

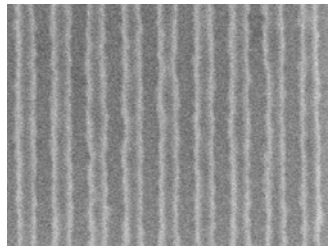


16.2 mJ/cm2

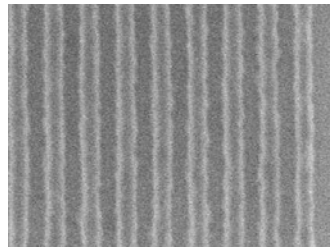
II. Resist A: 40 nm L/S Through Focus For Good Sensitivity Resist



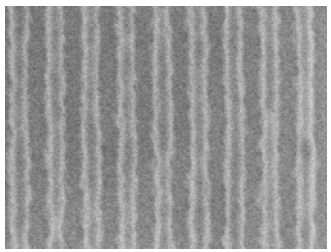
-50 nm



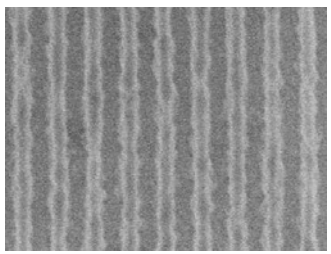
0 nm



+50 nm

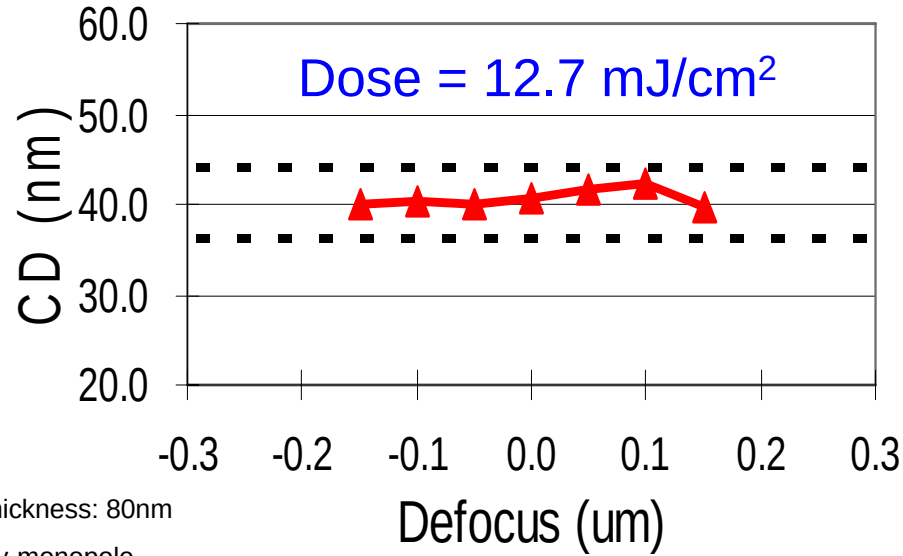


-100 nm



-150 nm

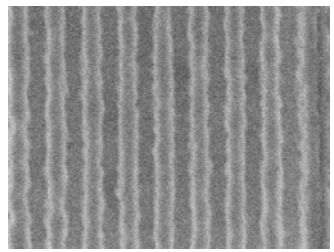
LER = (3.7nm) - vendor reported



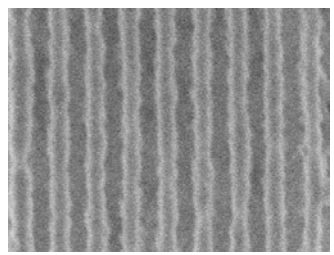
Film Thickness: 80nm

BMET y-monopole

PAB/PEB: 100˚C/100˚C



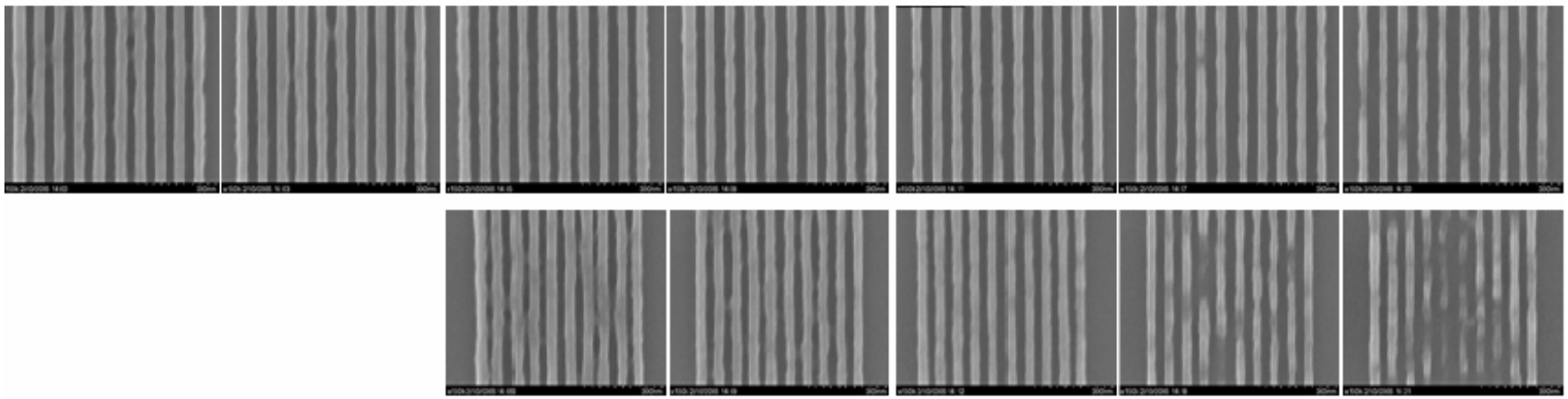
+100 nm



+150 nm

II. Resist B: 40 nm and 35 nm Images Through Dose

Blended High and Low Ea Polymer



17 mJ/cm² 17.9 mJ/cm² 18.8 mJ/cm² 19.7 mJ/cm² 20.7 mJ/cm² 21.8 mJ/cm² 22.9 mJ/cm²

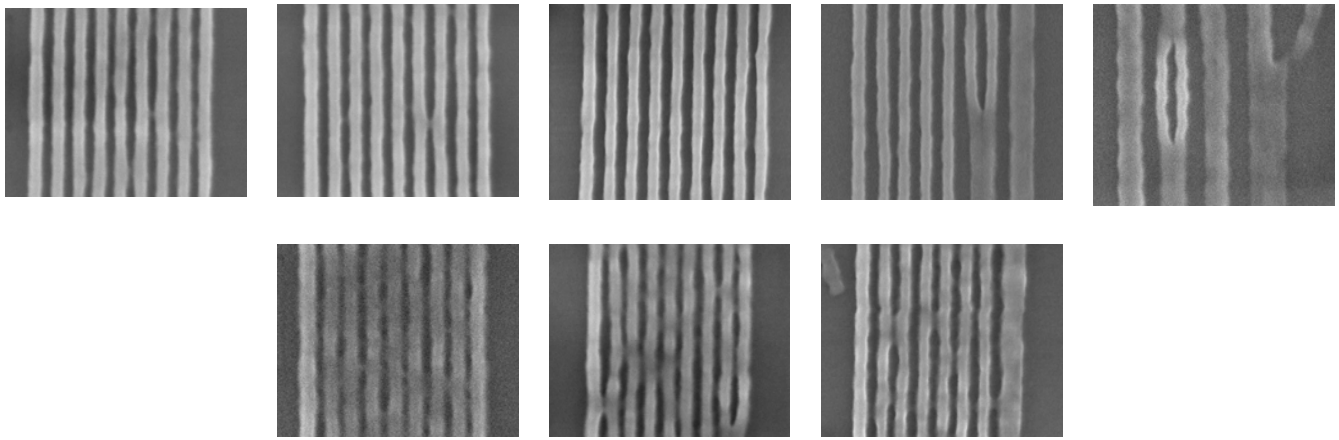
Film Thickness: 80nm
BMET y-monopole
PAB/PEB: 100˚C/90˚C

II. Resolution Through Dose For Different Sensitivity Resists

Resist C

LER = 4.5 @ 41.4 mJ/cm^2

36.8 mJ/cm^2 39.1 mJ/cm^2 41.4 mJ/cm^2 43.7 mJ/cm^2 46.0 mJ/cm^2



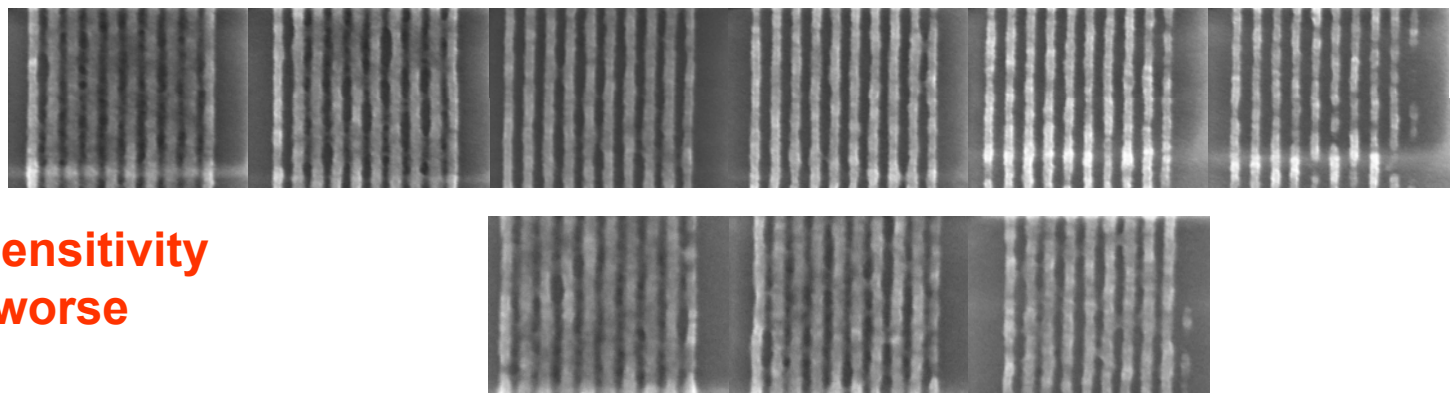
36 nm

32 nm

Film Thickness: 80nm
BMET y-monopole
PAB/PEB: 110˚C/90˚C

Resist D

27 mJ/cm^2 30 mJ/cm^2 33 mJ/cm^2



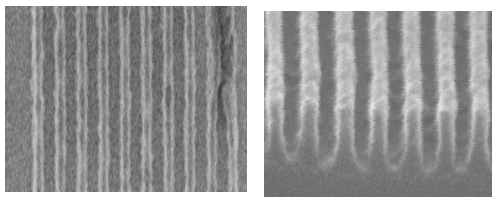
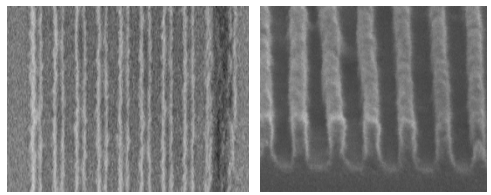
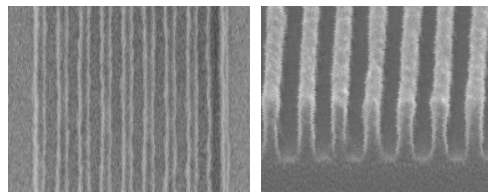
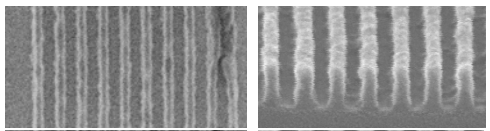
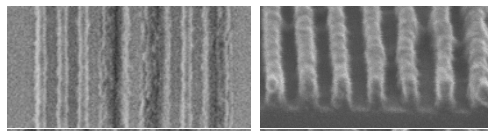
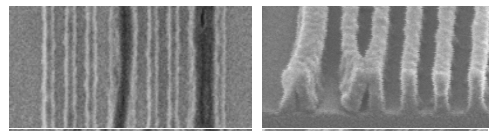
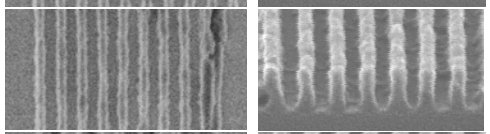
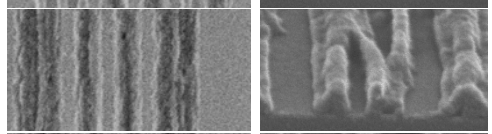
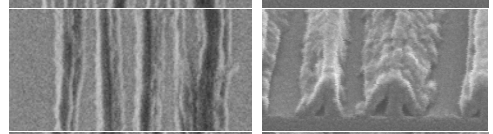
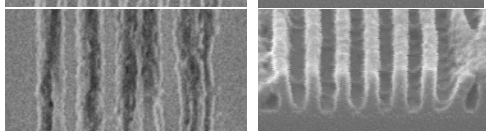
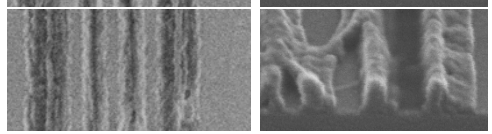
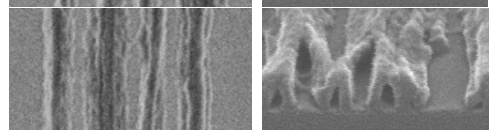
36 nm

32 nm

Improved Sensitivity but LER is worse

Film Thickness: 80nm
BMET y-monopole
PAB/PEB: 110˚C/90˚C

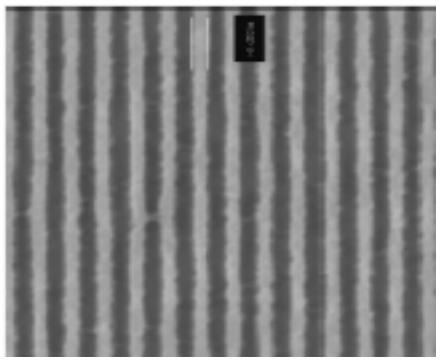
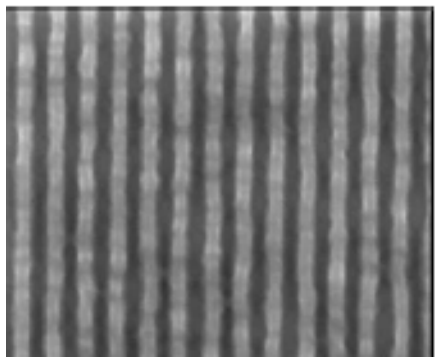
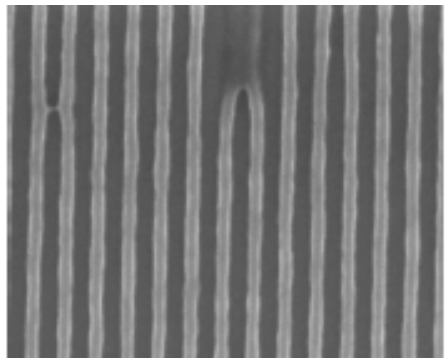
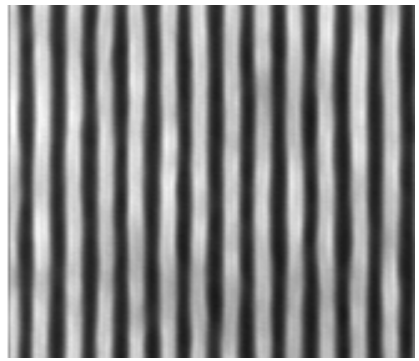
II. Resist E: PAB Temperature Effects on Resolution, LER and Sensitivity

	120 ºC PAB	110 ºC PAB	100 ºC PAB
40nm			
	19.9 mJ/cm^2	**20.7 mJ/cm^2**	**18.5 mJ/cm^2**
	LER @ 40nm = (5.3 nm)	**LER @ 40nm = (6.3 nm)**	**LER @ 40nm = (5.2 nm)**
38nm			
36nm			
34nm			

- Little or no effect seen on LER and Sensitivity with varying PAB temperature
- More pattern collapse at lower PAB temperatures

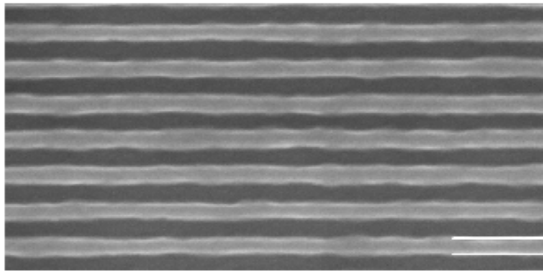
Film Thickness: 80nm
BMET y-monopole
PEB: 100˚C

II. 25 nm Resolution at Paul Scherrer Institut (PSI)

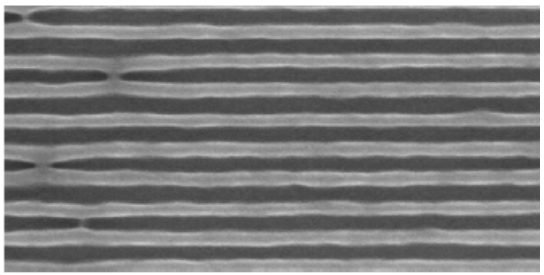
Resist E	Resist F	Resist G	Resist C
			
KrF Platform Low Ea	KrF Platform Low Ea	Short acid diffusion length polymeric resist	Low Ea
Dose = 30 mJ/cm^2	Dose = 40 mJ/cm^2	Dose = 65 mJ/cm^2	Dose = 61 mJ/cm^2

II. Resolution, LER, and Sensitivity Comparison at PSI

Resist G

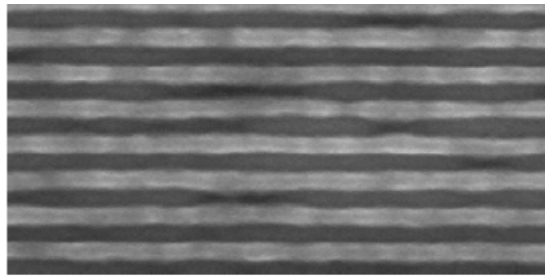


27 nm Line / 30 nm hp
54.3 mJ/cm²
LER = 2.3 nm

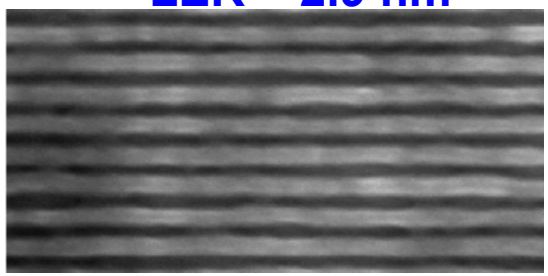


25 nm Line / 25 nm hp
65.2 mJ/cm²
LER = 2.3 nm

Resist H

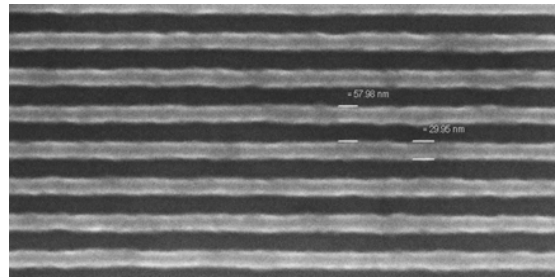


27 nm Line / 30 nm hp
32 mJ/cm²
LER = 2.9 nm

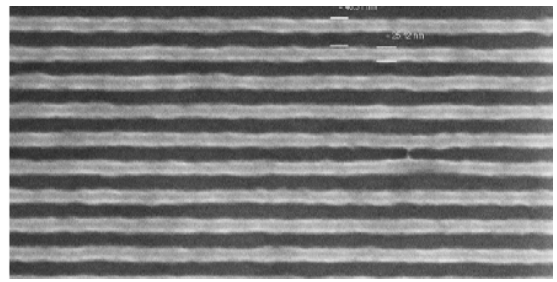


25 nm Line / 25 nm hp
33.6 mJ/cm²
LER = 3.8 nm

Resist I



27 nm Line / 30 nm hp
25.6 mJ/cm²
LER = 3.2 nm



25 nm Line / 25 nm hp
26.9 mJ/cm²
LER = 3.9 nm

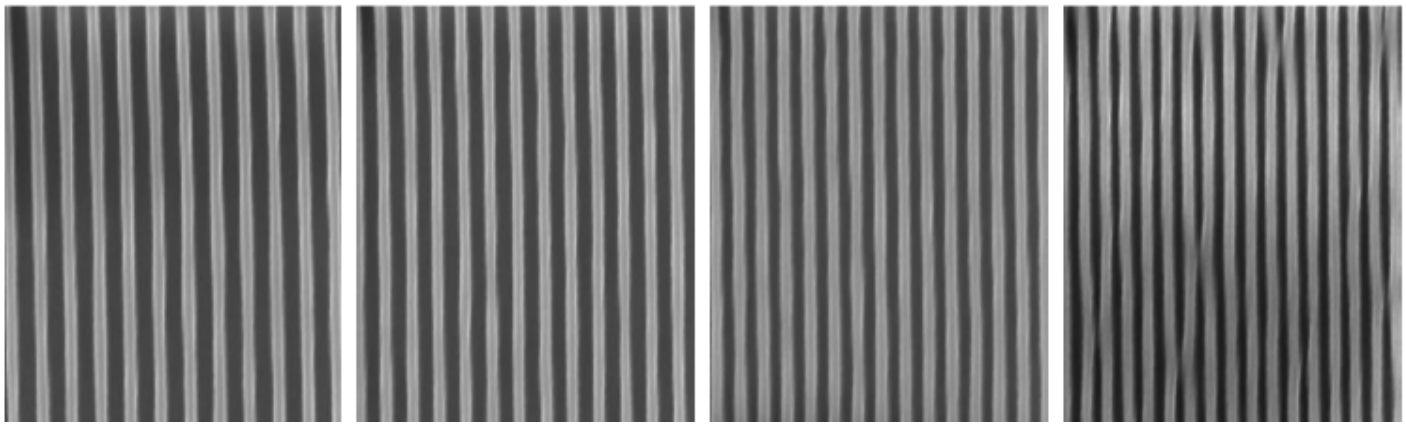
Sensitivity clearly gets worse as CD decreases

LER Increases as Sensitivity gets better for same resolution

Film Thickness: 80 nm
PSI

II. Resist G: EUV Line/Space Resolution at LBNL

27 mJ/cm^2 @ 32 nm half pitch



40 nm	36 nm	32 nm	28 nm
LER = 2.5	LER = 2.8	LER = 3.2	

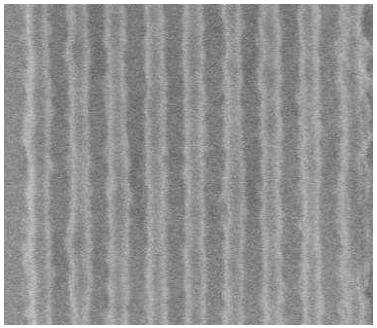
LER increases as CD decreases

INVENT
Micron Qimonda AMD IBM ALBANY NanoTech

II. EUV 1:1 Line/Space Resolution at LBNL

Resist A

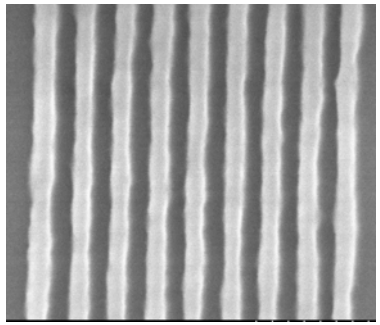
34 nm



Dose = 12.7 mJ/cm^2 @ 40hp
LER = (3.6 nm) @ 40hp

Resist C

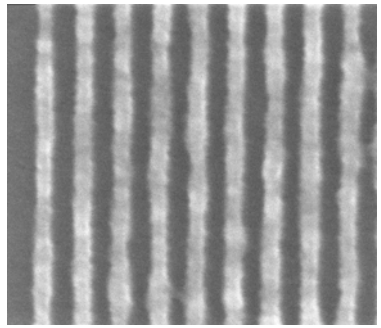
36 nm



Dose = 41.1 mJ/cm^2
LER = 4.5 nm

Resist D

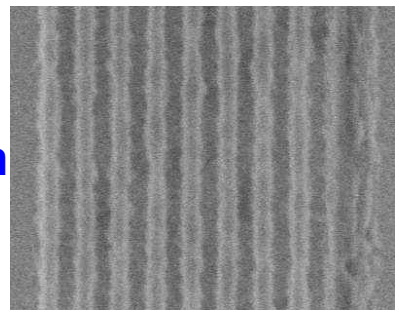
36 nm



Dose = 30.1 mJ/cm^2
LER = 5.4 nm @ 40hp

Resist E

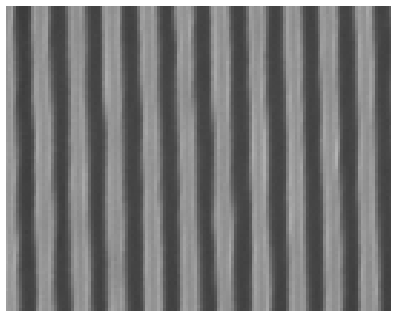
32 nm



Dose = 16.2 mJ/cm^2 @ 40hp
LER = (4.1nm) @ 40hp

Resist G

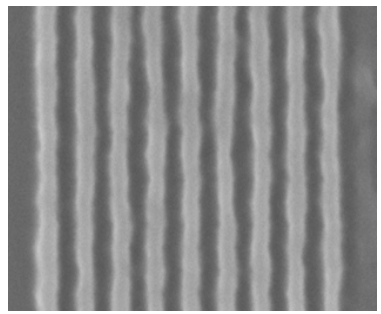
32 nm



Dose = 27 mJ/cm^2
LER = 3.2 nm

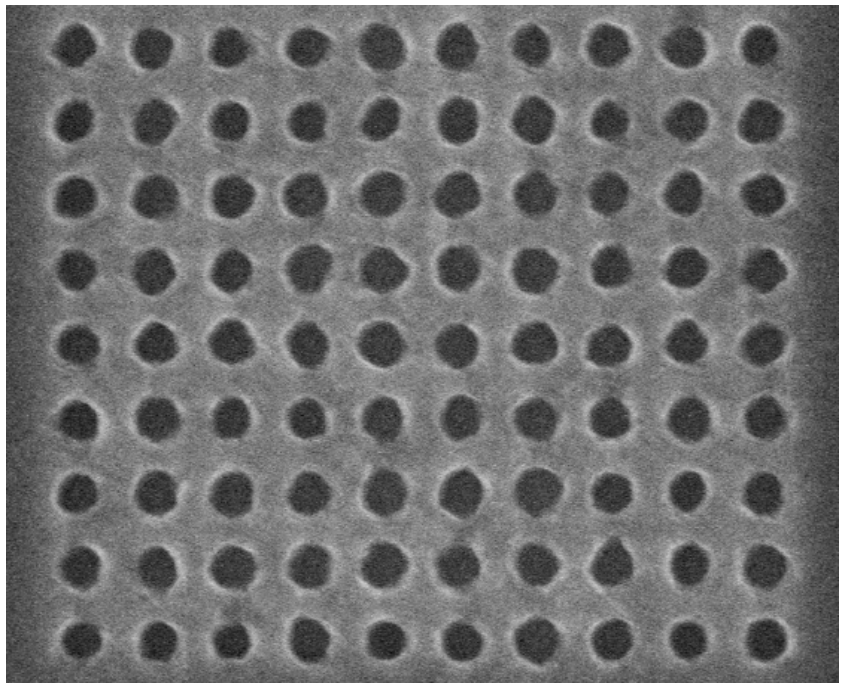
Resist J

34 nm



Dose = 32.2 mJ/cm^2
LER = 6.2 nm

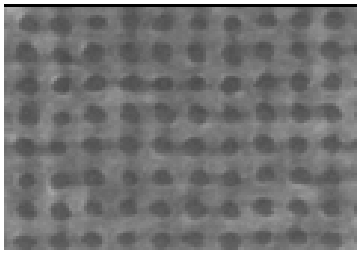
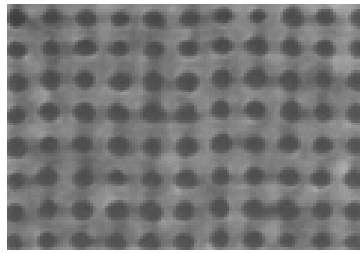
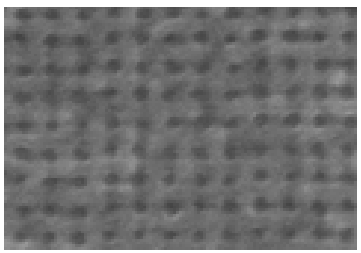
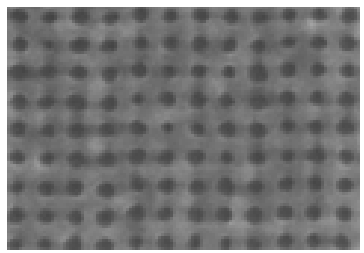
III. Resist B: 45 nm Contact Hole



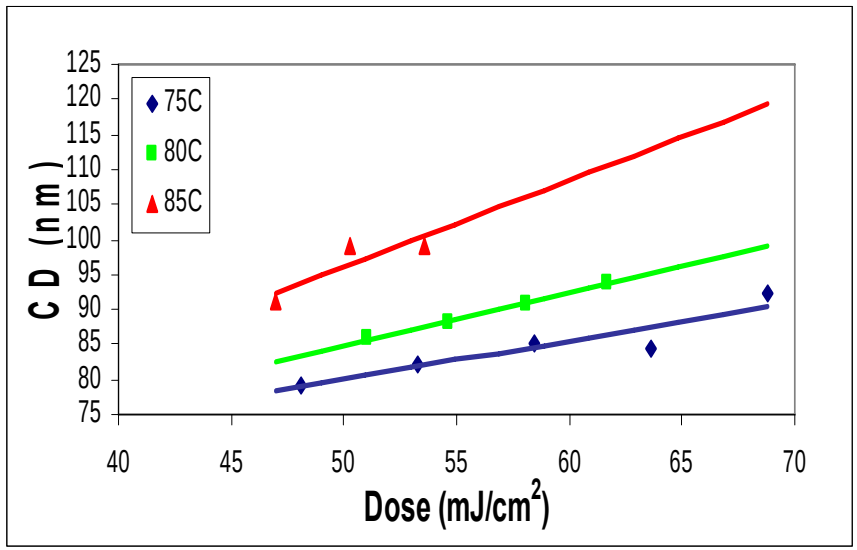
Dose = 80 mJ/cm^2

Film Thickness: 80 nm
BMET annular
PAB/PEB:

III. Resist K: Film Thickness Effects and PEB Sensitivity

	60 nm FT	80 nm FT
40 nm	 47 mJ/cm²	 62 mJ/cm²
35 nm	 47 mJ/cm2	 65 mJ/cm2

60 nm 1:1 Contacts



PEB Sensitivity: 1.6 nm/° C @50 nm

Thinner Film:

- **No Resolution Improvement**
- **Improved Sensitivity**

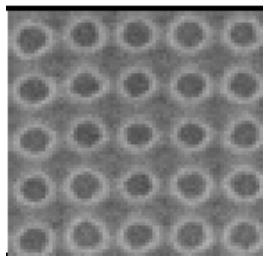
BMET Annular
PAB: 110˚/80˚C
PEB: 80˚C for FT study

III. Resists L and M: PAG Loading Effects on Resolution and Sensitivity

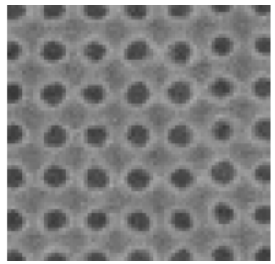
Increase PAG Loading

Resist L

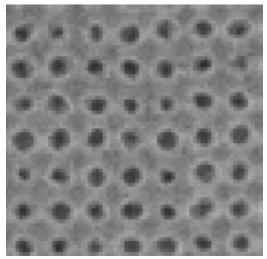
45 nm CH
31.4 mJ/cm²



35 nm CH
38.2 mJ/cm2



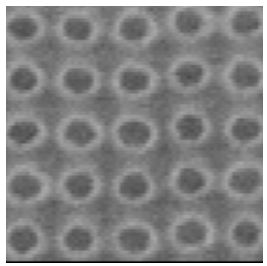
30 nm CH
42.1 mJ/cm²



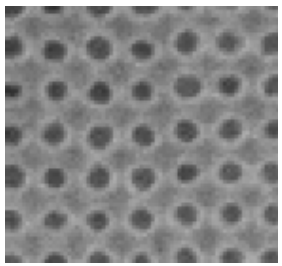
Better sensitivity with higher PAG

Resist M

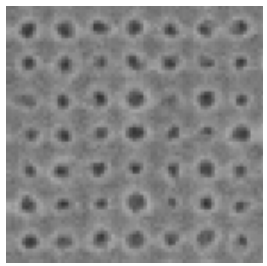
45 nm CH
34.7 mJ/cm²



35 nm CH
40.1 mJ/cm²



30 nm CH
42.1 mJ/cm²



No Resolution Improvement with higher PAG

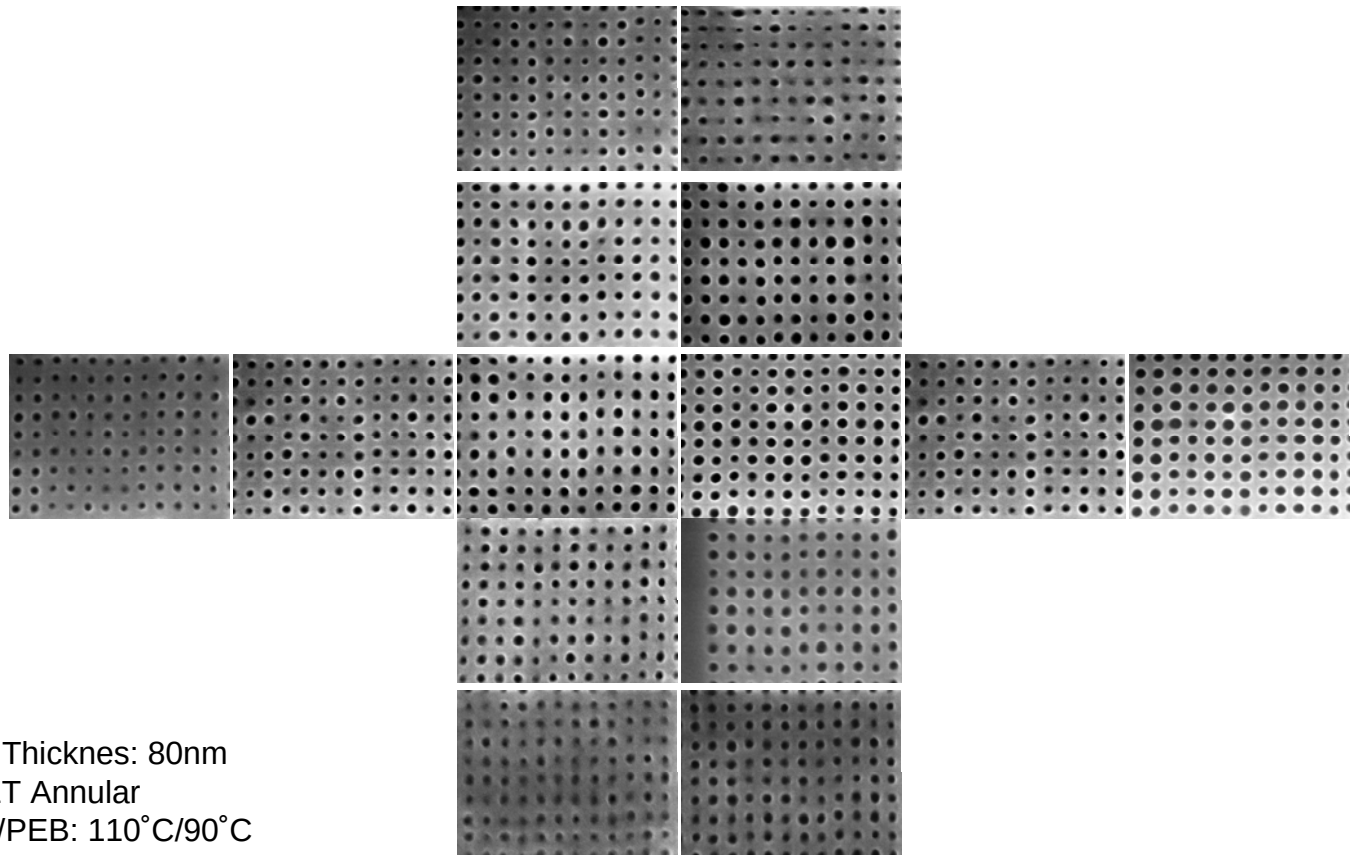
Decreasing CD

Film Thickness: 80 nm
BMET Annular
PAB/PEB: 120˚C/100˚C

III. Resist N: 35 nm 1:1 Contact Hole Through Dose and Focus

Dose (mJ/cm^2)

66.5	70	73.5	77	80.5	84

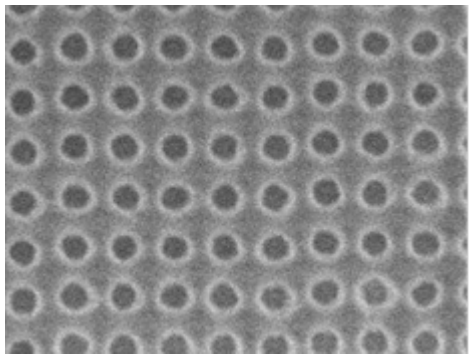


Focus (nm)
-150
-100
-50
0
50

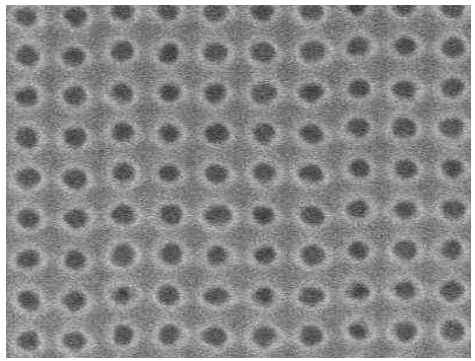
Film Thicknes: 80nm
BMET Annular
PAB/PEB: 110˚C/90˚C

III. Resist E: Contact Hole Resolution and Sensitivity Comparison

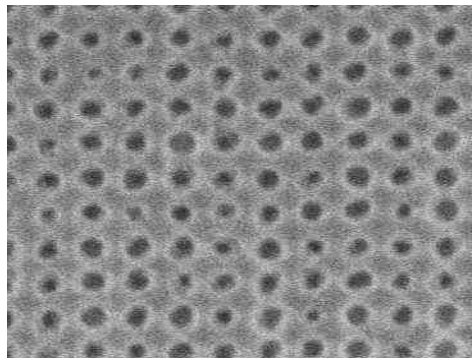
31.4 mJ/cm^2
45 nm

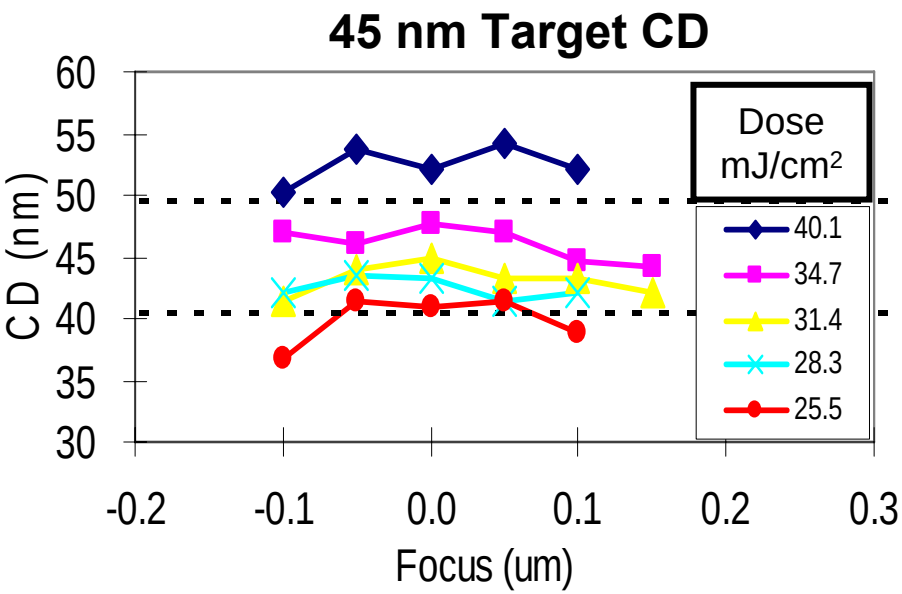


36.4 mJ/cm^2
35 nm



44.2 mJ/cm^2
30 nm





Sensitivity clearly decreases as CD decreases

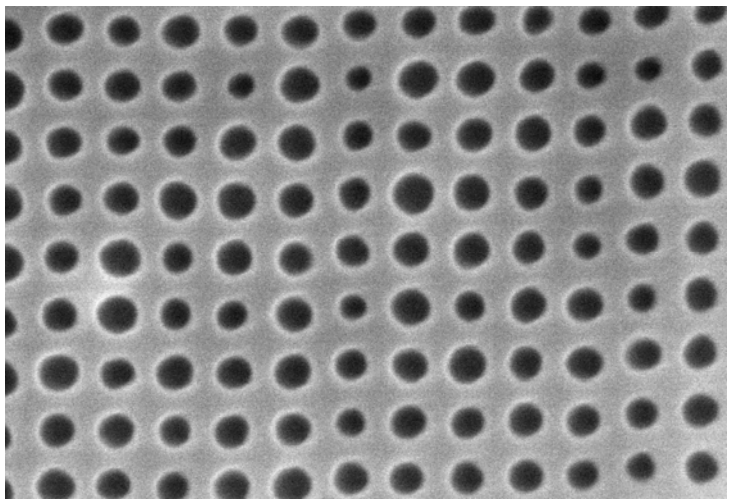
0.25 µm Depth of focus @ 45 nm resolution

Film Thickness: 80nm
BMET Annular
PAB/PEB: 110˚C/90˚C

INVENT
Micron Qimonda AMD IBM ALBANY NanoTech

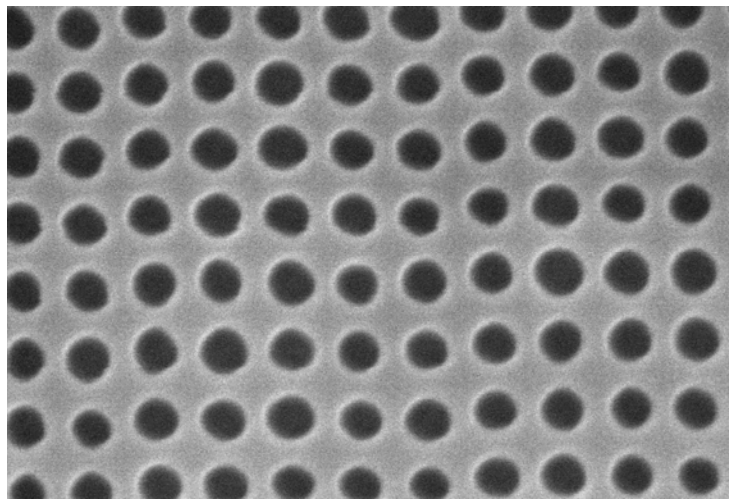
III. Resist P: 35 nm and 40 nm Contacts with Good Sensitivity

35 nm half pitch



37.5 mJ/cm^2

40 nm half pitch

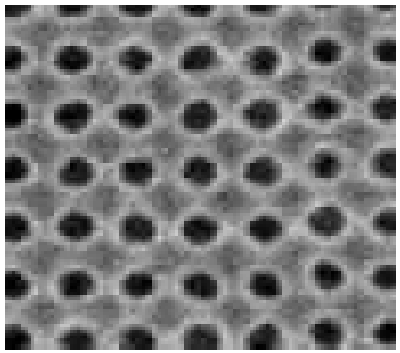


35 mJ/cm^2

INVENT
Micron Qimonda AMD IBM ALBANY NanoTech

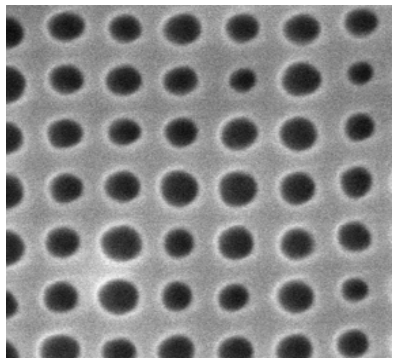
III. 35 nm Contact Hole Resolution at LBNL

Resist E



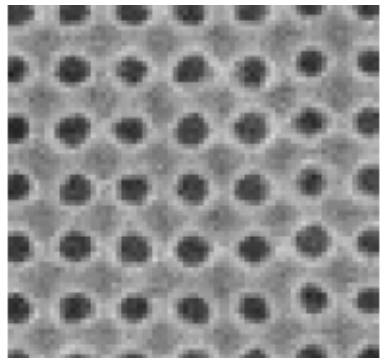
Dose = 36.4 mJ/cm^2

Resist P



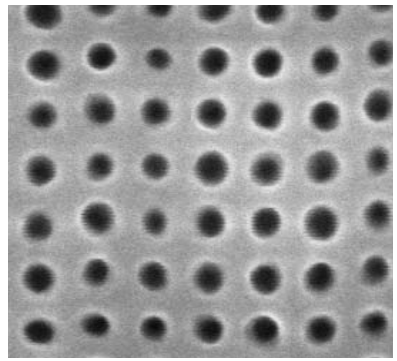
Dose = 37.5 mJ/cm^2

Resist L



Dose = 38.2 mJ/cm^2

Resist N



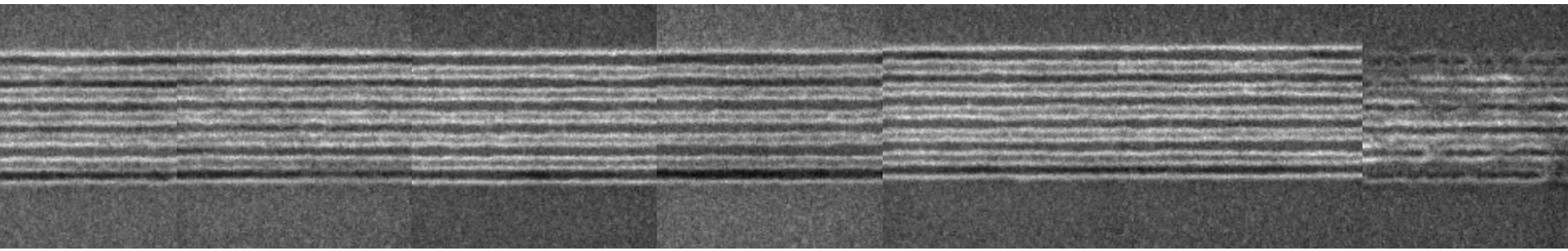
Dose = 73 mJ/cm^2

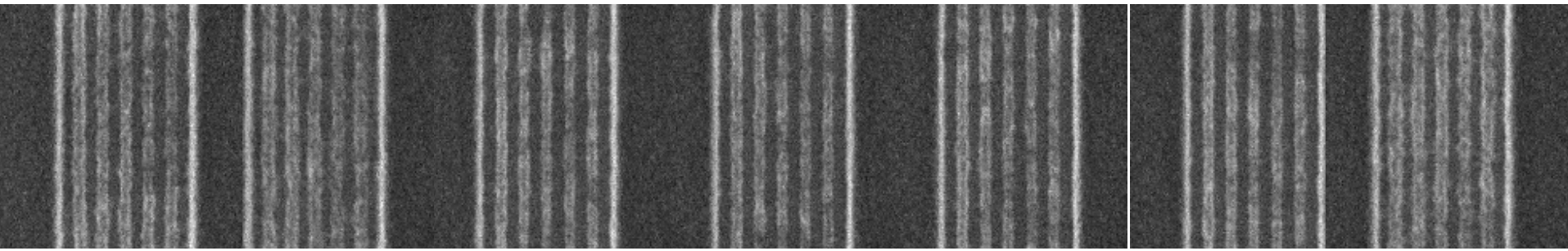
35 nm 1:1 Contact Holes

IV. Albany Demo Tool Data: 35 nm dense line features

FOCUS (nm)

-120 -80 -40 NF +40 +80 +120





Resist: Rohm Haas XP-5721F (MET-2D)

Thickness: 120nm

Dose: 23.6mJ/cm^2

NA = 0.25 σ = 0.5

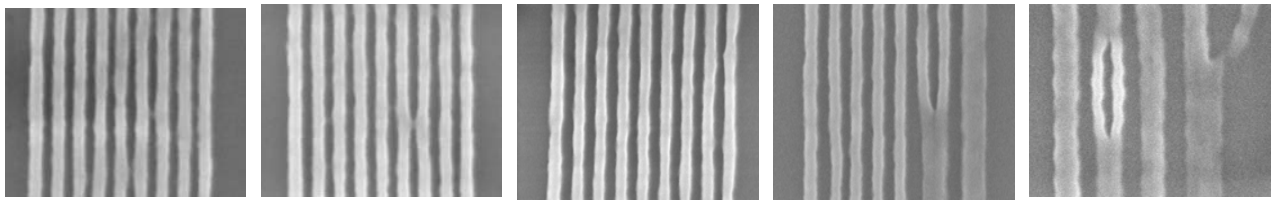
SEMS courtesy of ASML

V. EUV Resists for Dense Lines and Contacts at LBNL

Resist C

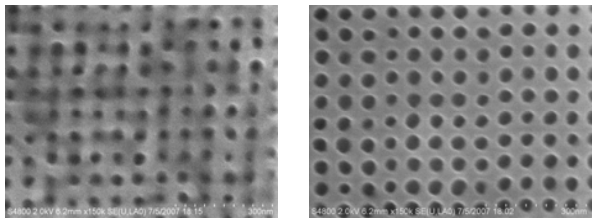
36 nm line
(y-monopole)
LER = 4.5 nm

36.8 mJ/cm² **39.1 mJ/cm²** **41.4 mJ/cm²** **43.7 mJ/cm²** **46 mJ/cm²**



35nm C/H
(annular)

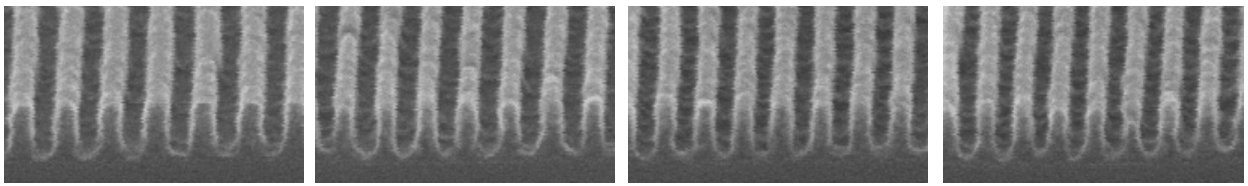
120 mJ/cm² **128 mJ/cm²**



Film Thickness: 80nm
PAB/PEB: 110˚C/90˚C

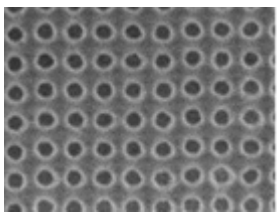
Resist E

16.2 mJ/cm2
(y-monopole)
LER = (4.1) nm

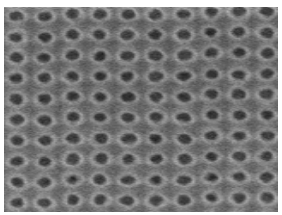


40 nm L/S **36 nm L/S** **34 nm L/S** **32 nm L/S**

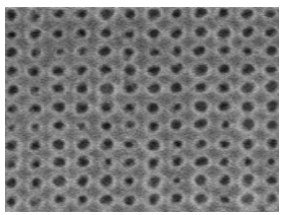
45 nm C/H
(annular)
31.4 mJ/cm²



35 nm C/H
(annular)
36.4 mJ/cm²



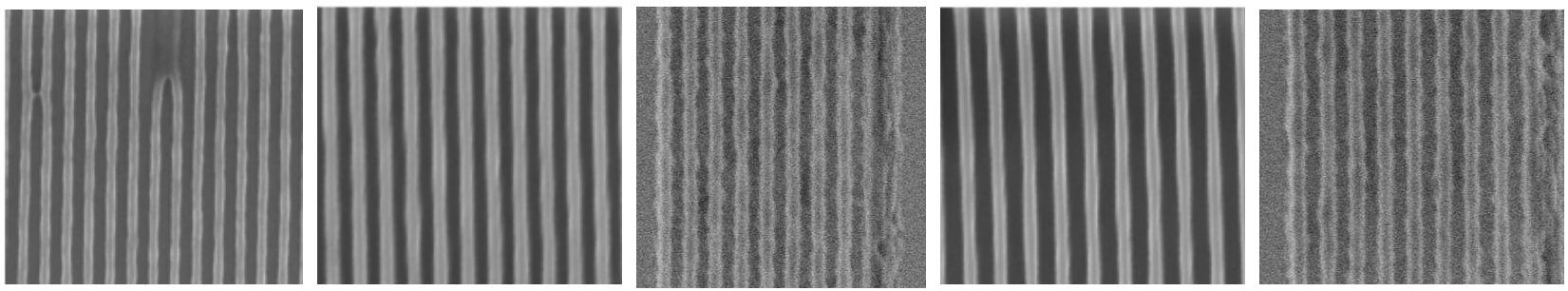
30 nm C/H
(annular)
44.2 mJ/cm²



Film Thickness: 80nm
PAB/PEB: 110˚C/90˚C

V. Current 1:1 Line/Space Status of INVENT Samples (Best)

	Resolution			LER	Sensitivity
Resist	**G**	**G**	**E**	**G**	**A**
Exposure	PSI	LBNL	LBNL	LBNL	LBNL

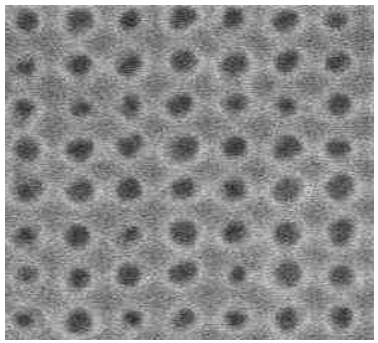
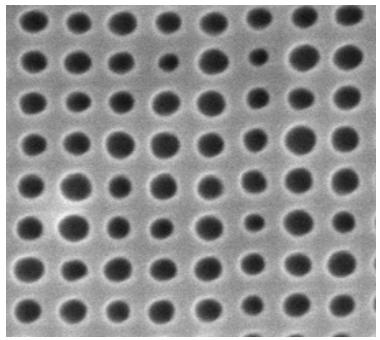
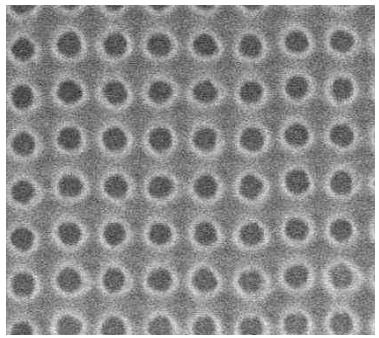
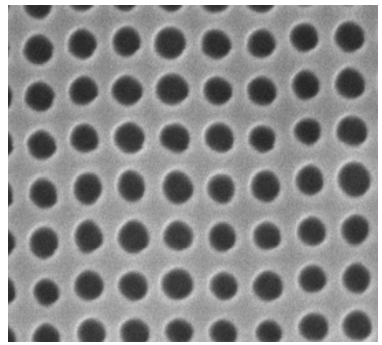


Resolution nm	**25**	**32**	**32**	**40**	**40**
LER nm	**2.3**	**3.2**	**(4.1) @ 40 nm hp**	**2.5**	**(3.7) – vendor reported**
Sensitivity mJ/cm²	**65.2**	**27**	**16.2 @ 40 nm hp**	**27 @ 32 nm hp**	**12.7**

V. Current 1:1 Contact Hole Status of INVENT Samples (Best)

Resolution **Sensitivity**

Resist **E** **P** **E** **P**

Resolution nm	30	35	45	40
Sensitivity mJ/cm²	44.2	37.5	31.4	35

V. Conclusions

Good progress with respect to resist development has been made.

Although no EUV resist meets all L/S targets, individual targets have been hit:

- **Resolution:** 32 nm at Berkeley and 25 nm at PSI
- **LER:** Less than 2.5 nm at Berkeley and PSI
- **Sensitivity:** Less than 15 mJ/cm^2 at Berkeley

Improvements in EUV resists on Contact Hole performance have also been shown.

- Resists have shown 35 nm resolution at less than 40 mJ/cm^2

Simultaneous improvements in resolution, LER and sensitivity are still needed for lines/spaces and contact holes.

The ASML Alpha Demo Tool in Albany is printing 35 nm L/S and sub 55 nm contact holes.

VI. Acknowledgments

Collaborators at Resist Vendors

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Rich Conte

Boaz Alperson

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- Anja Weber

Sven Trogisch

Staff at LBNL

- Paul Denham
- Brian Hoef
- Gideon Jones
- Gerin Chiu