EUV RESIST EVALUATION AND PROCESS OPTIMIZATION TOWARDS NXE:3300

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imec

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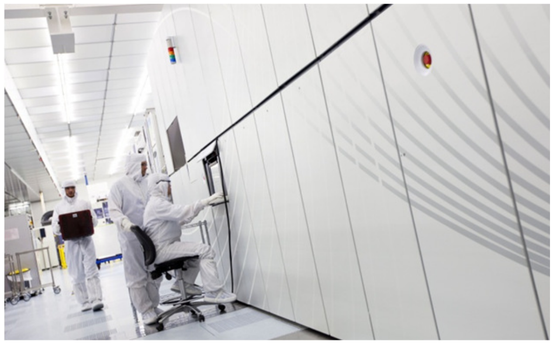
IMEC EUV LITHOGRAPHY
TOOL ROADMAP

Main specifications

- Field size: 26x33mm^2
- NA=0.25 and σ=0.81
- 6 off-axis illumination conditions available
- Flare < 8%
- MMO vs NXT:1950i < 7nm



2011 - now	2014
ASML NXE:3100 - 0.25 NA 27nm LS: conventional 22nm LS: dipole	ASML NXE:3300 – 0.33 NA 22nm LS: Conventional 18nm LS: off-axis

Resist screening and benchmarking

- Follow up the performance of EUV resist towards the yearly set targets requirements
- Select and optimize baseline resist processes to be installed on track for use in the imec EUV program (3100 → 3300) and for device implementation*

* M. Ercken, session 1

EUV RESIST PERFORMANCE TARGETS
2013 H1 TARGETS ON NXE:3100

Resist Performance Targets on NXE3100	H12013
CH screening with Quasar ill Resolution Contacts 1:1 (nm) Dose-to-size (at 20% bias) DOF@10%EL LCDU at 26nm HP (1σ) Resist thickness	 **26nm** **<20mJ** **>100nm** **<1.0nm** **60nm**
LS dipole 60 ill Resolution L/S 1:1 (nm) DOF@10%EL dose-to-size LER on 22nm L/S (3σ) Ultimate resolution Resist thickness	 **22nm** **>100nm** **<15mJ** **3.0nm** **18nm** **35-40nm**
Ultimate resolution for LS With dipole	**16nm**

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Introduction

Contact hole process

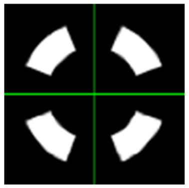
- Resist screening
- Process optimization
- Performance on NXE3300

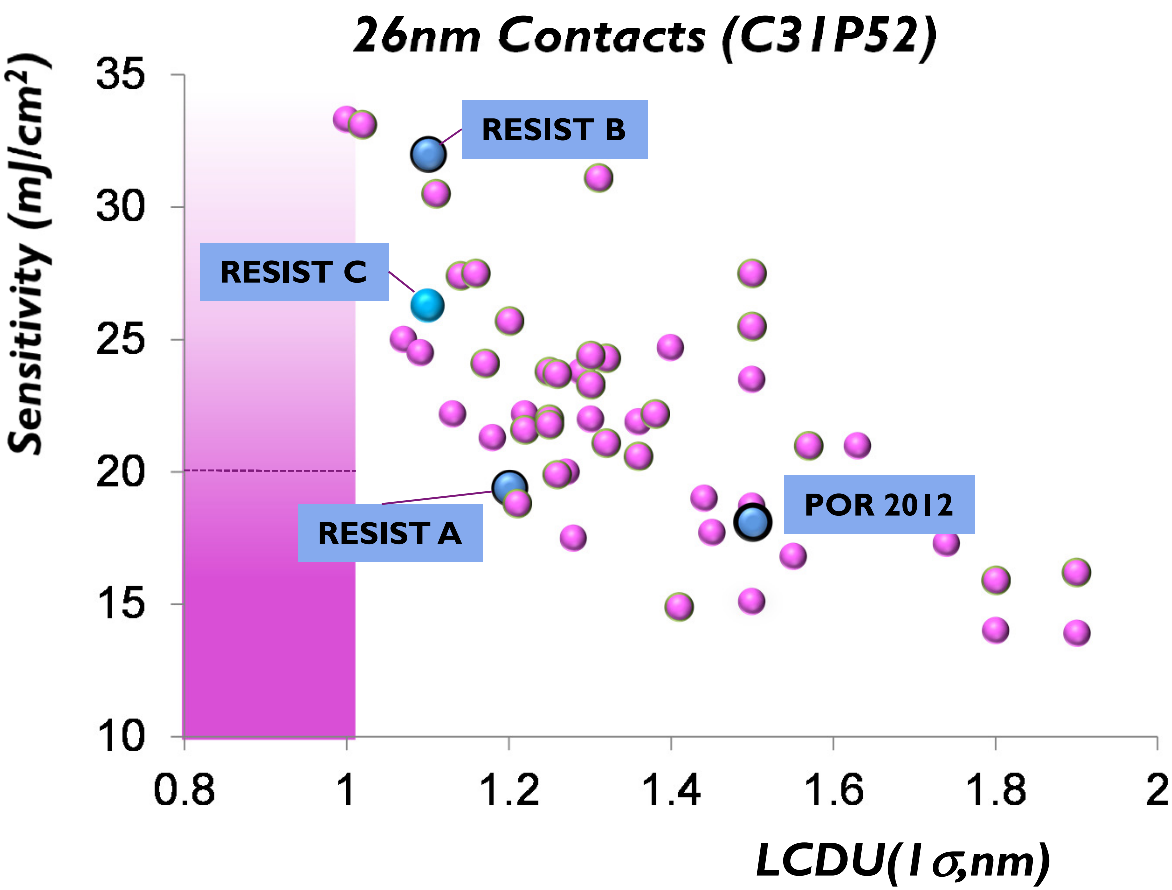
Line space process

- Resist screening
- Process optimization
- Performance on NXE3300

Conclusions

EUV RESIST CH PERFORMANCE
SMALL SAMPLES SCREENING

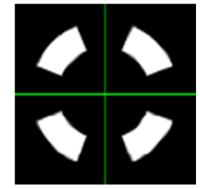

NXE:3100



Several resists demonstrate 1.3-1.2nm (1s) LCDU in a 20-26mJ/cm^2 dose range
Lower LCDU values of 1.1-1nm are achieved at doses >26mJ/cm^2

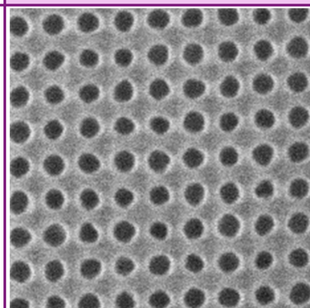
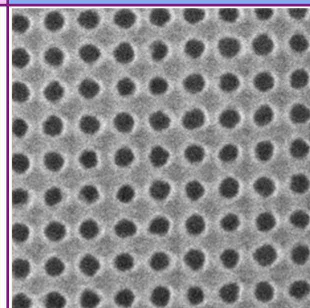
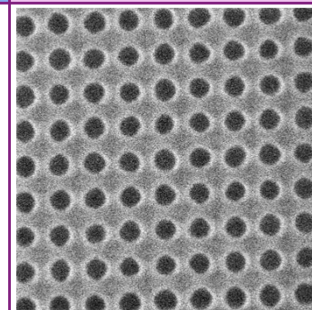
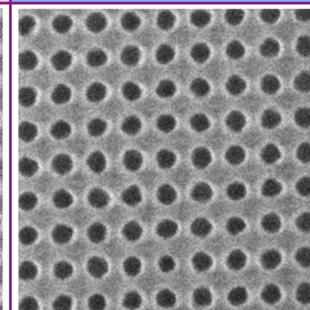
EUV RESIST CH PERFORMANCE

GALLON SAMPLE PRINTING PERFORMANCE



NXE:3100

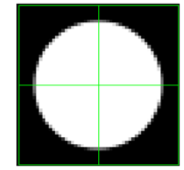
26nm Contacts (C31P52)

Resist	2012 POR	RESIST A	RESIST B	RESIST C
Top view 26nmCH (C31/P52)				
Dose to Size ≤20mJ/cm2	18.1mJ/cm2	19.4mJ/cm2	31.7mJ/cm2	26.3mJ/cm2
1σ LCDU ≤1.0nm	1.5nm	1.2nm	1.1nm	1.1nm
Max EL Max DOF	15% 160nm	15% 160nm	17.1% >300nm	21% 290nm

Resist B and C have largest process windows, but Resist C has a lower dose to size. Resist A is still has the best sensitivity - LCDU compromise

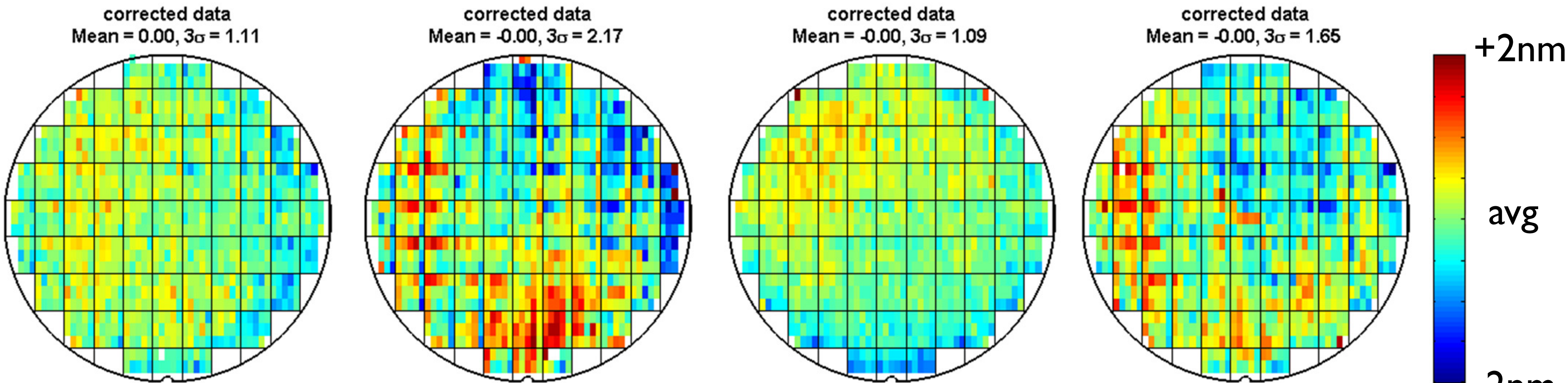
EUV RESIST CH PERFORMANCE

30NM DENSE CH CDU - PUDDLE DEVELOPMENT PROCESS



NXE:3100

POR 2012 | RESIST A | RESIST B | RESIST C



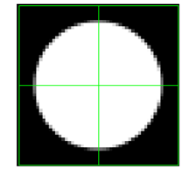
CDU_{corr}=1.11nm | CDU_{corr}=2.17nm | CDU_{corr}=1.09nm | CDU_{corr}=1.65nm

The standard puddle process works fine for 2012 POR and RESIST B, the other two resists clearly have a higher process sensitivity

* Corr = average IF CD fingerprint subtracted

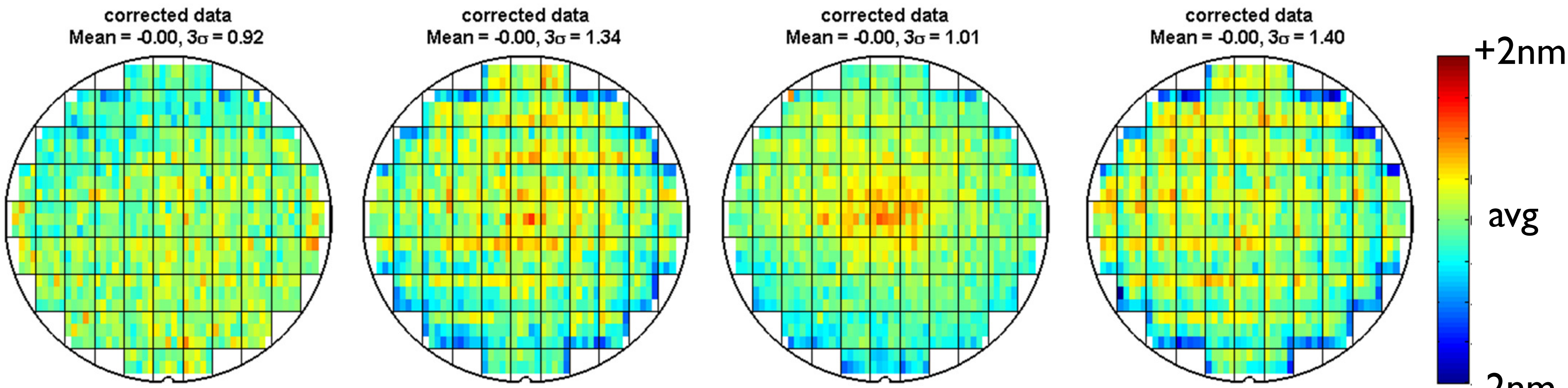
EUV RESIST CH PERFORMANCE

30NM DENSE CH CDU - DYNAMIC DEVELOPMENT PROCESS



NXE:3100

POR 2012 | RESIST A | RESIST B | RESIST C



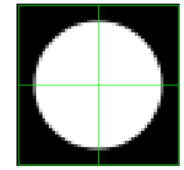
CDU_{corr}=0.92nm | CDU_{corr}=1.34nm | CDU_{corr}=1.01nm | CDU_{corr}=1.40nm

Overall CDU performance is better for dynamic development process
Resists A and C again show an increased CDU

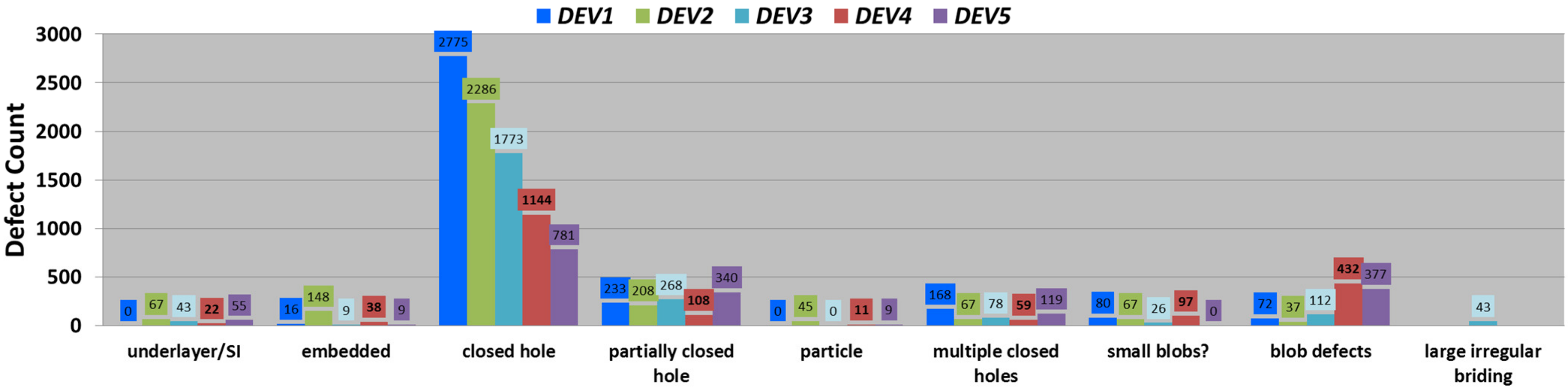
* Corr = average IF CD fingerprint subtracted

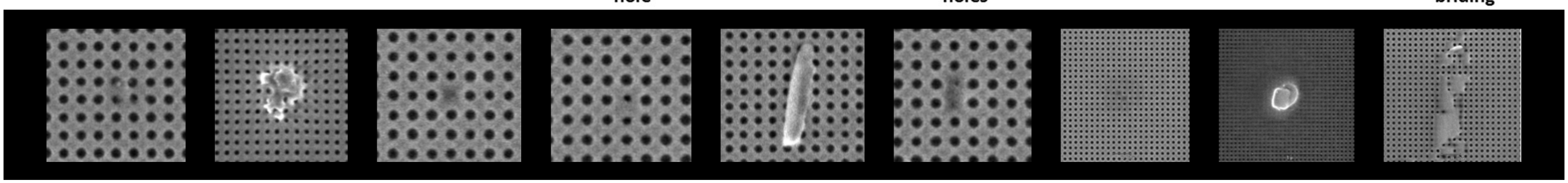
EUV RESIST CH PERFORMANCE

30NM DENSE CH DEFECTIVITY – RESIST B



NXE:3100



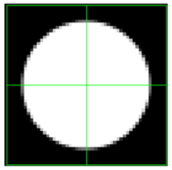


Dominant defect type: single (partially) closed contact holes

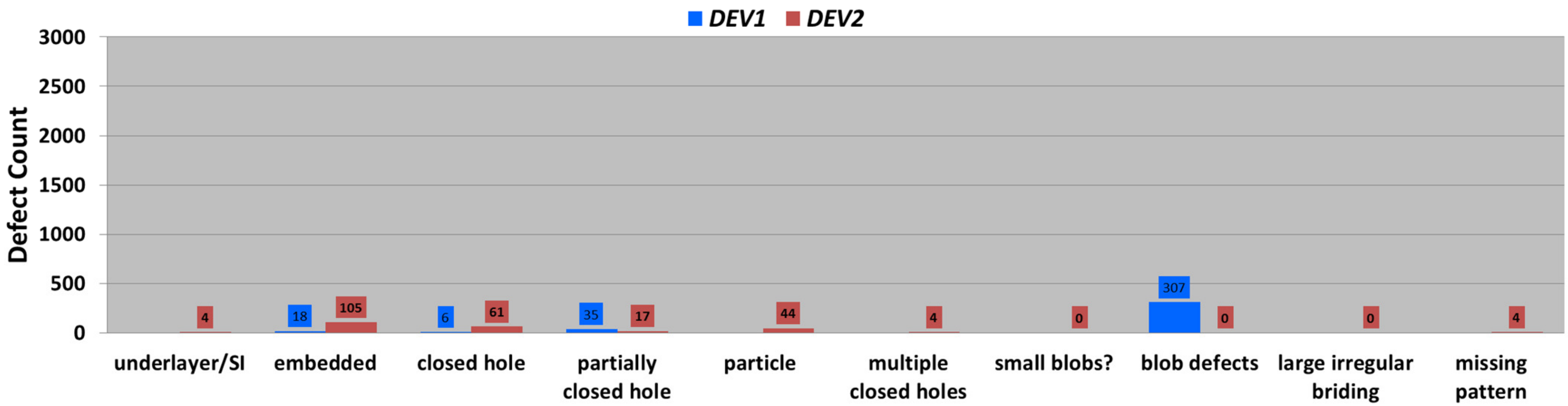
Developer recipe tuning does allow to improve upon this, but additional optimization still is needed

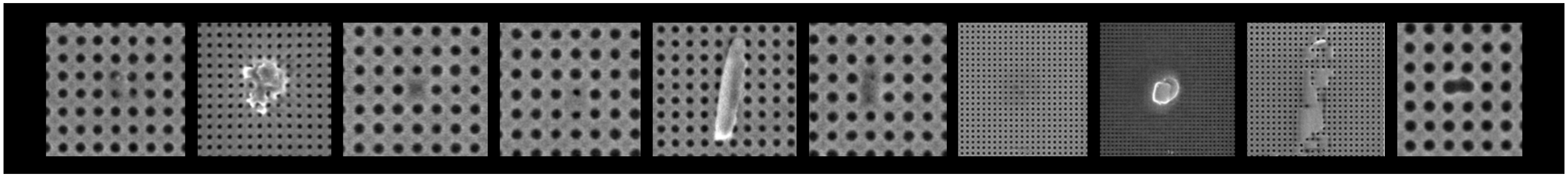
See also P-RE-43 Yuhei Kuwahara

EUV RESIST CH PERFORMANCE
30NM DENSE CH DEFECTIVITY – RESIST A



NXE:3100

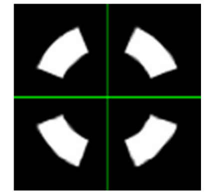




Though inspection sensitivity matching between resists is difficult, current results suggest superior defectivity after DEV recipe optimization: Defect density of ~ 1 defect/cm^2

EUV RESIST CH PERFORMANCE

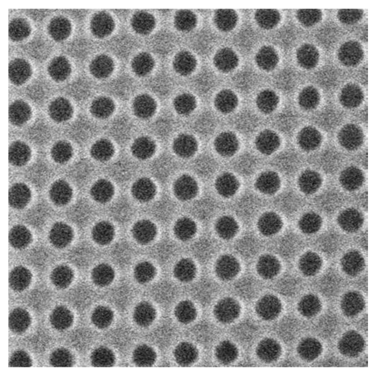
ULTIMATE RESOLUTION IN RESIST B - 3100

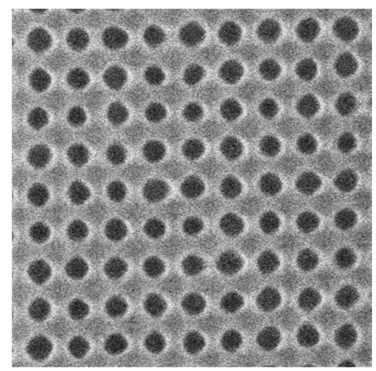


NXE:3100

	26nm CH	24nm CH
	C31P52	C29P48
Dose-to-size	31.7mJ/cm2	33.5mJ/cm2
1 sigma LCDU (<1nm)	1.1nm	1.7nm
Average CER (3σ nm)	1.2nm	1.32nm
DOF@10%EL	290nm	No process window
Max EL/DOF	17.1%/300nm	

BEST10
NA=0.25
Quasar ill
60nm FT

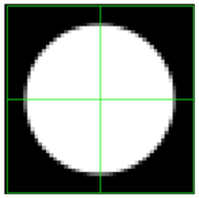




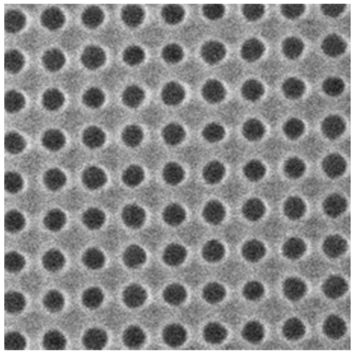
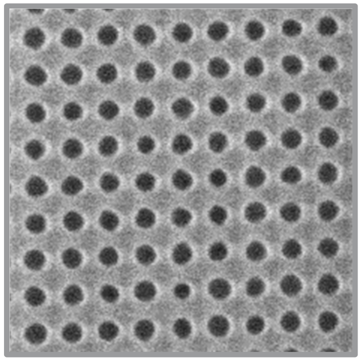
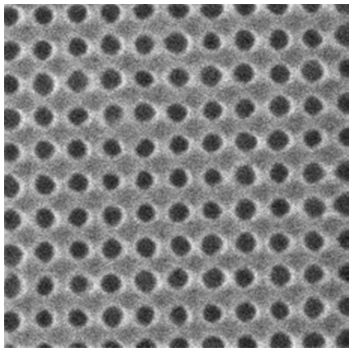
Down to 24nm HP contacts resolved on NXE3100 with Quasar illumination – but no process window

EUV RESIST CH PERFORMANCE

ULTIMATE RESOLUTION IN RESIST B - 3300



NXE:3300

	26nm CH	24nm CH	22nm CH
	C31P52	C29P48	C26P44
BEST10 Conventional NA=0.33 60nm FT			

14.5% EL at 120nm DOF process window for 24nm CH - Down to 22nm HP contacts resolved using conventional illumination in resist B

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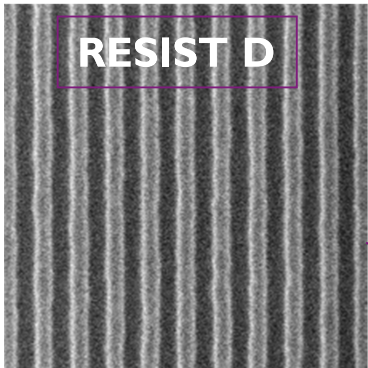
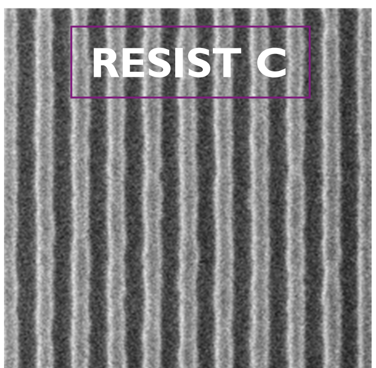
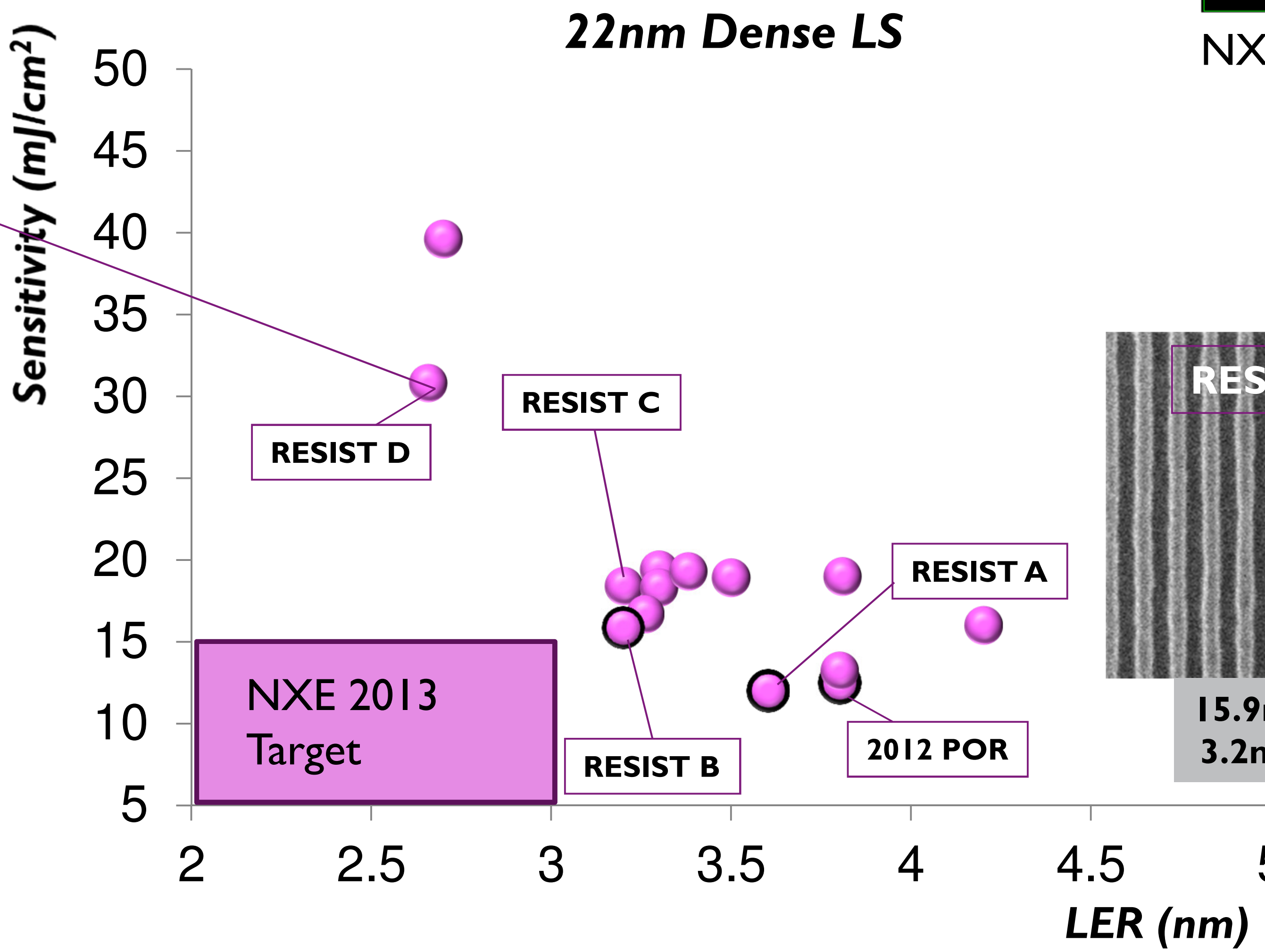
EUV RESIST LS PERFORMANCE
SMALL SAMPLES SCREENING

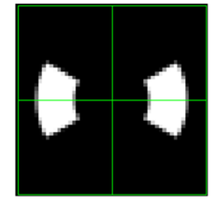


30.8mJ/cm2
2.66nm LER

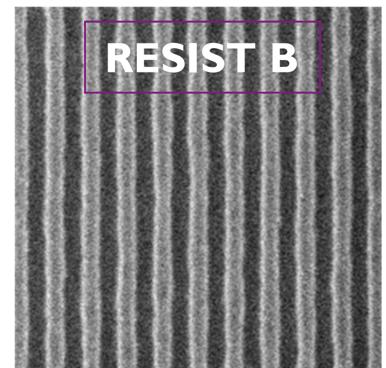


18.4mJ/cm2
3.2nm LER





NXE:3100

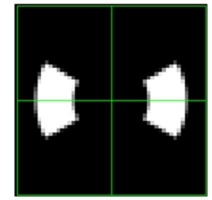


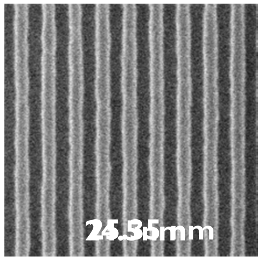
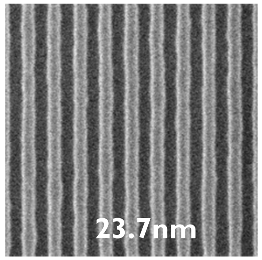
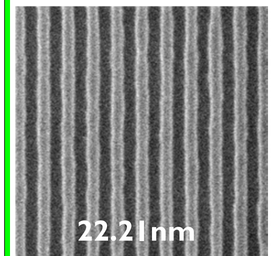
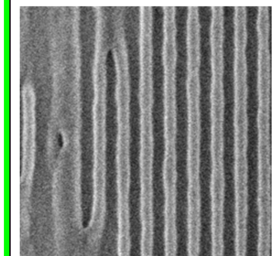
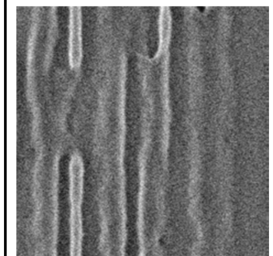
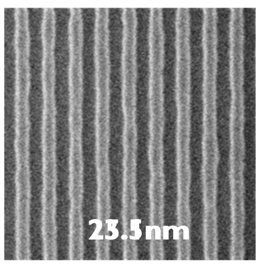
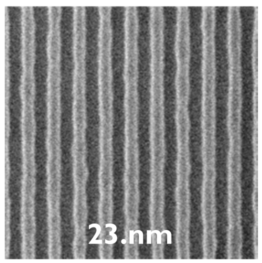
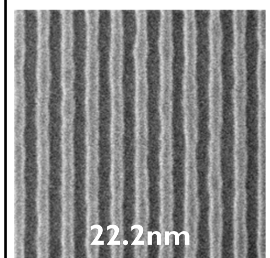
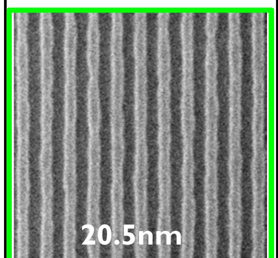
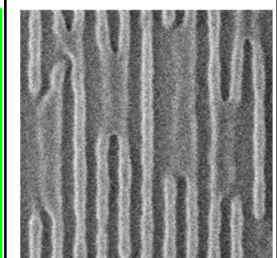
15.9mJ/cm2
3.2nm LER

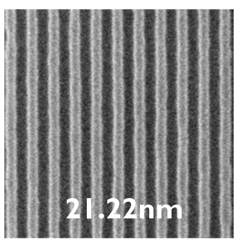
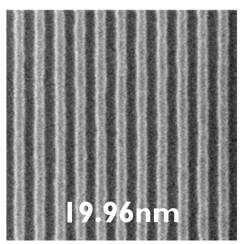
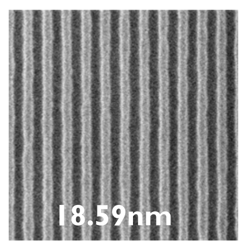
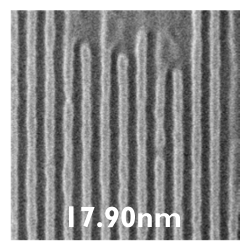
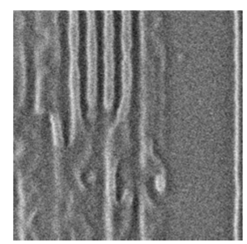
Resist D has smallest LER and highest resolution on NXE3100 at imec
Resist B and C are closest to target

EUV RESIST LS PERFORMANCE

ULTIMATE RESOLUTION – RESIST B and D



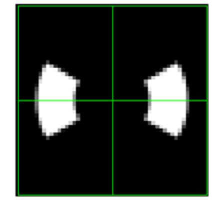
LS Pitch	L24P48	L23P46	L22P44	L21P42	L20P40
RESIST B 40nmFT 16.0mJ/cm2					
RESIST B 32nmFT 15.5mJ/cm2					

LS Pitch	L21P42	L20P40	L19P38	L18P36	L17P37
RESIST D 40nmFT 33mJ/cm2					

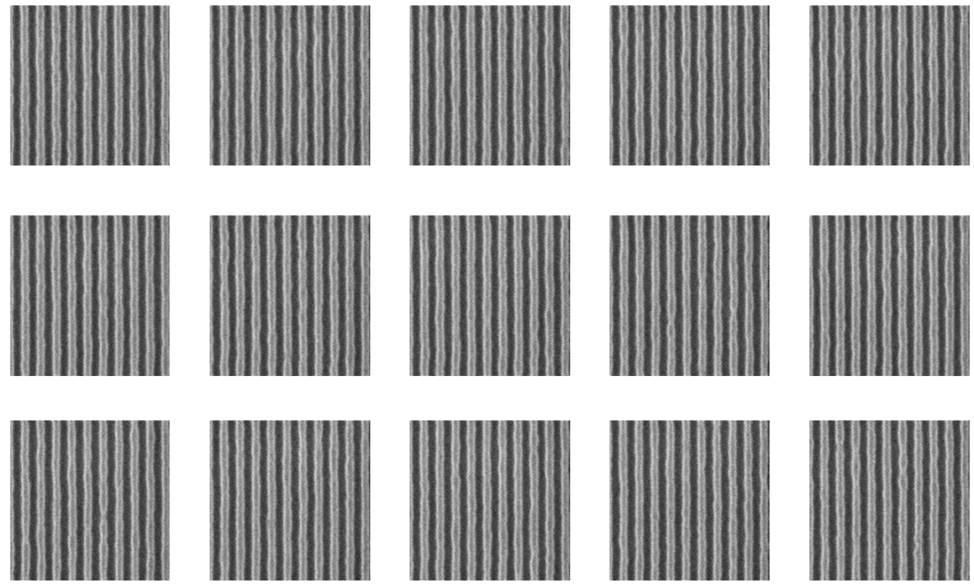
Pattern collapse limits the resolution of resist B, also 22nm CDU NOK
- Resist D shows 19nm LS resolution on NXE:3100

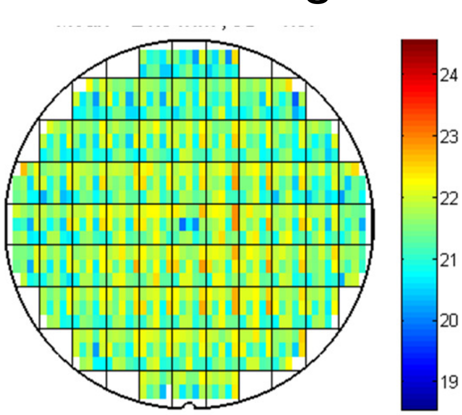
EUV RESIST LS PERFORMANCE

22nm LS CDU – RESIST C

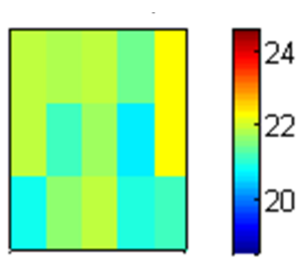


- NXE:3100 exposure
- Wafer coated on TEL Lithius Pro
- Dipole 60-X illumination, 20.5 mJ/cm^2
- Full wafer and full field exposure
- CD measured in 3 x 5 field positions, including field edges
- Raw data reported – split up in IF and across wafer signature

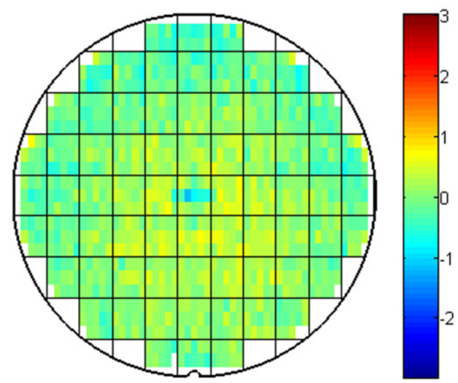




Total
1.67nm 3s



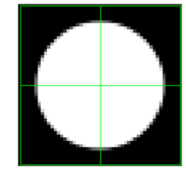
Intrafield
1.50nm 3s



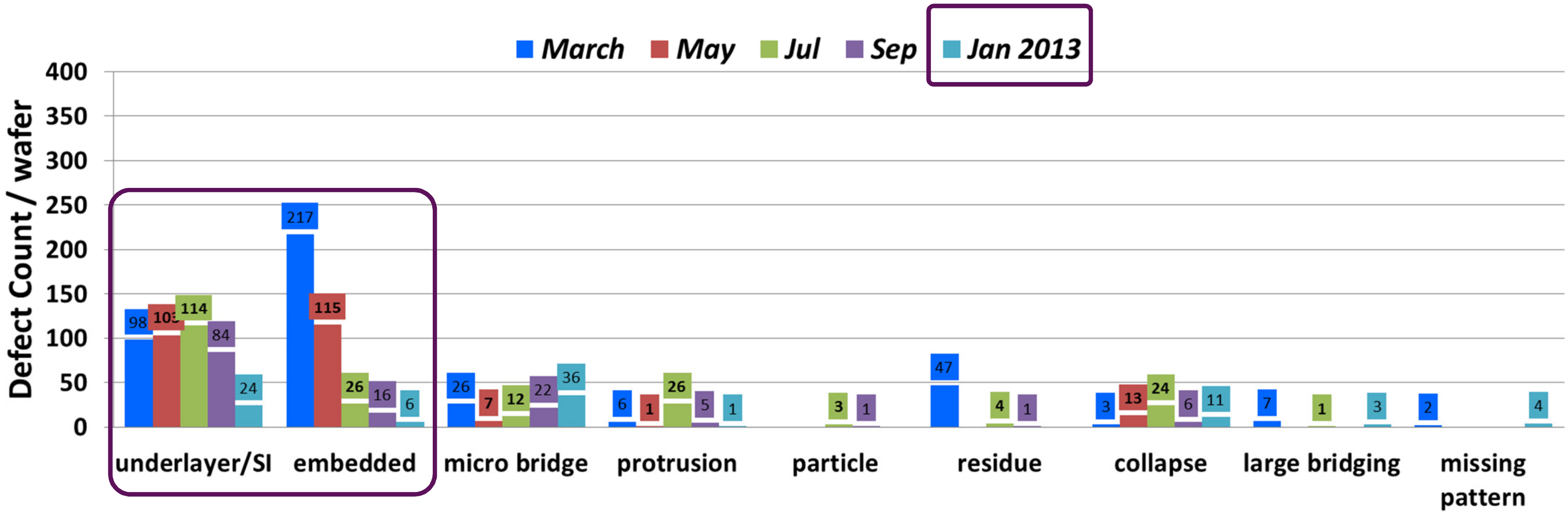
Intrafield subtracted
0.82nm 3s

EUV RESIST LS PERFORMANCE

32NM DENSE LS DEFECTIVITY – 2012 POR



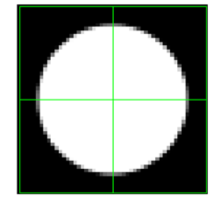
NXE:3100



Improvement in embedded defects reduces defect density further to 0.24 defects/cm^2

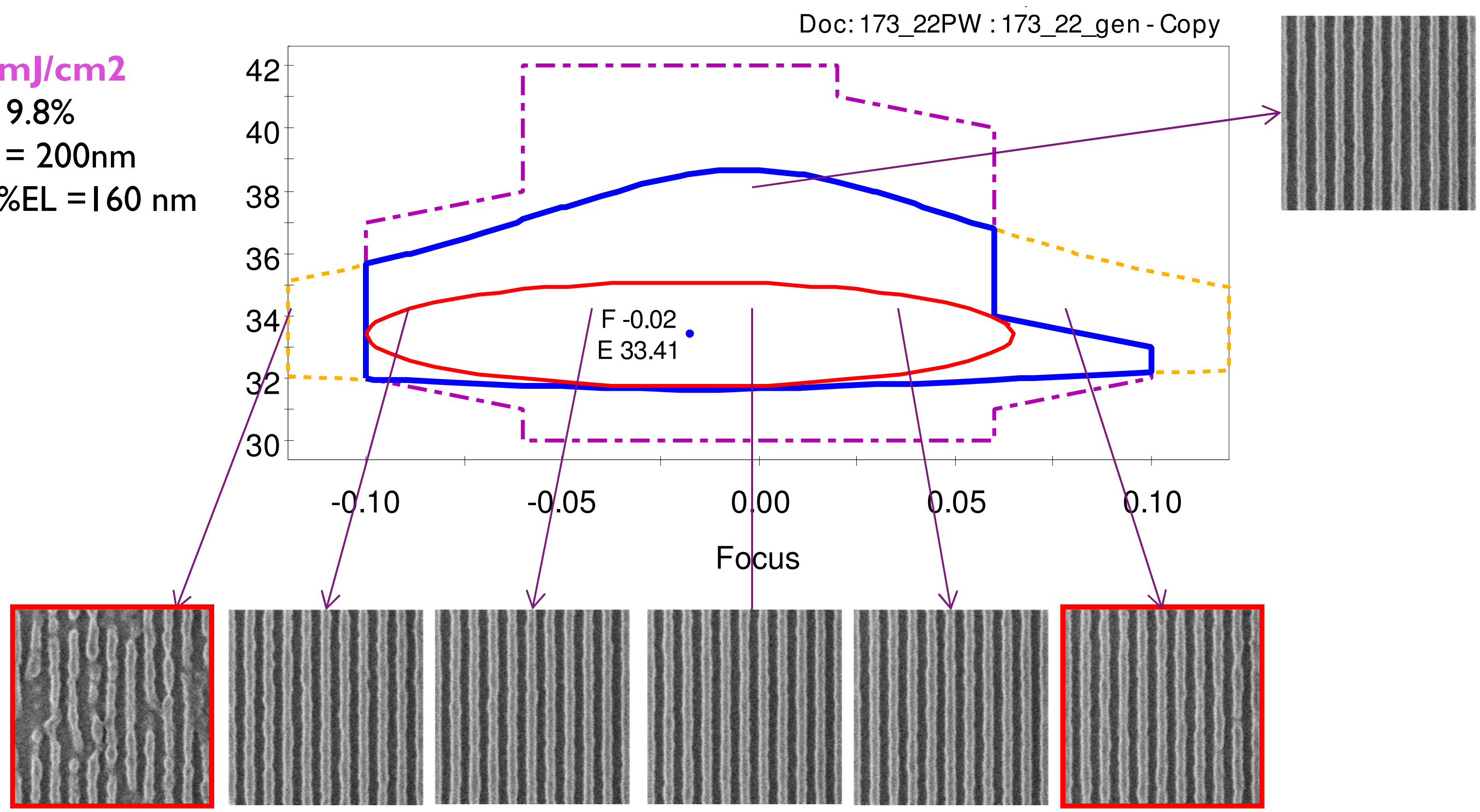
EUV RESIST LS PERFORMANCE

22NM DENSE LS PROCESS WINDOW – RESIST D



NXE:3300

DTS is 34mJ/cm2
Max EL =19.8%
Max DOF = 200nm
DOF@10%EL =160 nm

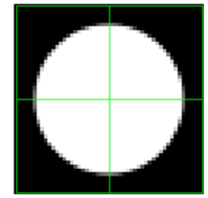


LER=4.1nm LER=3.4nm LER=3.2nm LER=3.5nm LER=4.3nm

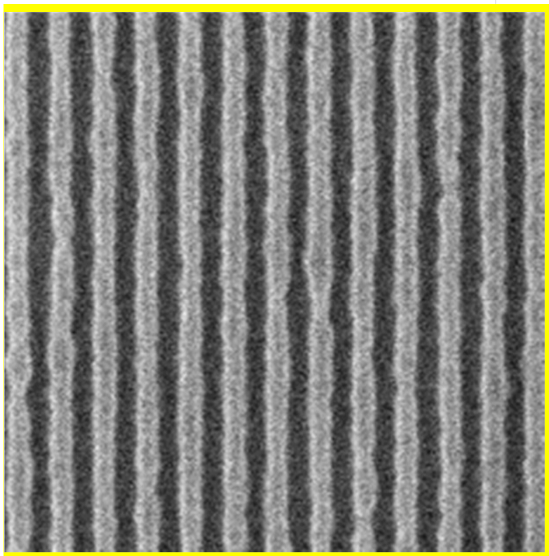
Good process window for 22nm HP

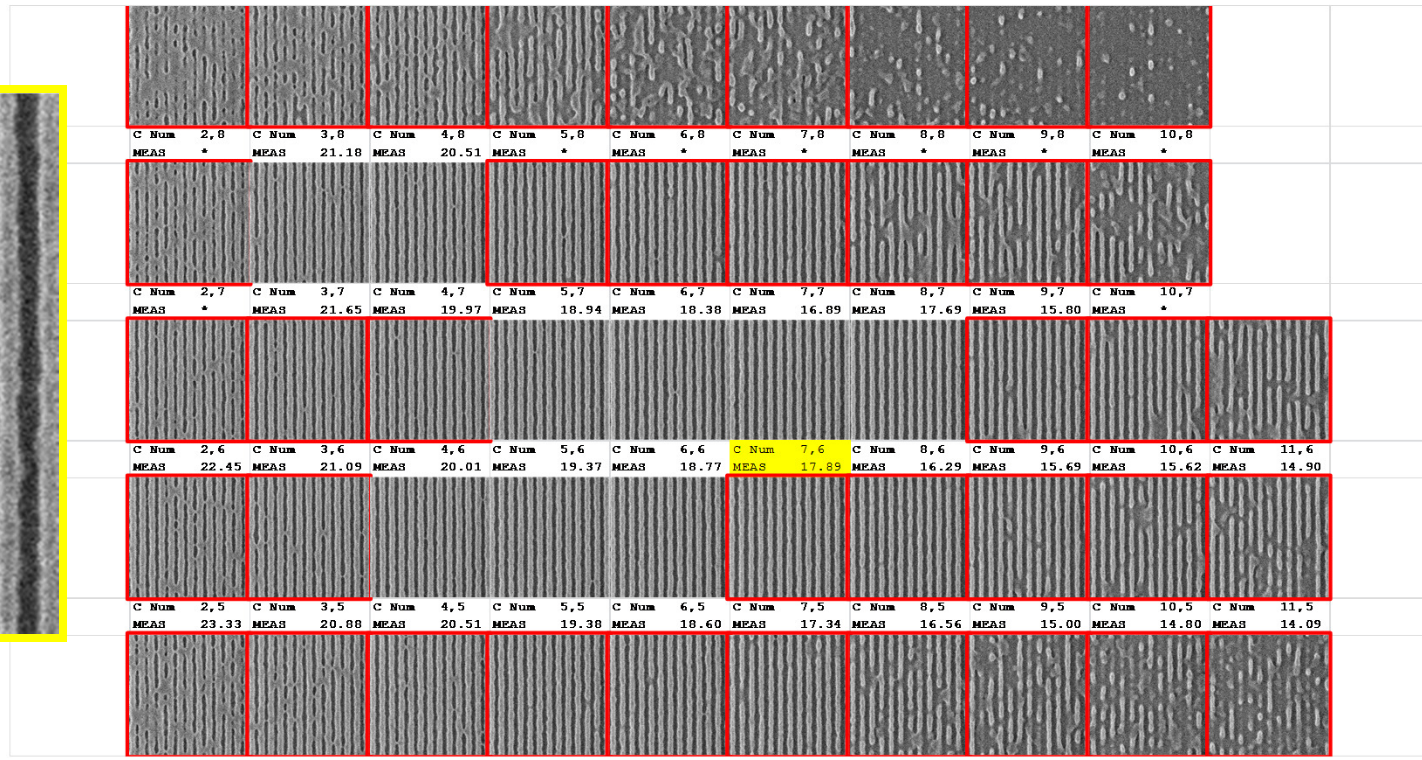
EUV RESIST LS PERFORMANCE

18NM DENSE LS FEM – RESIST D



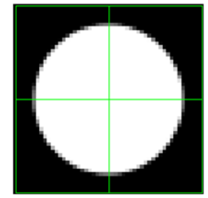
NXE:3300





No real process window in 18nm features as pinching is seen at best dose/focus condition in resist D in 30nm FT

EUV RESIST LS PERFORMANCE
DENSE LS RESOLUTION – RESIST D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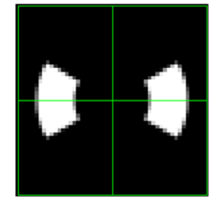
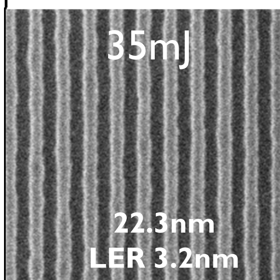
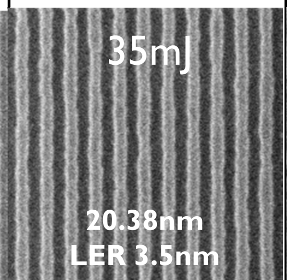
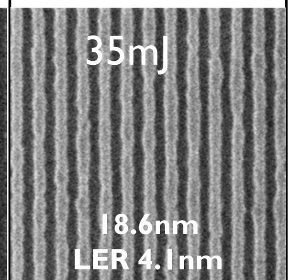
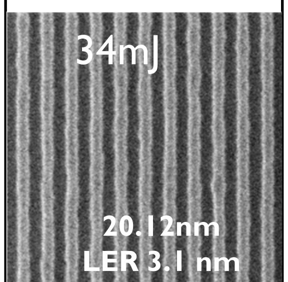
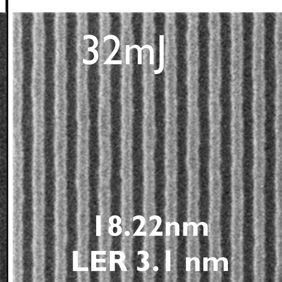
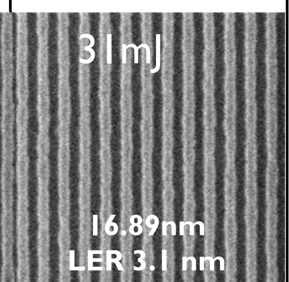
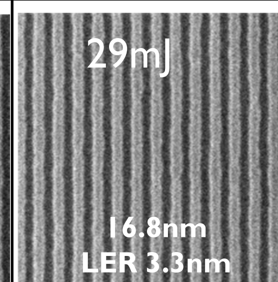
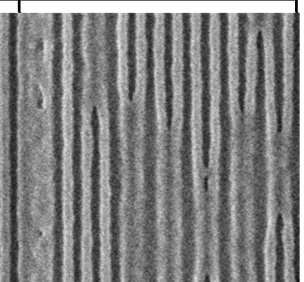
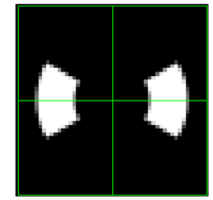

NXE:3300

LS Pitch	L22P44	L20P40	L18P36	L17P34	L16P32	L15P30
NXE3300 conventional 30nmFT Firm rinse 35mJ/cm2						
LS Pitch	**L22P44**	**L20P40**	**L18P36**	**L17P34**	**L16P32**	**L15P30**
NXE3300 Dipole45 30nmFT Firm rinse mJ/cm2						

Ultimate resolution with dipole-45 is 16nm in 30nm FT in resist D

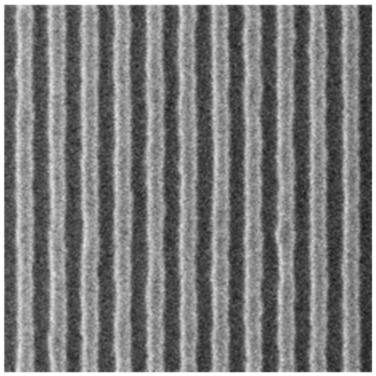
EUV RESIST LS PERFORMANCE

DENSE LS RESOLUTION – RESIST D



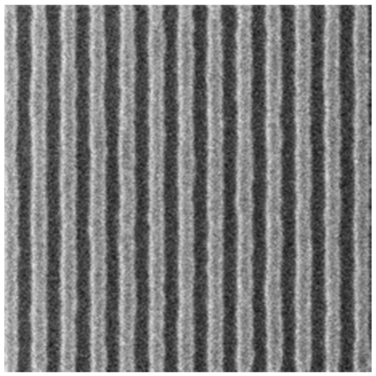
NXE:3300

20nm LS



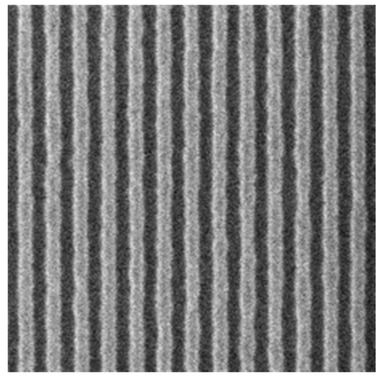
34mJ/cm2
3.1nm LER

18nm LS



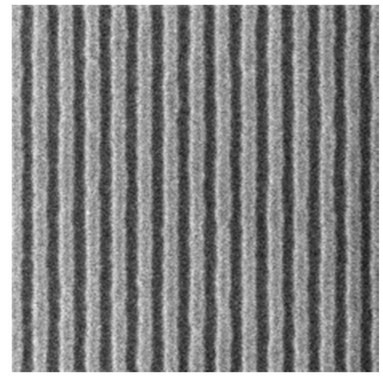
32mJ/cm2
3.1nm LER

17nm LS

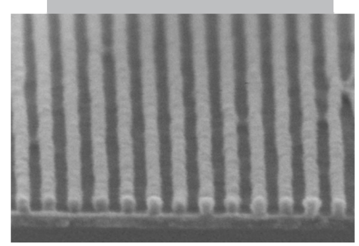


31mJ/cm2
3.1nm LER

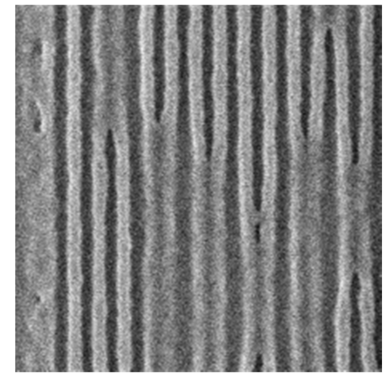
16nm LS



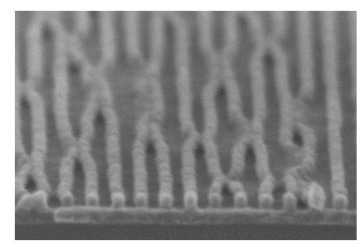
29mJ/cm2
3.3nm LER



15nm LS



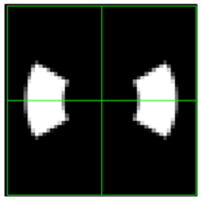
29mJ/cm2



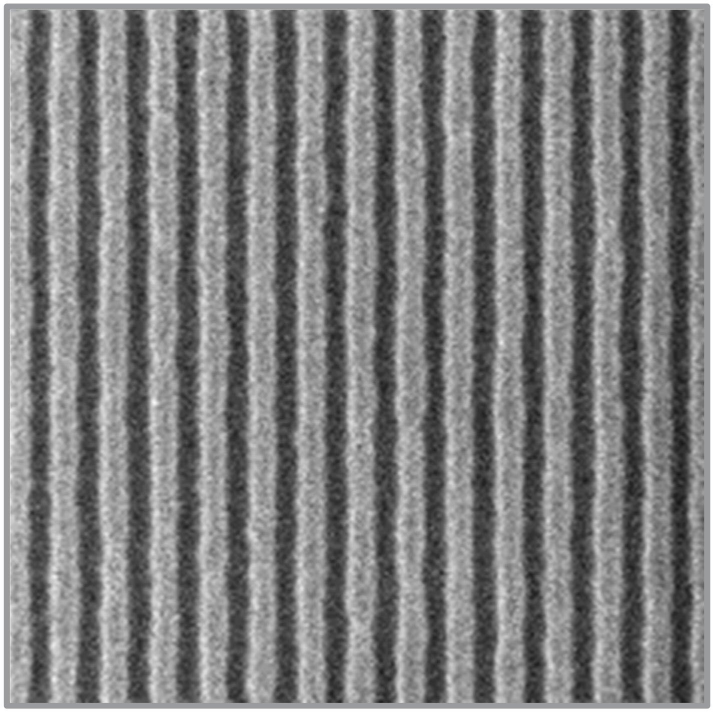
Ultimate resolution with dipole 45 is 16nm in 30nm FT in resist D - Pattern collapse is the major resolution limit

EUV RESIST LS PERFORMANCE

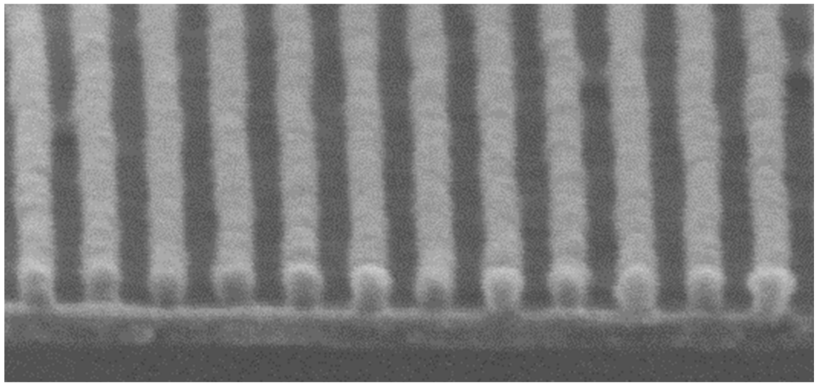
DENSE LS RESOLUTION – RESIST D



NXE:3300



30nmFT
Firm rinse
29.0mJ/cm2



CD=16.8nm
LER=3.3nm 3s
10% EL

CONTENTS

CONCLUSIONS

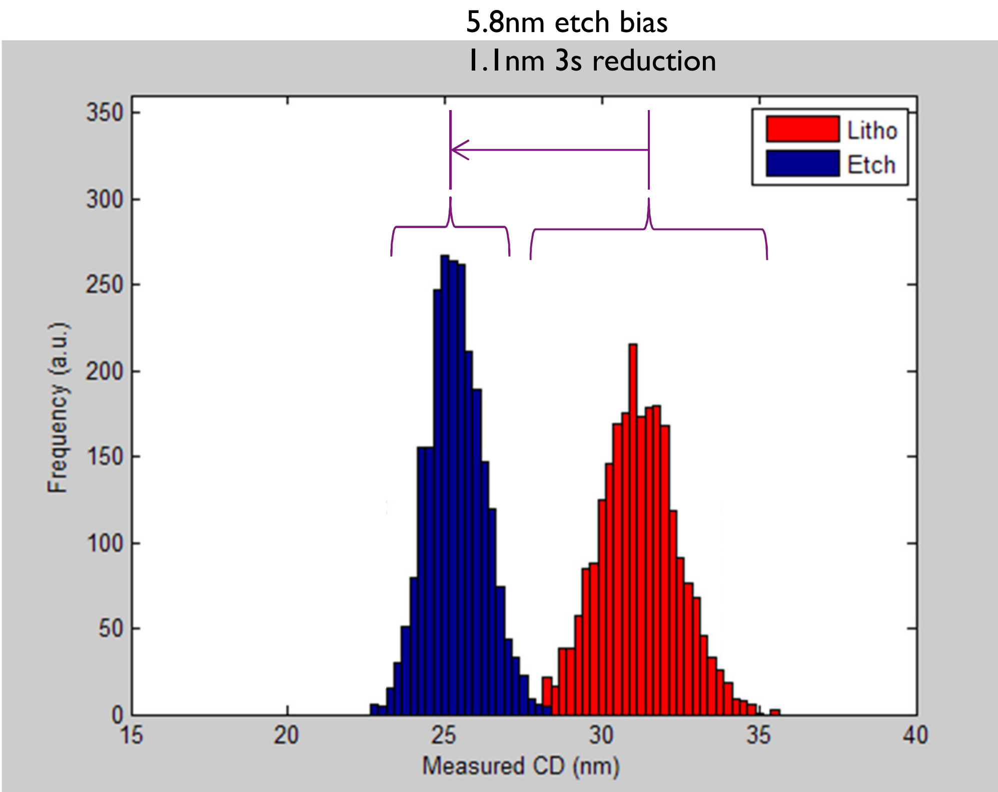
Item	Current status
CH LCDU vs. dose	**None achieving target – <1.2nm only at >20 mJ/cm^2**
LS LER vs. dose	2 resists close to 3nm LER at 15 mJ/cm^2 target
Resolution	**For LS resolution is collapse limited for CAR – at best 16nm HP**
Defectivity 32nm LS	Best datapoint for 2012 POR: 0.24 defects\cm^2
Defectivity 30nm CH	Best datapoint resist A – 1 defect\cm^2
22nm LS CDU	1.7nm 3s fullfield/full wafer on NXE:3100
30nm dense CH CDU	All 0.9-1.3nm 3s after DEV recipe optimization

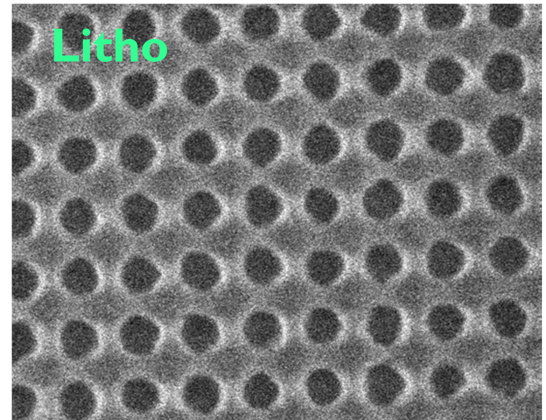
DEV recipe Sensitive!

Current resists are a good starting point for initial 3300 operation – but further improvements are needed in CAR to achieve the full potential of the NXE:3300 (13nm HP)

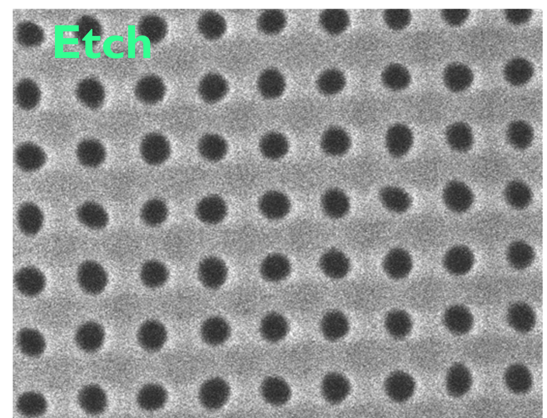
SMOOTHING BY POST-PROCESSING TECHNIQUES

RESIST C 52NM PITCH CH CD UNIFORMITY AFTER LITHO-ETCH





Mean CD: 31.16 nm
LCDU 3σ : 3.79 nm



Mean CD: 25.34 nm
LCDU 3σ : 2.70 nm

Contact hole uniformity 3s across wafer improves to 2.70nm 3s through resist etch

31nm CH at 52nm pitch printed to 31nm after litho
CD distribution over 32 fields, 75 CH per field, 27.25 mJ/cm2

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