ASSESSMENT OF EUV RESIST PERFORMANCE FOR SUB-22NM HP LINES AND 26NM HP CONTACTS ON NXE3100

A.M. Goethals, F. Van Roey, K. Hosokawa[2], R. Hoefnagels[1], A. Niroomand[3] and Ph. Foubert

IMEC, Leuven, Belgium

[1]ASML, Veldhoven, The Netherlands

On assignment from [2]Elpida, [3]Micron

International EUVL Symposium, 1-4 Oct 2012, Brussels

INTRODUCTION
NXE3100 CLUSTER AT IMEC

ASML NXE:3100 (NA=0.25, σ 0.81) , XTREME LDP source interfaced to a TEL CLEAN TRACK™ LITHIUS Pro™ -EUV

Field size: 26x33mm^2

NA=0.25 and σ=0.81

6 off-axis illumination conditions available

Flare < 8%

MMO vs NXT:1950i < 7nm

- **Resist screening and benchmarking :**
- Follow up the performance of EUV resist towards the annual set targets
- Select and optimize baseline resist processes to be installed on track for use in the imec EUV program and for device implementation.

EUV RESIST PERFORMANCE TARGETS

2012 TARGETS ON NXE:3100

Resist Performance Target on NXE3100	2012
CH screening with quasar ill	
Resolution Contacts 1:1 (nm)	**26nm**
Dose-to-size	**<20 mJ**
DOF@10%EL	**>100nm**
LCDU at 26nm HP (1σ)	**<1.0nm**
Resist thickness	**60nm**
LS screening with dipole 60 ill	
Resolution L/S 1:1 (nm)	**22nm**
DOF@10%EL	**>100nm**
dose-to-size	**<15mJ**
LER on 22nm L/S	**3.0nm**
Ultimate resolution	**<20nm**
Resist thickness	**40-50nm**
Ultimate resolution for LS With dipole 30 (extreme dipole)	**16nm**

In 2012, screening focus on 26nm CH & 22nmLS.
continue to measure 25nmLS & 28nmCH as reference.

© IMEC 2012

OUTLINE

Introduction

Resist benchmarking for POR process

Resist screening for LS

Resist screening for CH

Summary

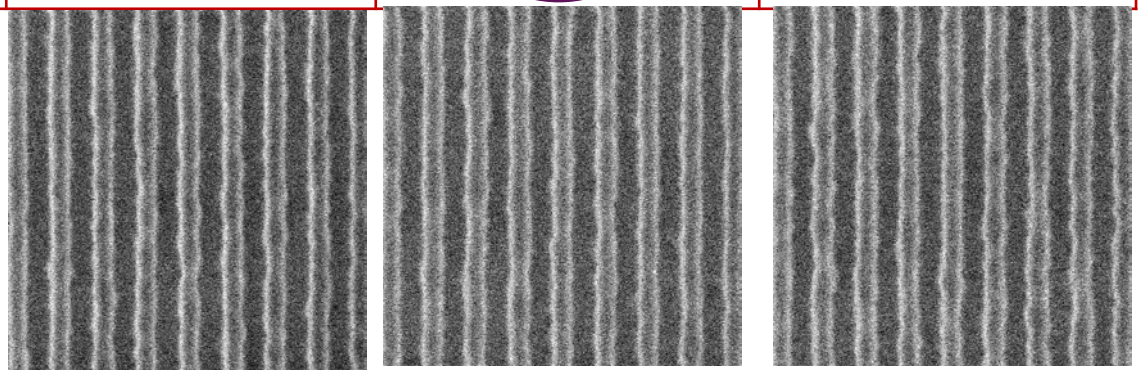
Acknowledgements

RESIST BENCHMARKING 27NM L/S

ON NXE:3100 (NA=0.25,σ=0.81)

	POR2010 SEVR-140	Resist D	Resist C
Dose to Size	12.8mJ/cm2	14.2mJ/cm2	12.4mJ/cm2
Max Exp latitude	7.8%	14.2%	8.4%
Max DOF	80nm	120nm	40nm
DOF at 10% EL	0nm	100nm	0nm

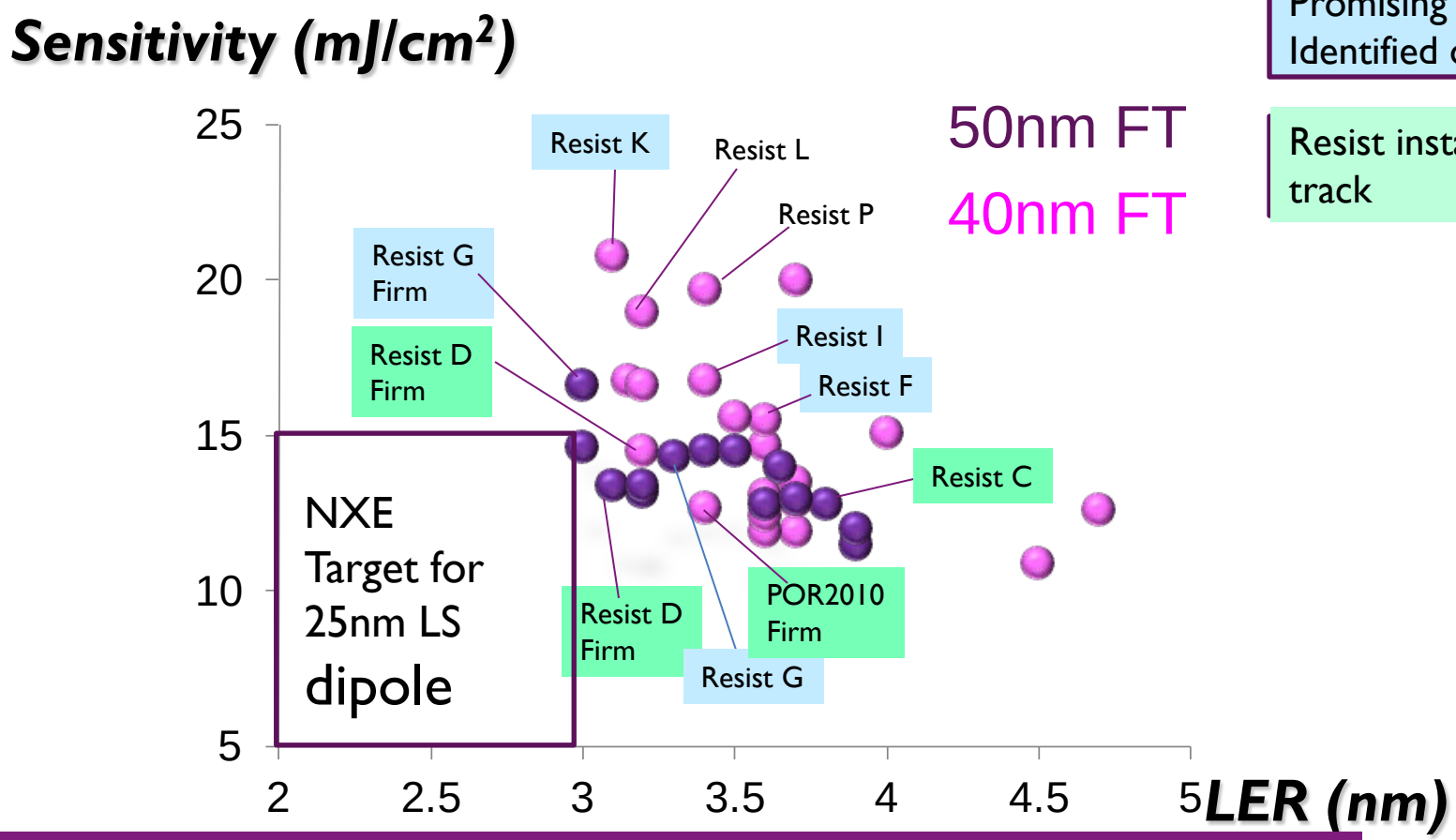
Resist FT at 50nm
Std UL. FT 20nm
NXE :3100



On NXE:3100 for **27nm LS** Resist D has the best performance using conventional illumination

RESIST SCREENING DIPOLE ON NXE 25NM LS

2011 target : 25nm LS



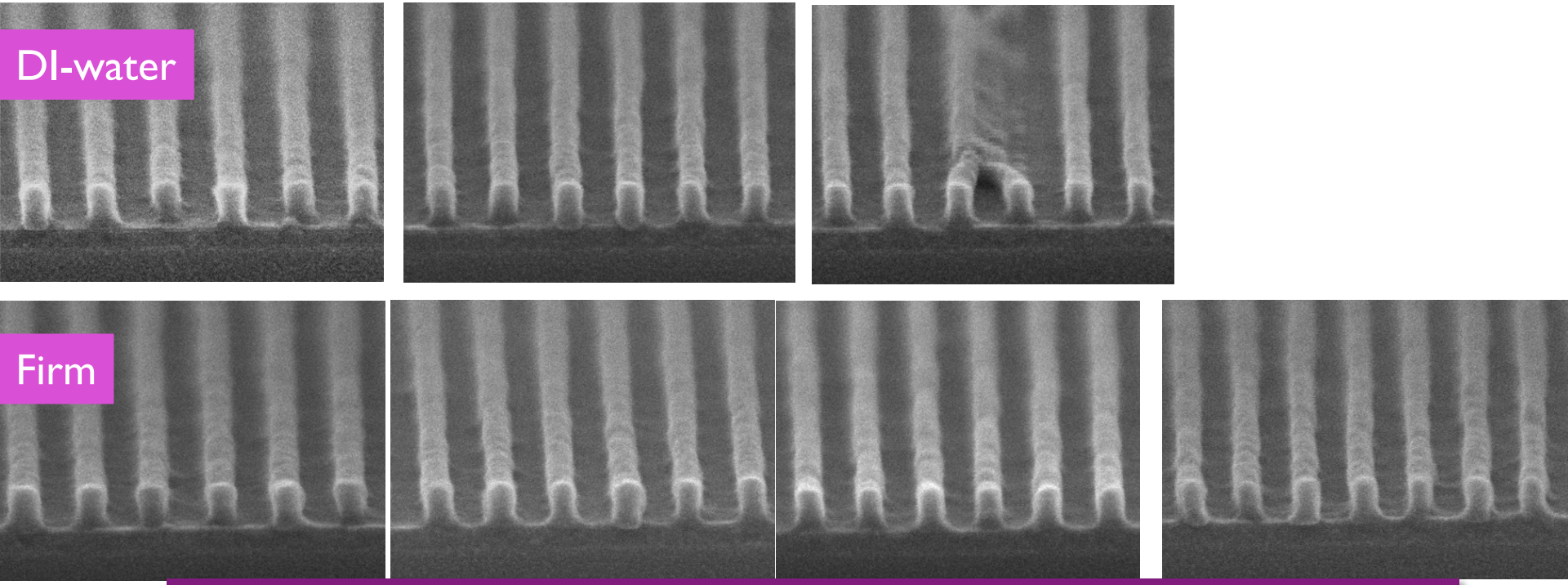
Promising resist Identified on ADT

Resist installed on track

From the resists installed on track, resist D is closest to meet the specifications.

SURFACTINATED RINSE EFFECT ON PROFILES
RESIST D WITH DIW AND FIRM™ EXTREME, 40NM FT

25nm L/S | 24nm LS | 23nm LS | 22nm LS



Surfactinated rinse improves the pattern collapse
No effect of Firm rinse on the profiles of resist D

© IMEC 2012

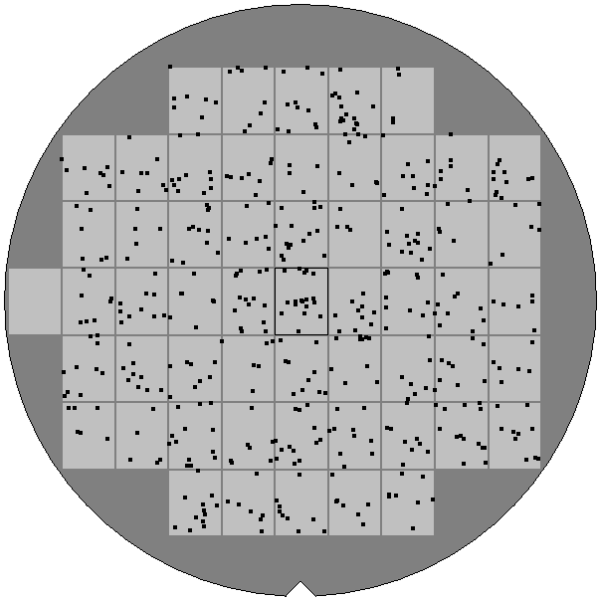
EUV RESIST BENCHMARKING ON NXE

PROCESS DEFECTIVITY FOR 32NM LS

Resist baseline defect density: 1-1.5 defects/cm^2.

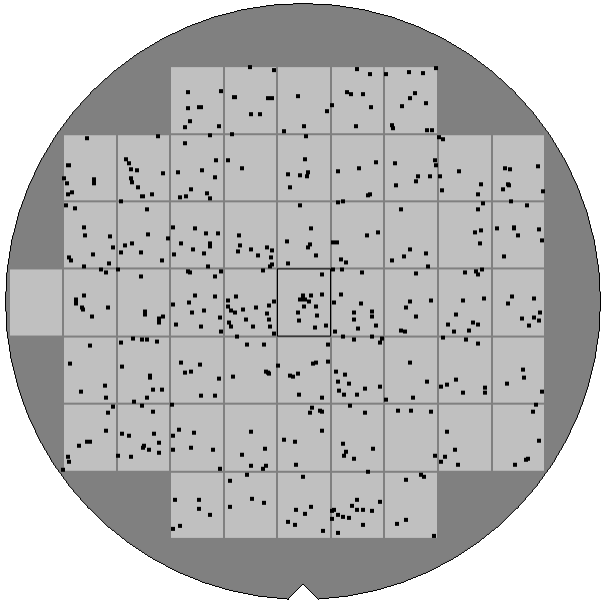
Baseline
SEVR-140 (POR 2010)

New resist process (resist D)
without and with FIRM rinse



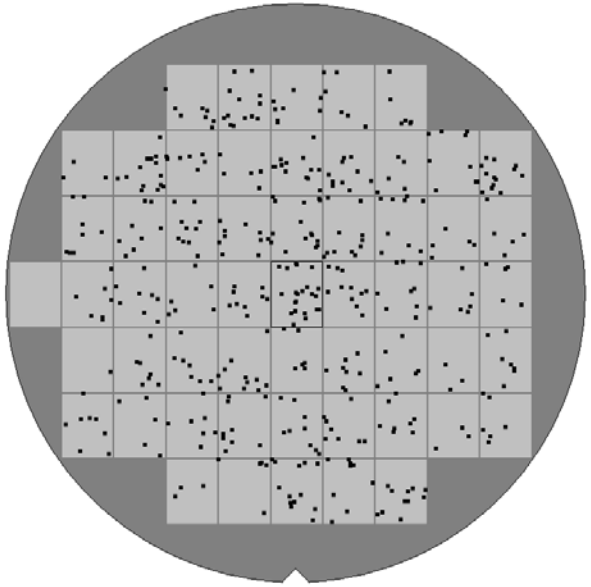
492 defects

Density = 1.41 defects/cm^2



406 defects

Density = 1.16 defects/cm^2

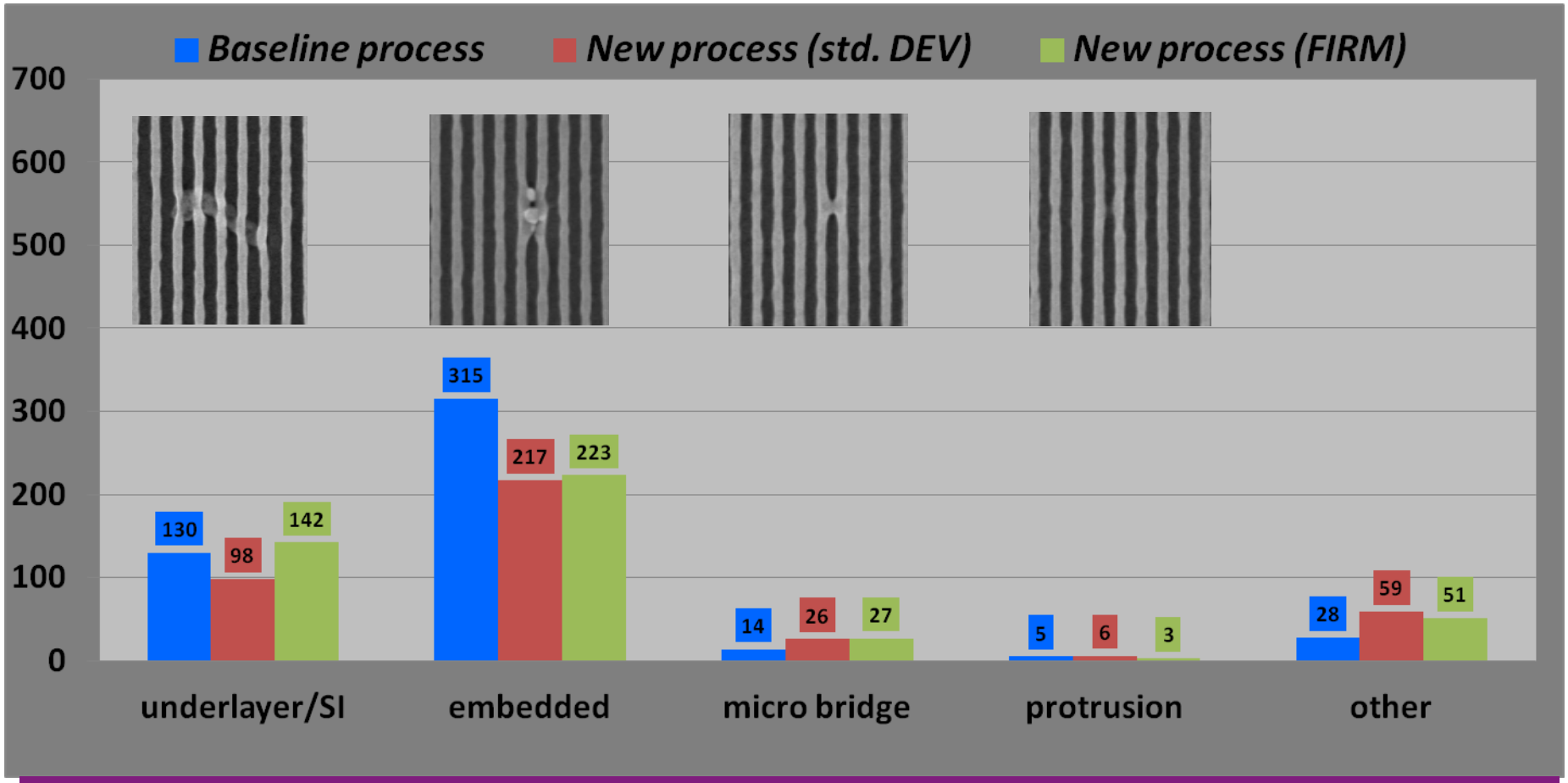


446 defects

Density = 1.27 defects/cm^2

Surfactinated FIRM rinse does not degrade defectivity levels compared to the previous POR2010 baseline process.

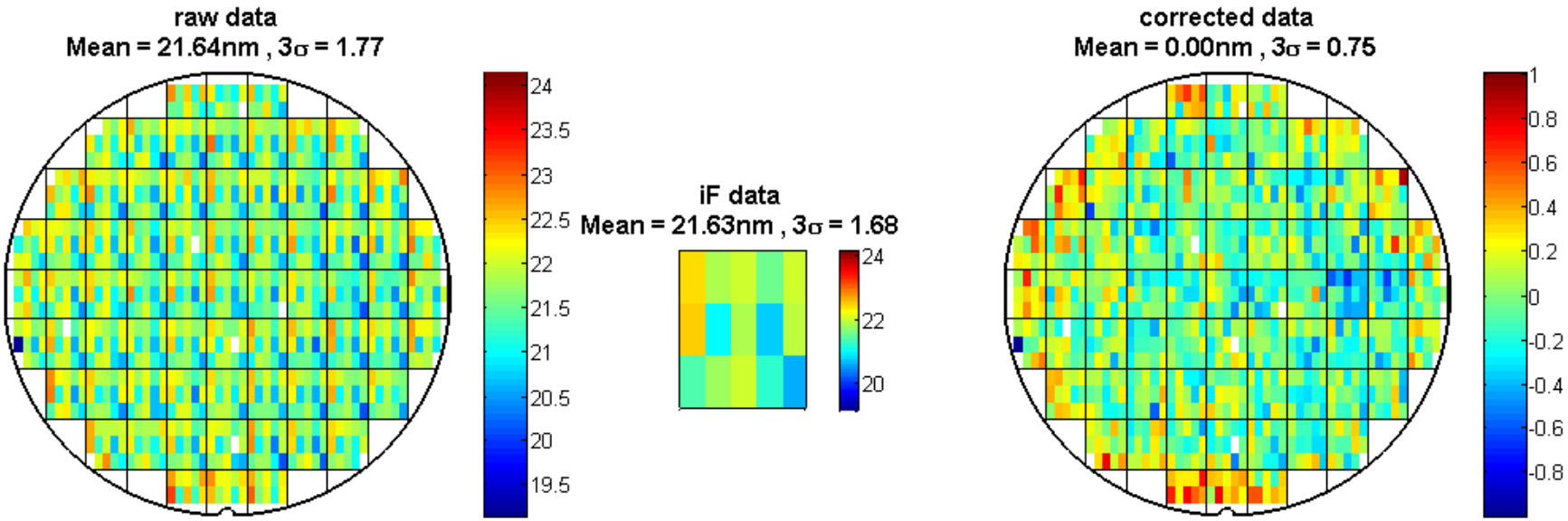
DEFECTIVITY
32NM 1:1, CLASSIFICATION



Defects embedded in resist are major contributors.

Ph. Foubert "Process evaluation and optimization for EUV manufacturing"

PROCESS OPTIMIZATION AT 22NM CD CONTROL FOR NEW POR2012



Using dipole illumination and FIRM surfactinated rinse, 22nm LS can be resolved with good uniformity across wafer

OUTLINE

Introduction

Resist benchmarking for POR process

Resist screening for LS

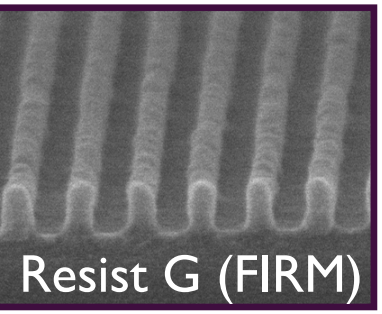
Resist screening for CH

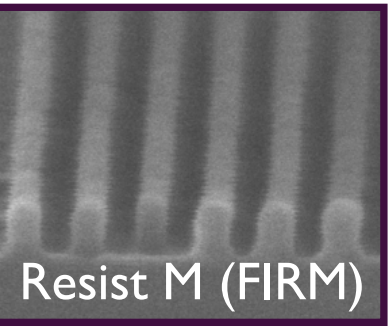
Summary

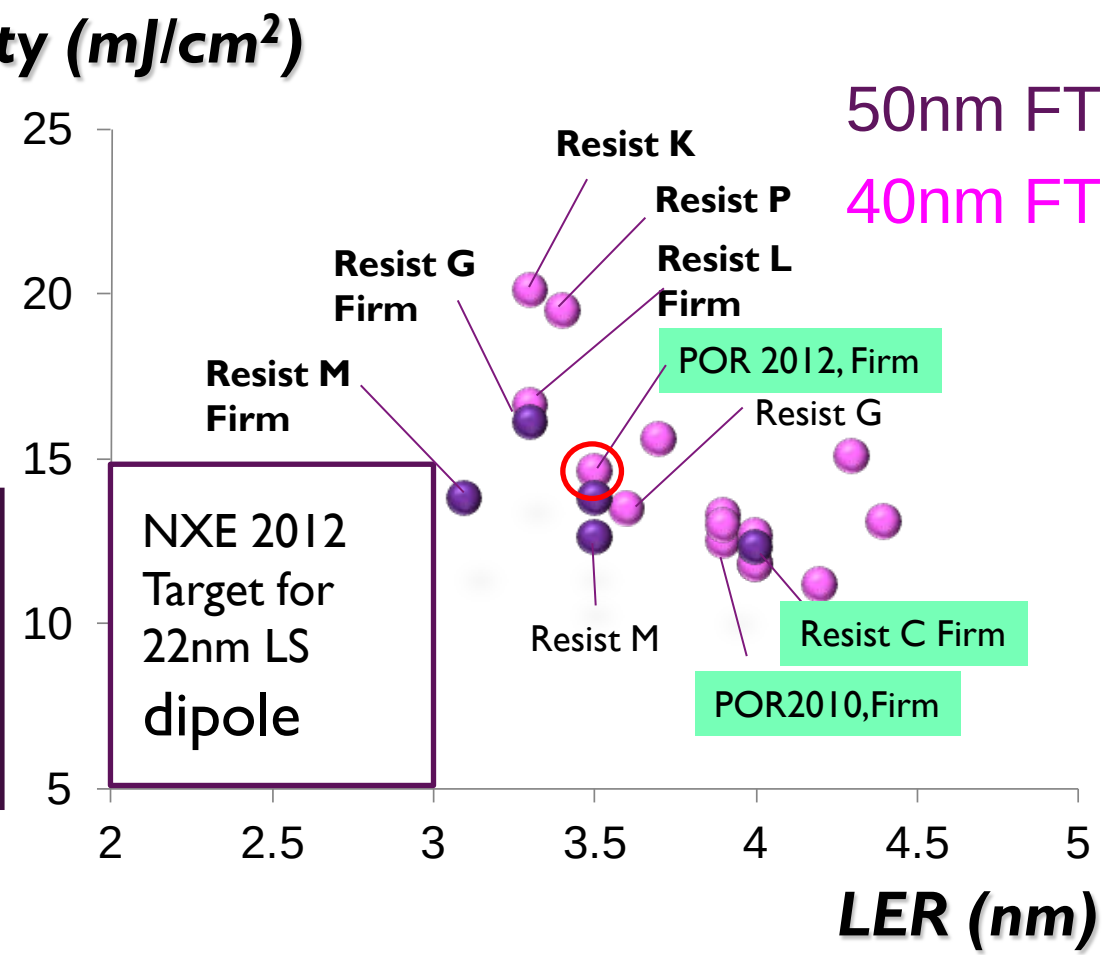
Acknowledgements

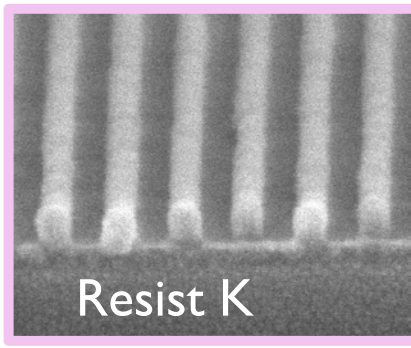
RESIST SCREENING DIPOLE ON NXE
22NM LS

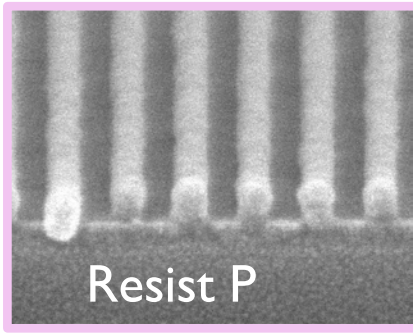
2012 target : 22nm LS

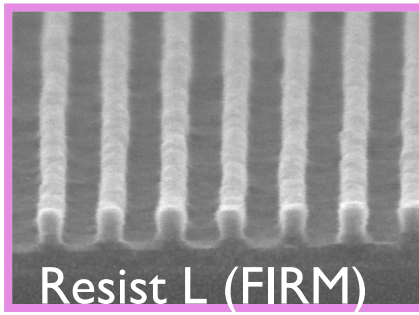






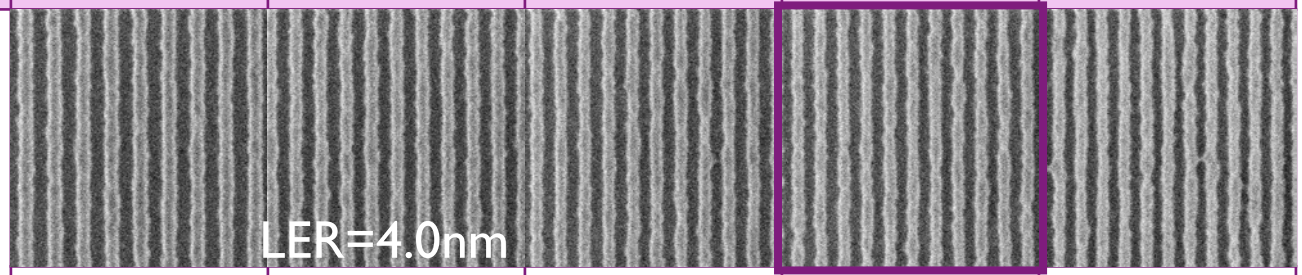
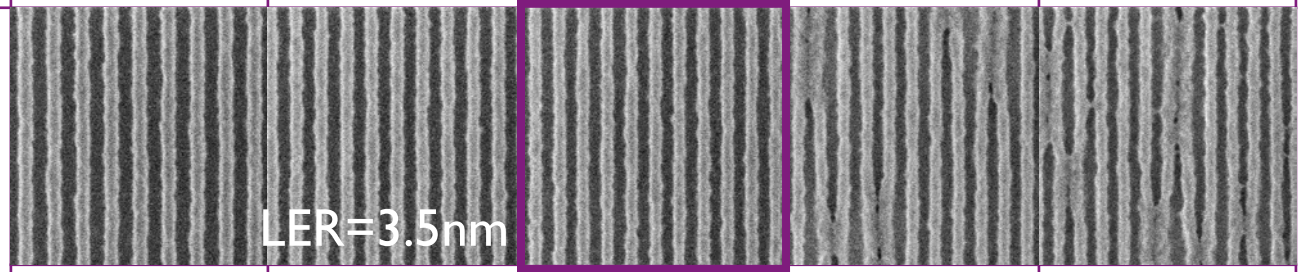
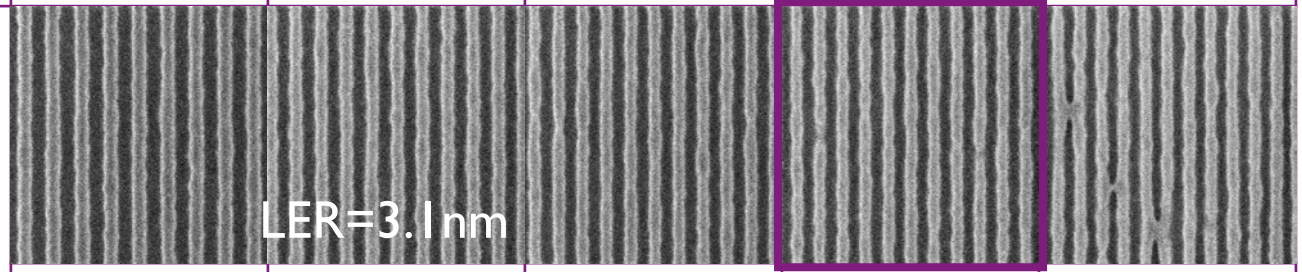






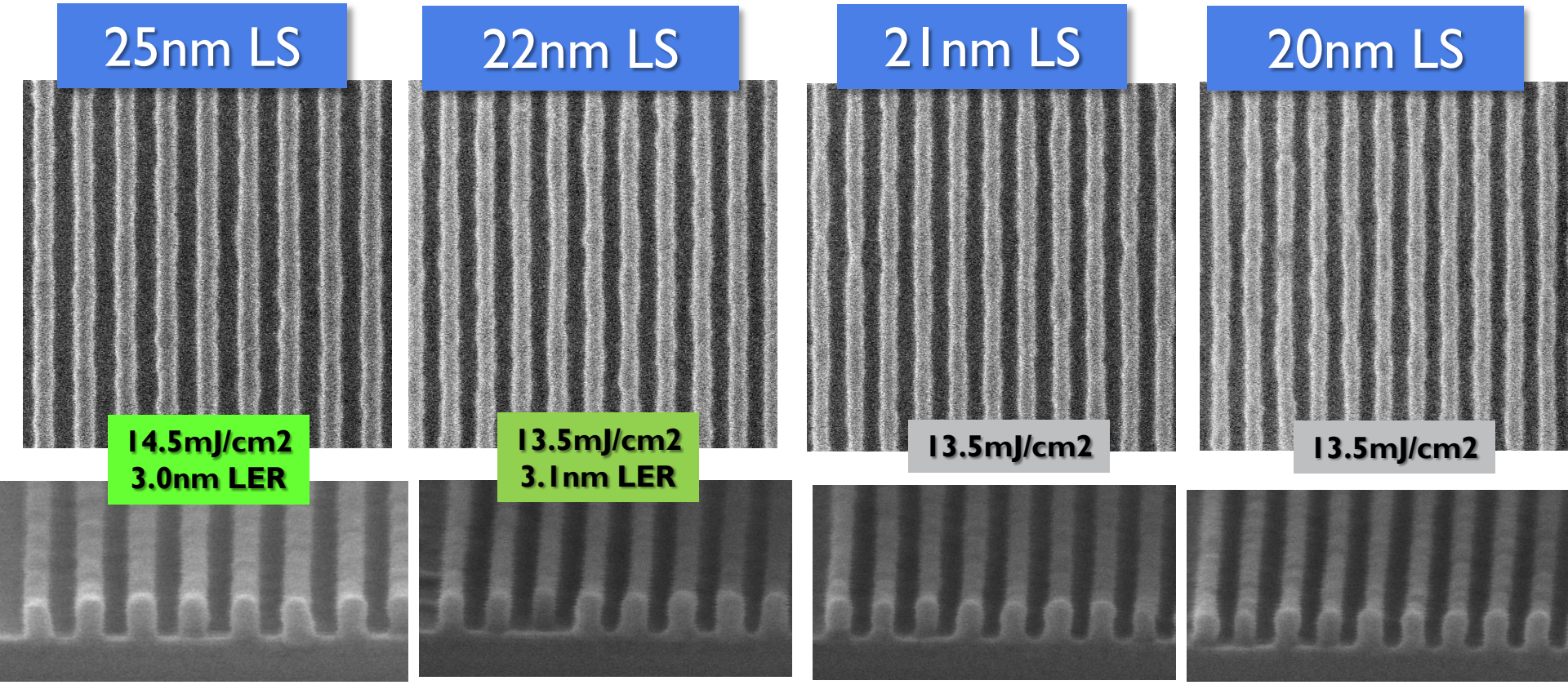
© IMEC 2012

ULTIMATE RESOLUTION FOR RESIST M
EFFECT OF THICKNESS AND FIRM RINSE

LS/Pitch	L25P50	L22P44	L21P42	L20P40	L19P38
40nmFT	 LER=4.0nm				
	12.5mJ, 24.8nm	12.0mJ, 21.7nm	12.0mJ, 20.6nm	12.0mJ, 19.4nm	12.0mJ, 19.1nm
50nmFT	 LER=3.5nm				
	13.5mJ, 24.6nm	12.5mJ, 22.1nm	12.5mJ, 20.7nm	12.5mJ, 20.4nm	12.5mJ, -nm
50nmFT FIRM	 LER=3.1nm				
	14.5mJ, 25.2nm	13.5mJ, 22.5nm	13.5mJ, 21.1nm	13.5mJ, 20.1nm	13.5mJ, 19.7nm

Ultimate resolution is 20nm at a dose of 12mJ/cm^2
Firm rinse improves the collapse margin to aspect ratio of 2.5 and reduces LER

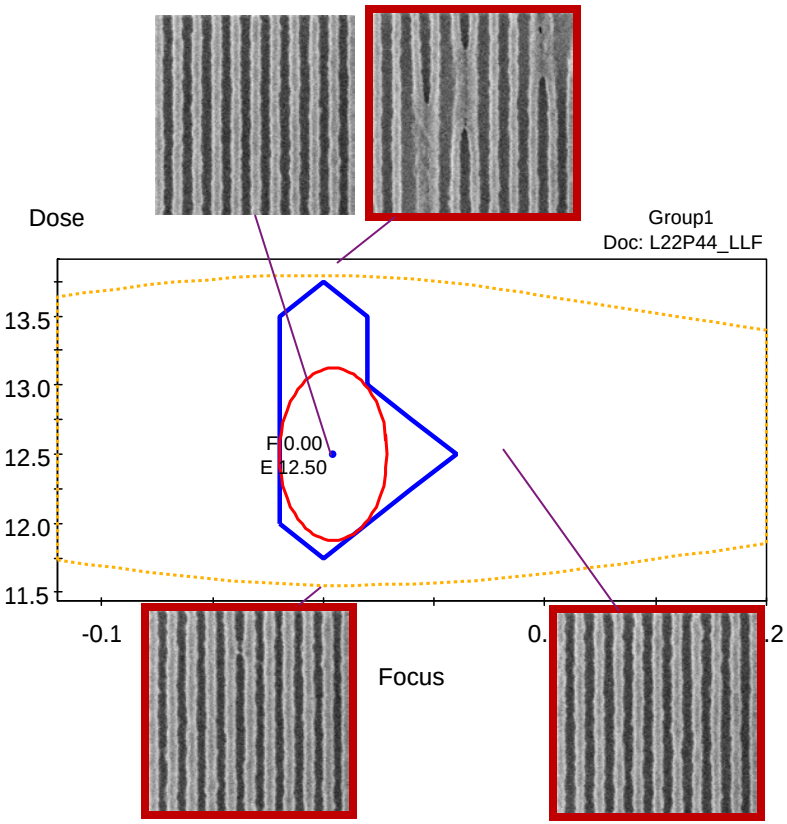
RESIST PERFORMANCE ON NXE, DIPOLE ILL RESIST M WITH FIRM, 50NM THICKNESS ON 20NM E²STACK AL412



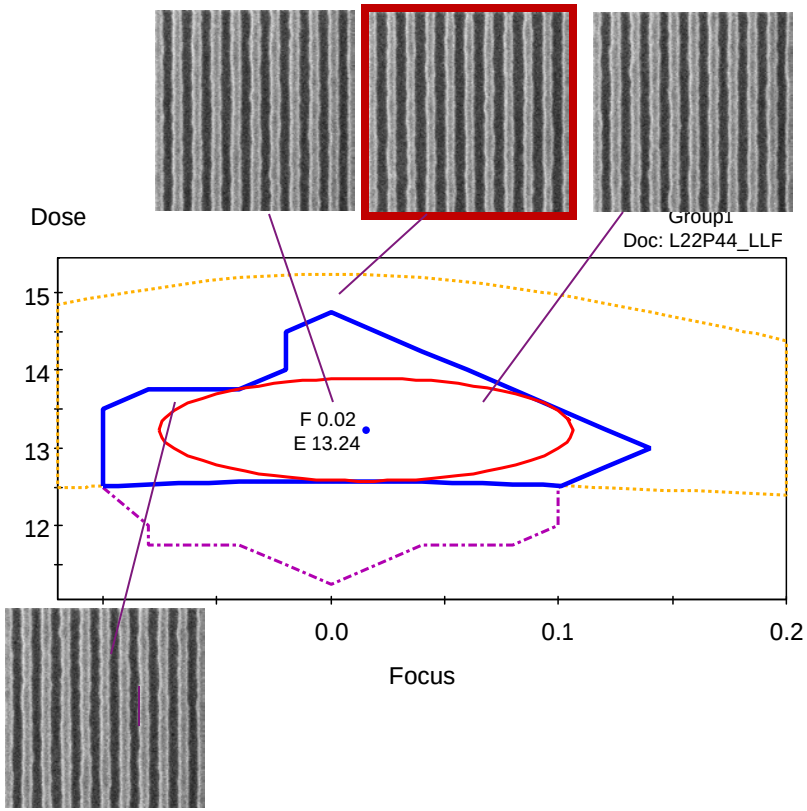
Resist M almost meets the requirements for 22nm LS. The ultimate resolution is 20nm

PROCESS WINDOW FOR 22NM LS
RESIST M IN 50NM FT DI-WATER VS FIRM

DI-water

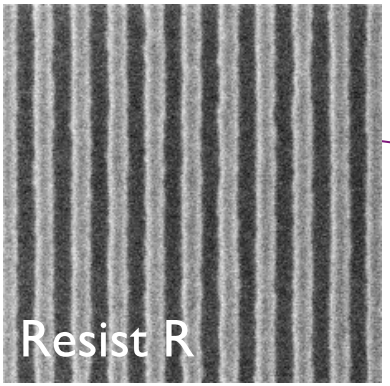


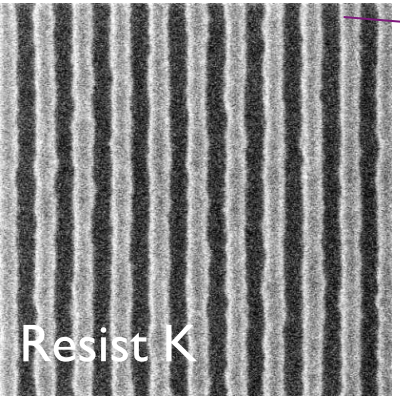
FIRM

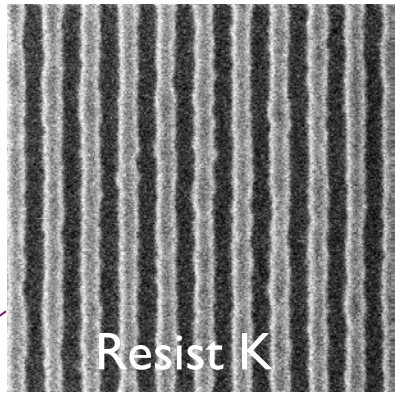


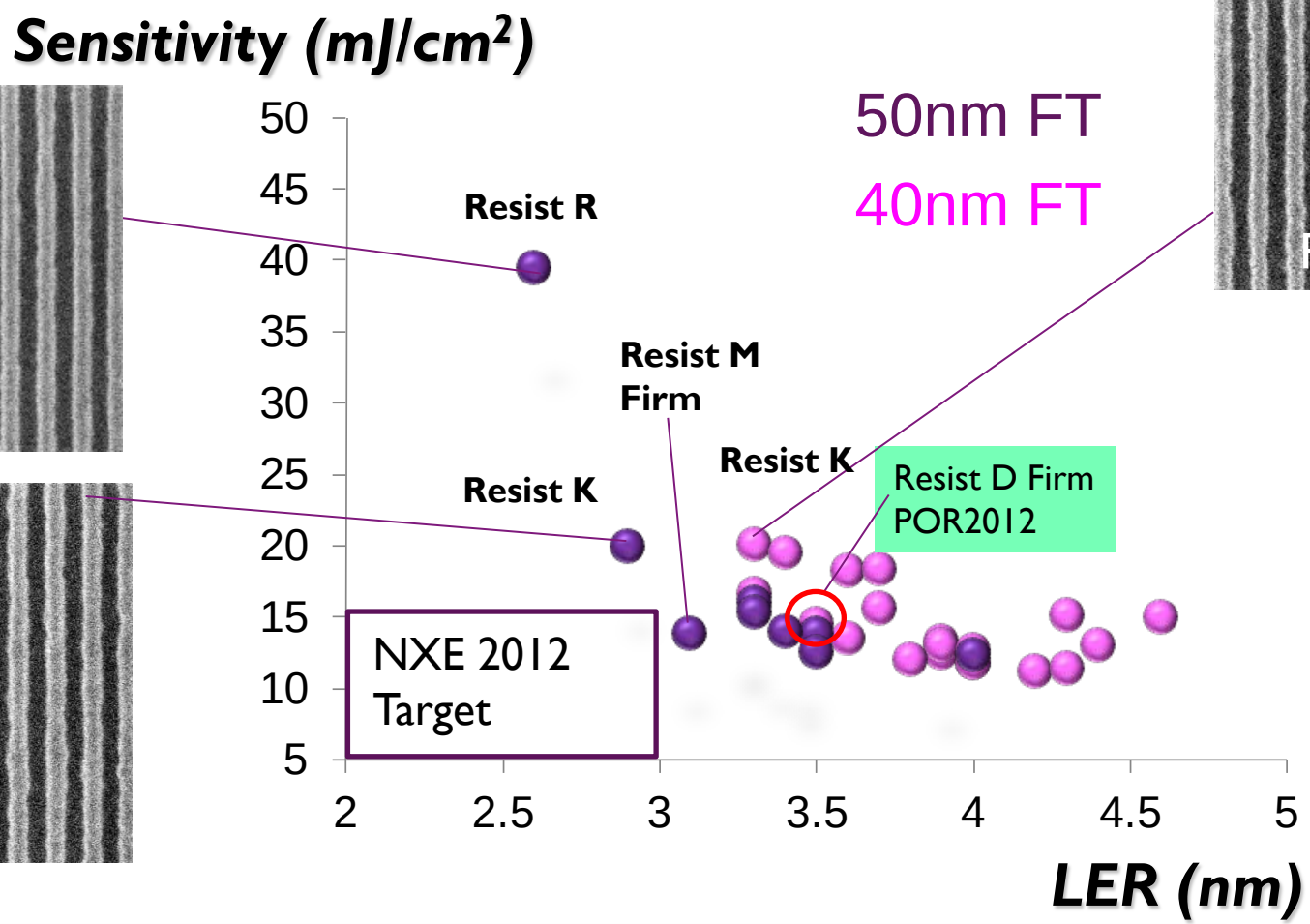
Firm rinse results in larger process window through improvement of the LER (line quality)

RESIST SCREENING DIPOLE ON NXE
22NM LS









LER meeting the spec at increasing dose-to-size.

© IMEC 2012

RESIST PERFORMANCE ON NXE, DIPOLE 60 ILL

RESIST K, ON 20NM E²STACK AL412

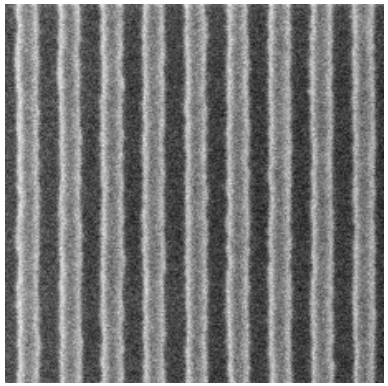
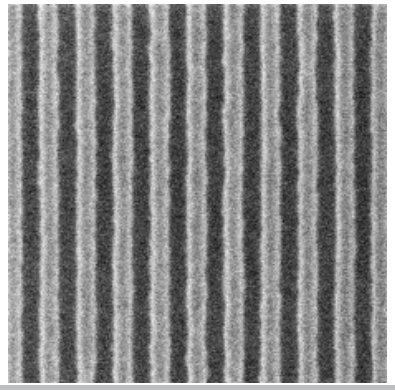
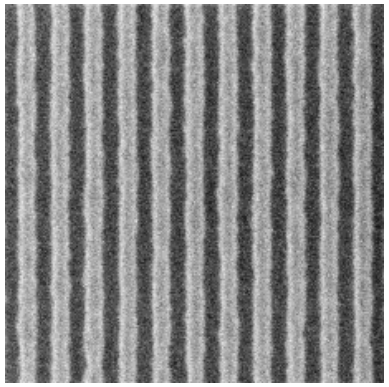
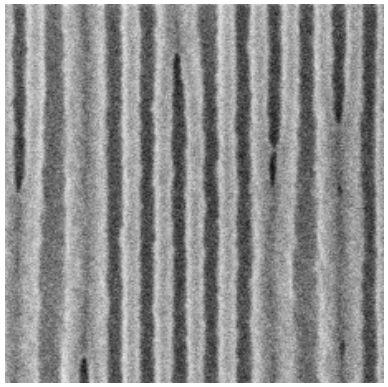
	25nm LS	22nm LS	20nm LS	19nm LS
40nm FT	21mJ/cm2 3.1nm LER	20.1mJ/cm2 3.3nm LER	20.1mJ/cm2	20.1mJ/cm2
50nm FT	22mJ/cm2 2.8nm LER	20.mJ/cm2 2.9nm LER	20.mJ/cm2	20.mJ/cm2

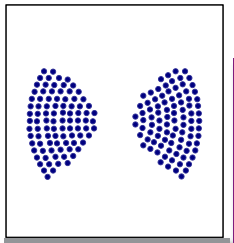
Resist K is the resolution champions but high dose-to-size:
19nm LS in 40nm resist thickness

© IMEC 2012

LER CHAMPION RESIST R

DIPOLE 60 ILLUMINATION, 50NM RESIST R, DI WATER

25nm LS	22nm LS	20nm LS	19nm LS
			
41mJ/cm2 2.5nm LER	**39.5mJ/cm2 2.6nm LER EL 19.5%, DOF>300nm**	**38mJ/cm2**	**38mJ/cm2**



60°Dipole
σ0.81/0.43

ultimate resolution is 20nm in 50nm resist thickness
Champion with regard to LER but low sensitivity (factor X3 with regard to imec dose target specs)

© IMEC 2012

EUV RESIST PERFORMANCE TARGETS

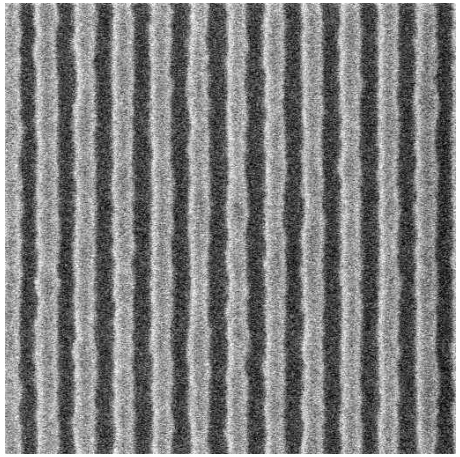
2012 TARGETS ON NXE:3100

Resist Performance Target on NXE3100	2012
CH screening with quasar ill Resolution Contacts 1:1 (nm) Dose-to-size DOF@10%EL LCDU at 28nm HP (1σ) Resist thickness	 **26nm** **<20 mJ** **>100nm** **<1.0nm** **60nm**
LS screening with dipole 60 ill Resolution L/S 1:1 (nm) DOF@10%EL dose-to-size LER on 22nm L/S Ultimate resolution Resist thickness	 **22nm** **>100nm** **<15mJ** **3.0nm** **<20nm** **40-50nm**
Ultimate resolution for LS **With dipole 30 (extreme dipole)**	**16nm**

© IMEC 2012

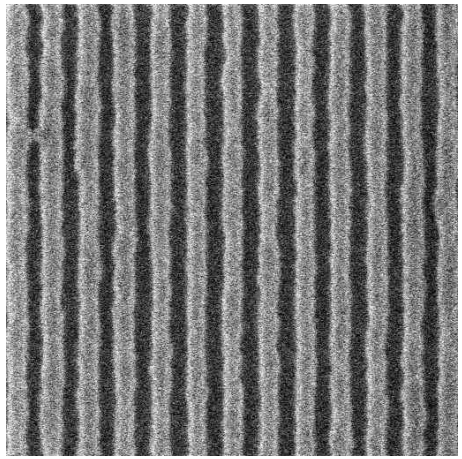
RESOLUTION CAPABILITY WITH DIPOLE 30, RESIST K

19nm LS



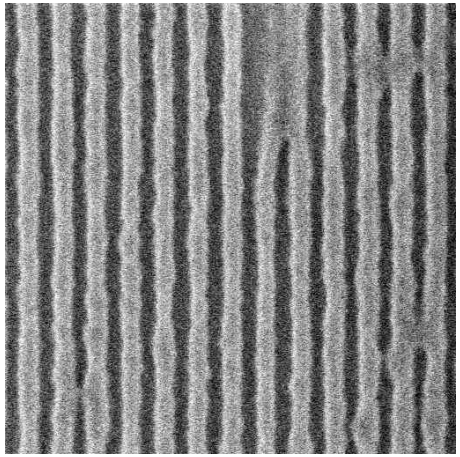
12.4mJ/cm2

18nm LS



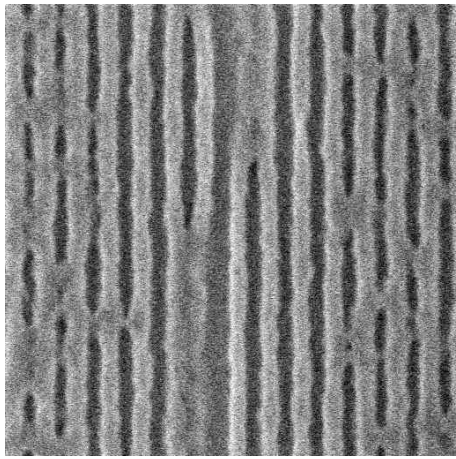
11.8mJ/cm2
3.7nm LER

17nm LS

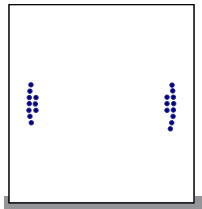


11.2mJ/cm2

16nm LS



11.2mJ/cm2



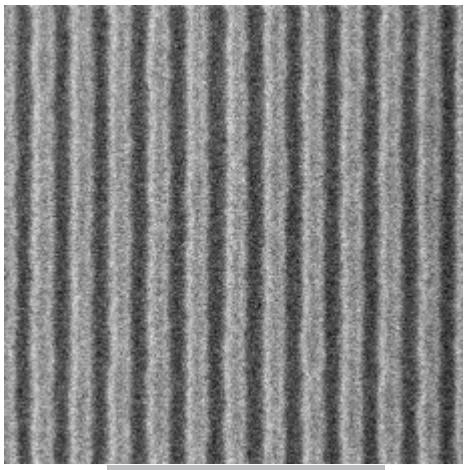
30°Dipole
σ0.8/0.7

ultimate resolution is 18nm in 35nm resist thickness
Collapse is limiting the performance

© IMEC 2012

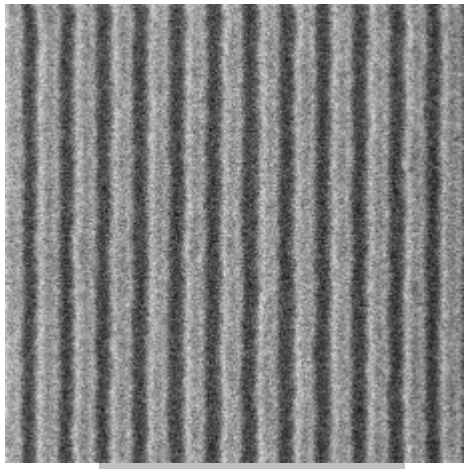
RESOLUTION CAPABILITY WITH DIPOLE 30, RESIST R

19nm LS



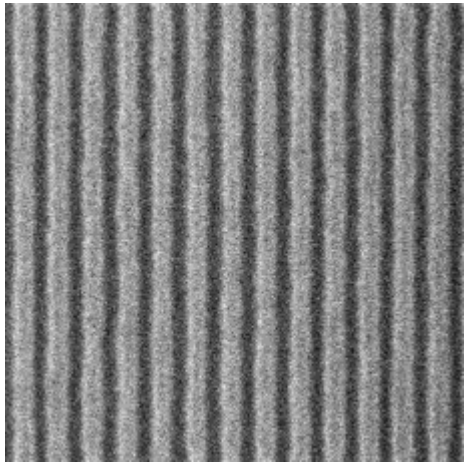
25.6mJ/cm2

18nm LS



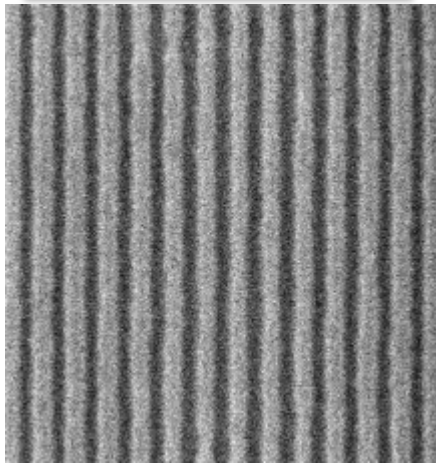
24.8mJ/cm2
3.0nm LER

17nm LS

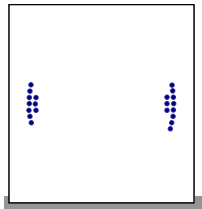


24mJ/cm2

16nm LS



24.8mJ/cm2



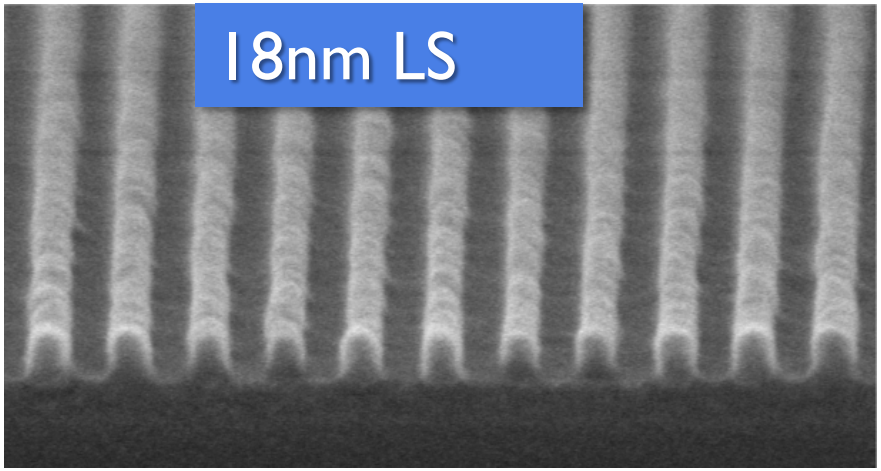
30°Dipole
σ0.8/0.7

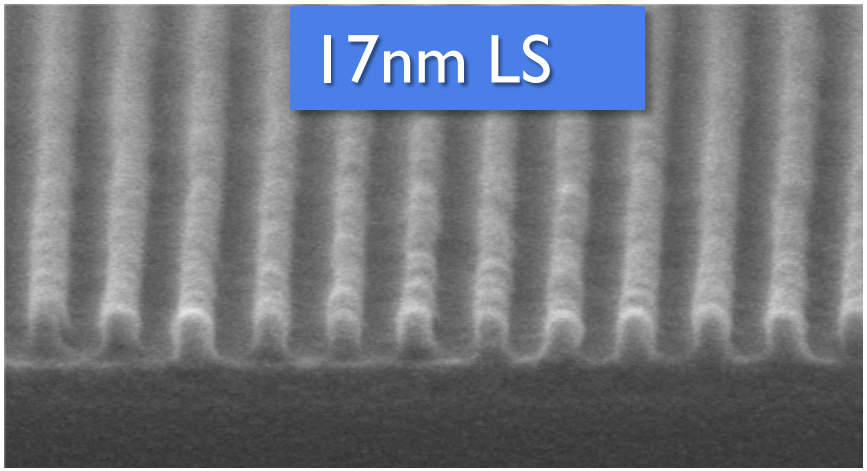
ultimate resolution is 16nm in 35nm resist thickness with Firm 18nm features with LER 3.0nm

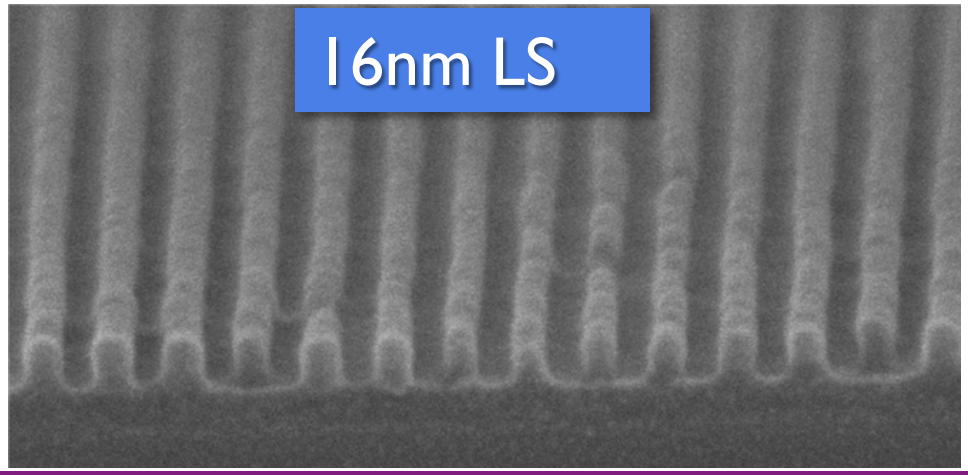
© IMEC 2012

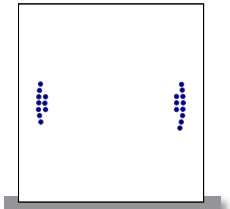
NXE:3100 ULTIMATE RESOLUTION

RESOLUTION WITH DIPOLE 30, RESIST R, 35NM FT









30°Dipole
σ0.8/0.7

ultimate resolution is 16nm in 35nm resist thickness with Firm rinse

OUTLINE

Introduction

Resist benchmarking for POR process

Resist performance for LS

Resist performance for CH

Summary

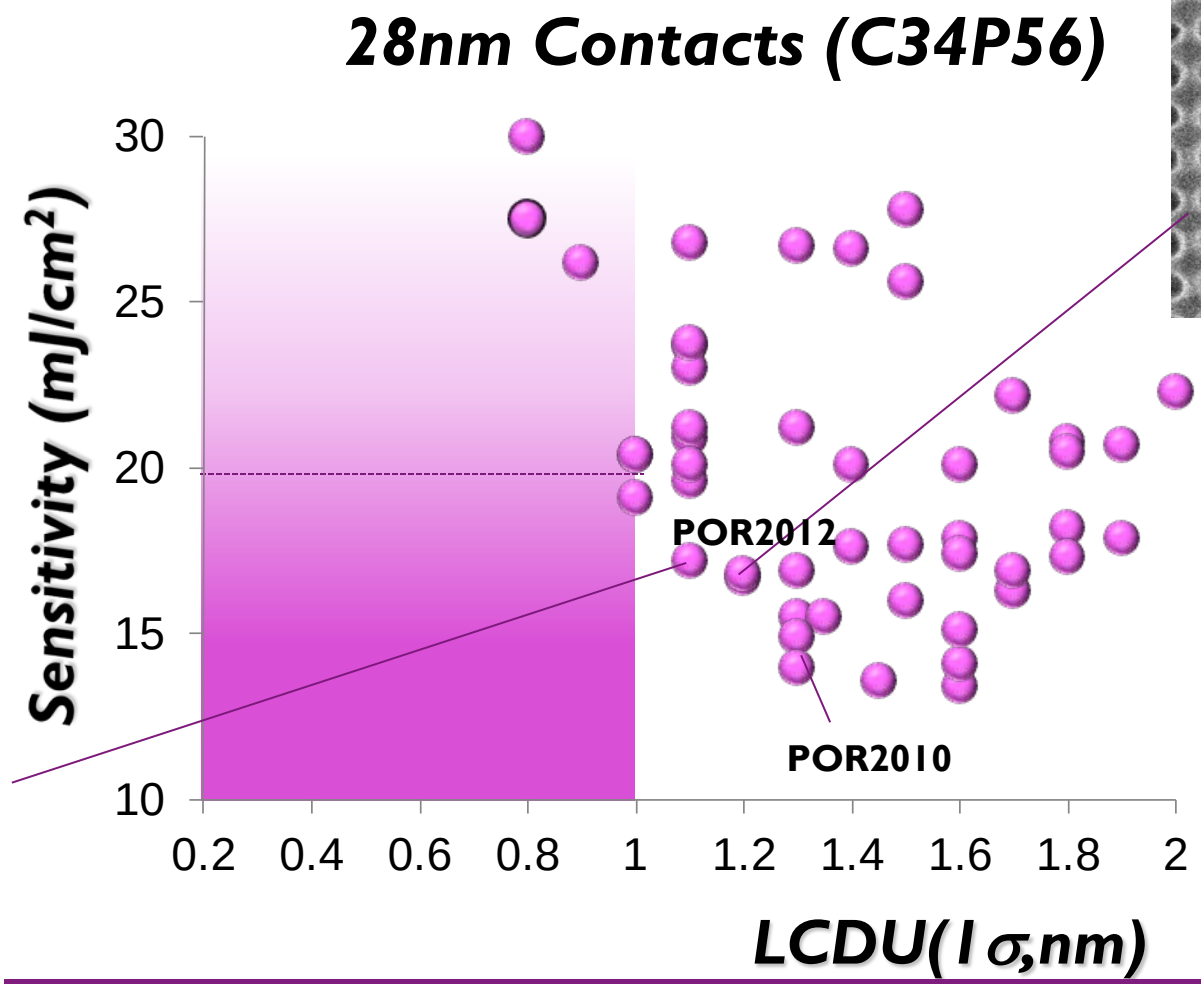
Acknowledgements

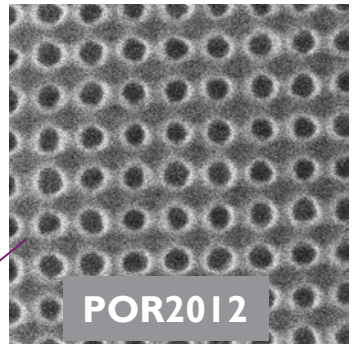
EUV RESIST PERFORMANCE TARGETS

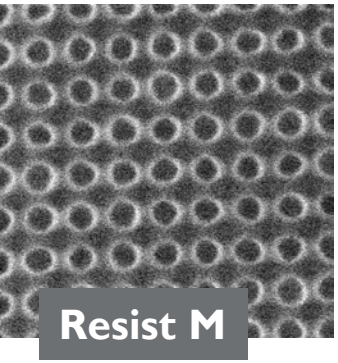
2012 TARGETS ON NXE:3100

Resist Performance Target on NXE3100	2012
CH screening with quasar ill	
Resolution Contacts 1:1 (nm)	**26nm**
Dose-to-size	**<20 mJ**
DOF@10%EL	**>100nm**
LCDU at 26nm HP (1σ)	**<1.0nm**
Resist thickness	**60nm**
LS screening with dipole 60 ill	
Resolution L/S 1:1 (nm)	**22nm**
DOF@10%EL	**>100nm**
dose-to-size	**<15mJ**
LER on 22nm L/S	**3.0nm**
Ultimate resolution	**<20nm**
Resist thickness	**40-50nm**
Ultimate resolution for LS With dipole 30 (extreme dipole)	**16nm**

CONTACT HOLE SCREENING 28NM HP , QUASAR ILLUMINATION

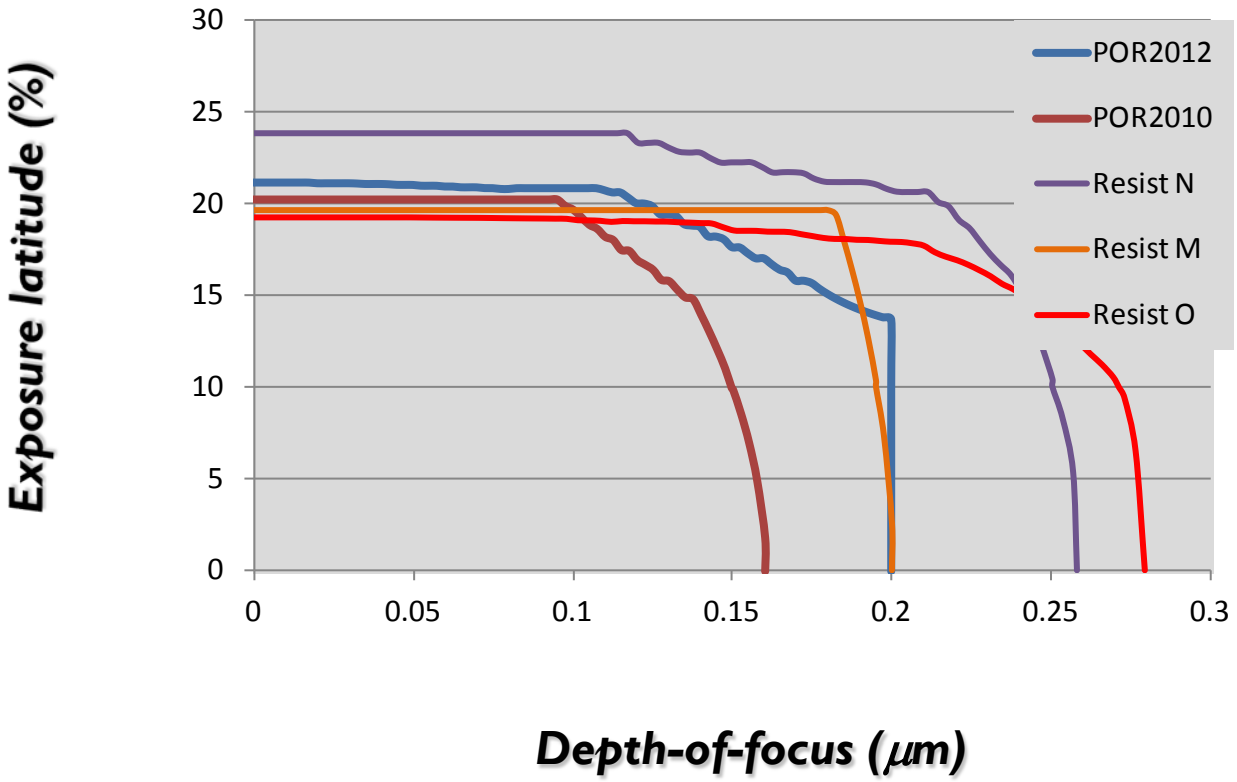






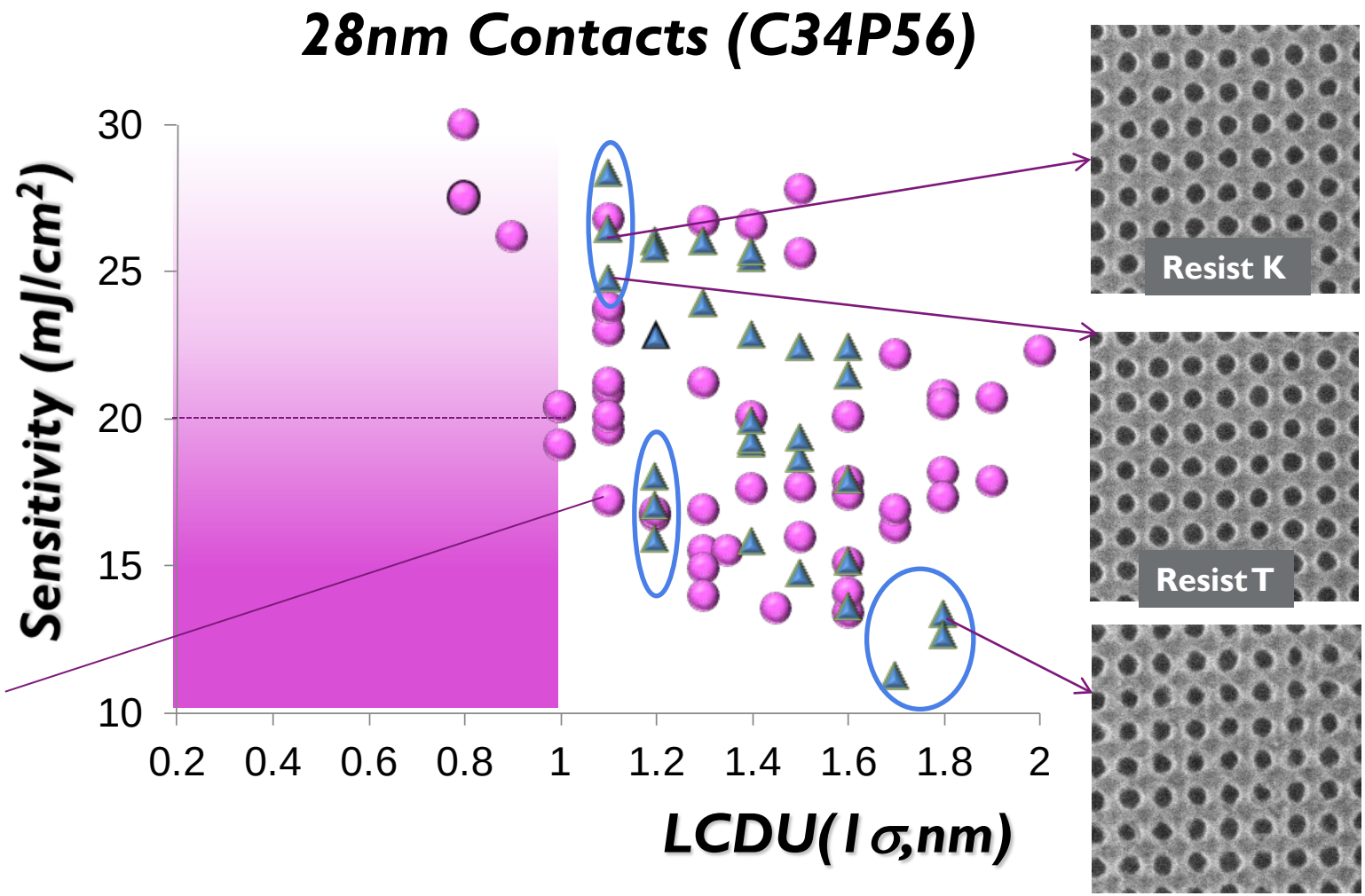
Few resists are meeting the LCDU specification
Relaxing the dose beyond 20 mJ might be required

PW FOR 28NM (C34/P56) CH QUASAR ILLUMINATION



Large processing windows for several resist outperforming the POR resist

CONTACT HOLE SCREENING 28NM HP , QUASAR ILLUMINATION

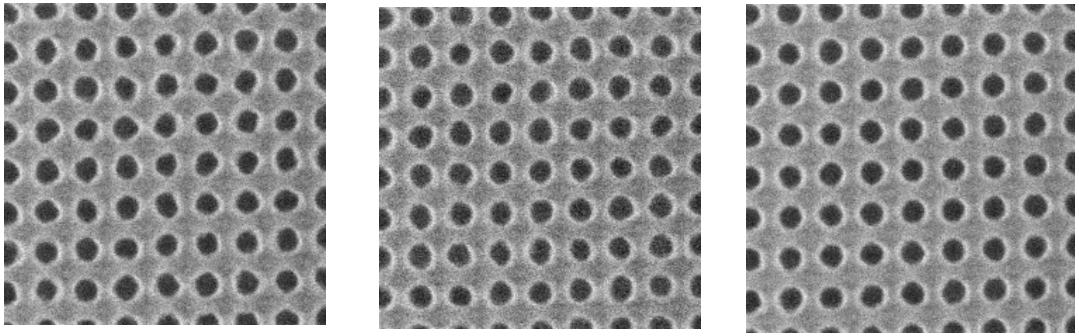


New resist screenings (blue triangles) , trend remains of lower LCDU at higher doses

CER TO QUALIFY CONTACT HOLE SHAPE
28NM HP CONTACTS

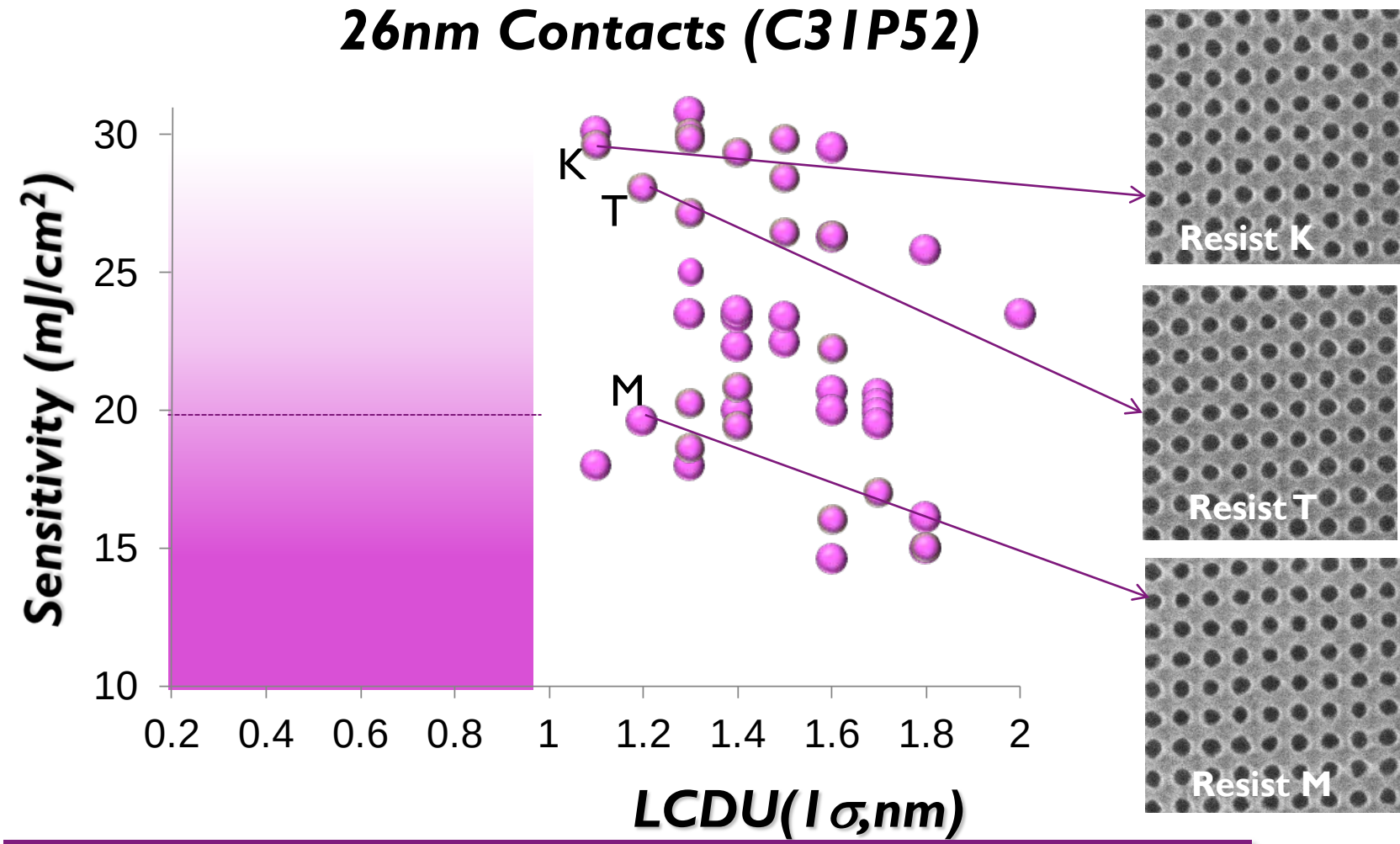
	Resist M	Resist M Firm rinse	Resist R
Dose-to-size	17.2mJ/cm2	18mJ/cm2	52.5mJ/cm2
1 sigma LCDU (<1nm)	1.1nm	1.2nm	0.8nm
Average CER (3σ nm)	1.4nm	1.2nm	1.0nm
Variability on CER (1σ nm)	0.43	0.35	0.27nm

60nm Resist thickness
CD on reticle: C34P56



CER seems to be a good measure for the quality of the shape of the contacts (roughness and circularity)
CER can be seen as the equivalent of the LER in case of LS
Lowest LCDU and lowest CER in resist (R) with low sensitivity
Firm rinse might improve the CER value

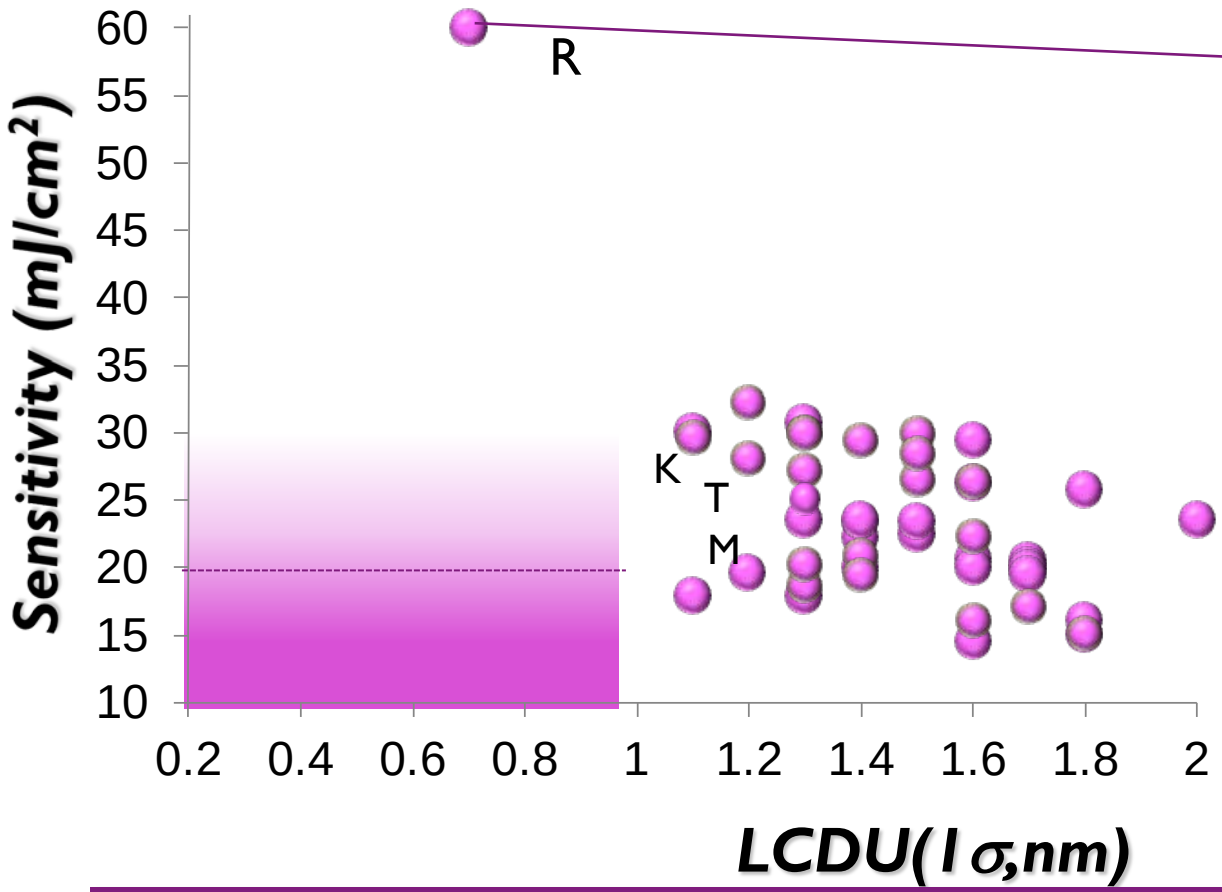
CONTACT HOLE SCREENING 26NM HP , QUASAR ILLUMINATION

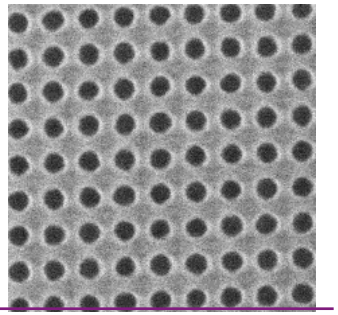


None of the resists meet the LCDU spec of 1.0nm

CONTACT HOLE SCREENING 26NM HP , QUASAR ILLUMINATION

26nm Contacts (C31P52)





60mJ/cm2

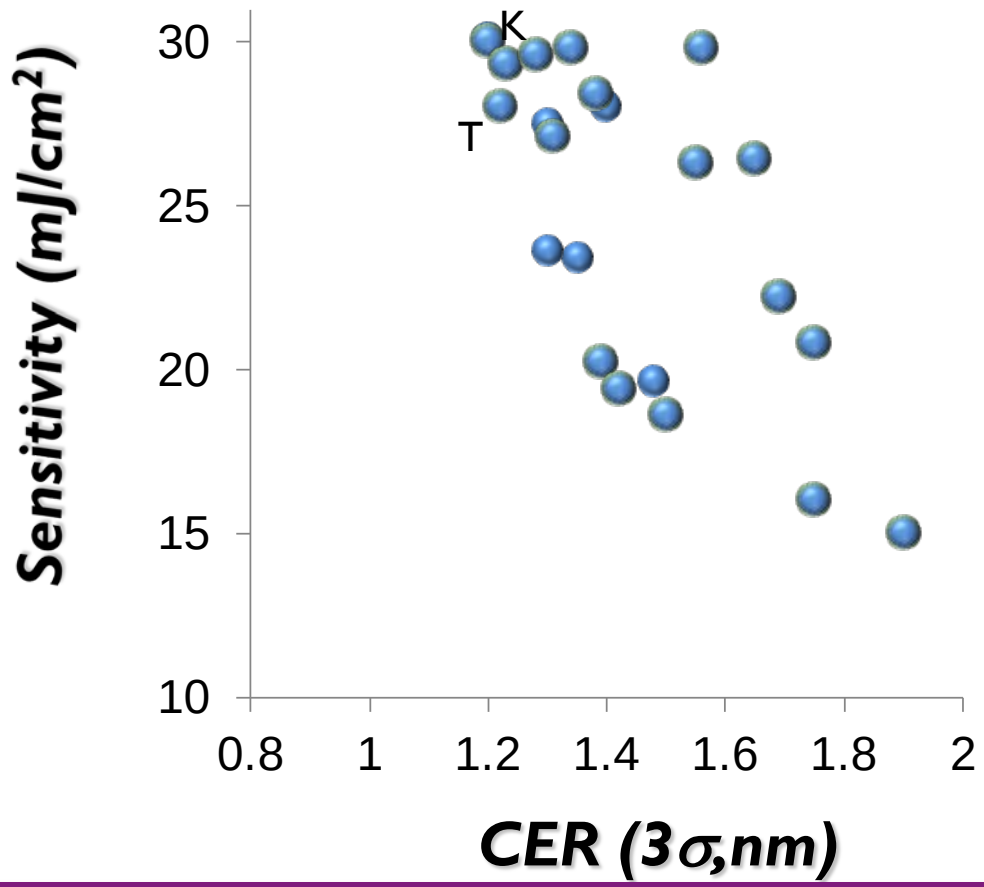
LCDU= 0.7nm (1σ)

CER =1.06 nm (3σ)

At very high dose, LCDU of 0.7nm achieved with also low CER

CONTACT EDGE ROUGHNESS

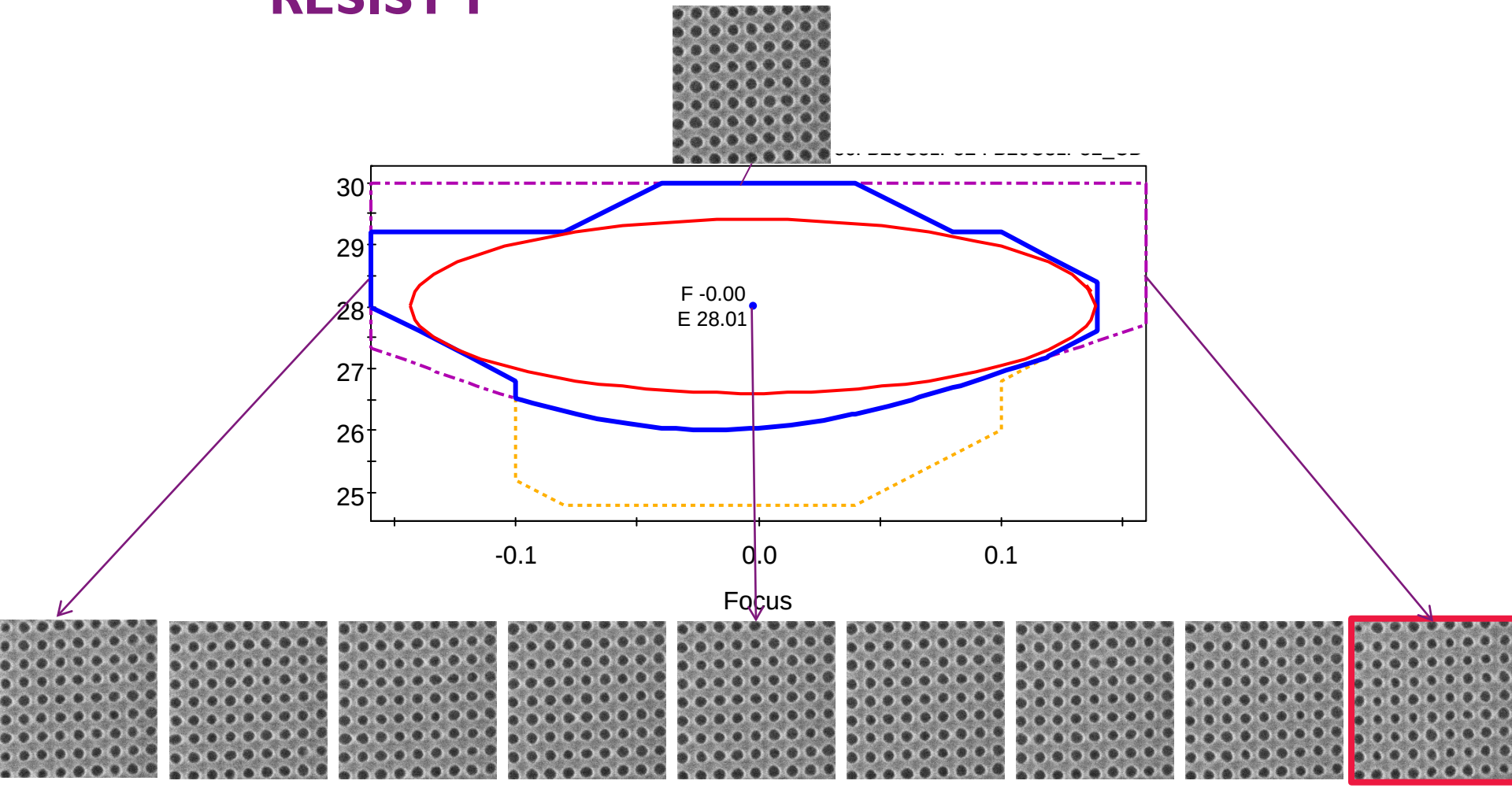
26nm Contacts (C31P52)



Some correlation seen between Contact Edge Roughness and sensitivity

PROCESS WINDOW 26NM (C31P52)

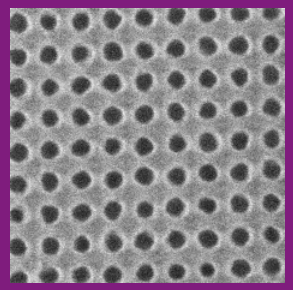
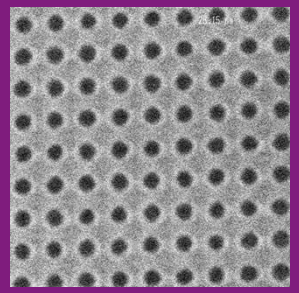
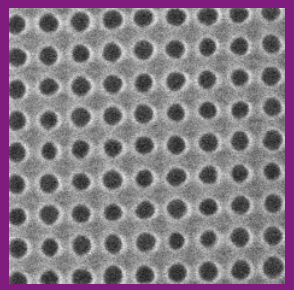
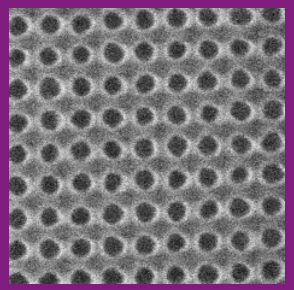
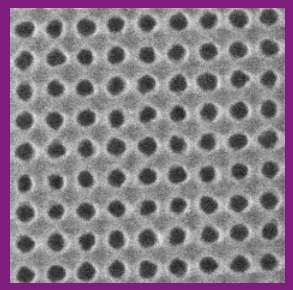
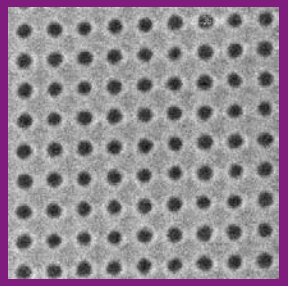
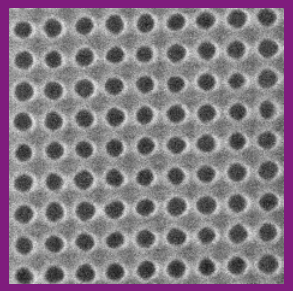
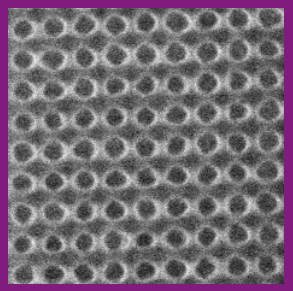
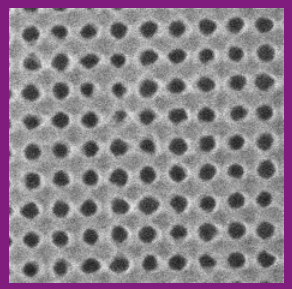
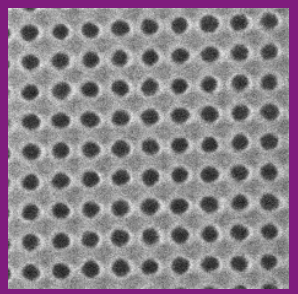
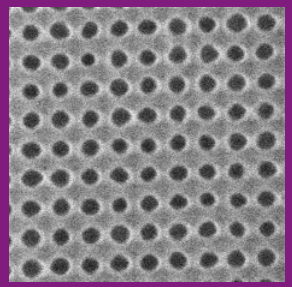
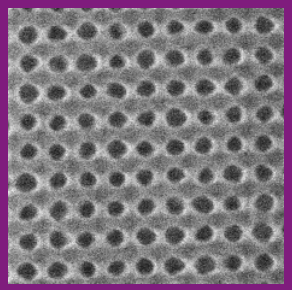
RESIST T



LCDU=1.6nm CER=1.3nm | LCDU=1.5nm CER=1.2nm | LCDU=1.3nm CER=1.3nm | LCDU=1.2nm CER= 1.2nm | LCDU=1.2nm CER=1.2nm | LCDU=1.4nm CER=1.2nm | LCDU=1.6nm CER=1.2nm

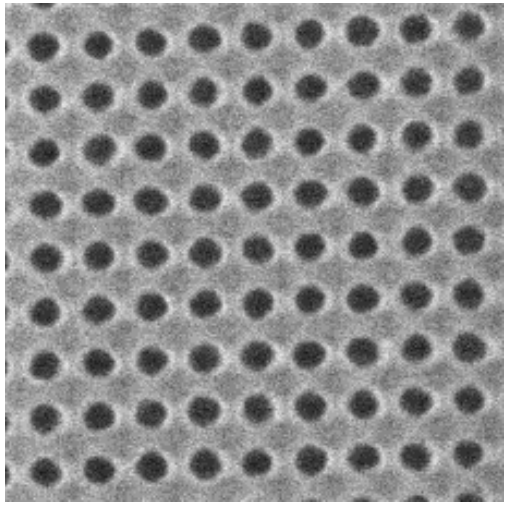
Wide latitudes : 15% exposure latitude and 300nm DOF

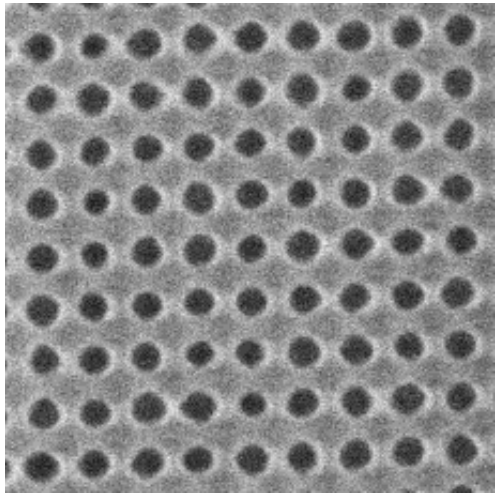
ULTIMATE RESOLUTION FOR CONTACTS : 24NM HP (20% BIAS)

	Resist M	Resist R	Resist T	Resist O
26nm HP	 19.6mJ	 55mJ	 30mJ	 22mJ
25nm HP	 19.6mJ	 55mJ	 31mJ	 23.1mJ
24nm HP	 20.4mJ	 60mJ	 31mJ	 23.1mJ

24nm HP CONTACT HOLES
60NM FT (C29P48), QUASAR ILLUMINATION

	Resist R	Resist T
Dose-to-size	60mJ/cm2	31mJ/cm2
1 sigma LCDU (<1nm)	1.0nm	1.6nm
Average CER (3σ nm)	1.3nm	1.3nm





Low LCDU and low CER even for 24nm HP CH but at high dose

OUTLINE

Introduction

Resist benchmarking for POR process

Resist performance for LS

Resist performance for CH

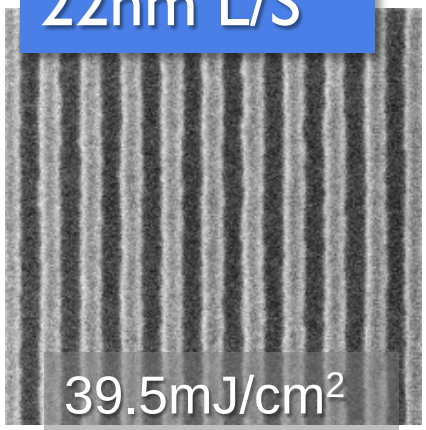
Summary

Acknowledgements

LOWEST LER AND CONTACT CER IN LOW SENSITIVITY RESIST

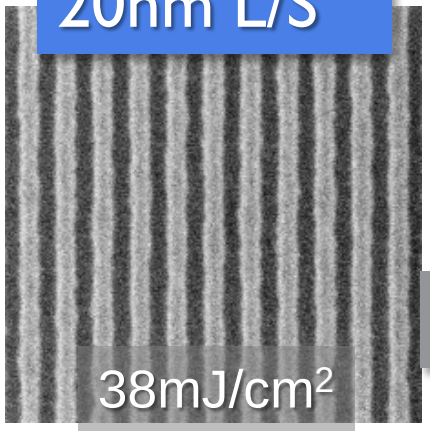
Resist R

22nm L/S

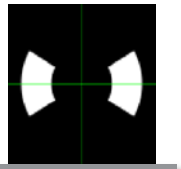


39.5mJ/cm²
LER = 2.6nm

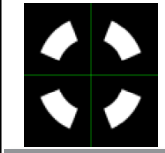
20nm L/S



38mJ/cm²

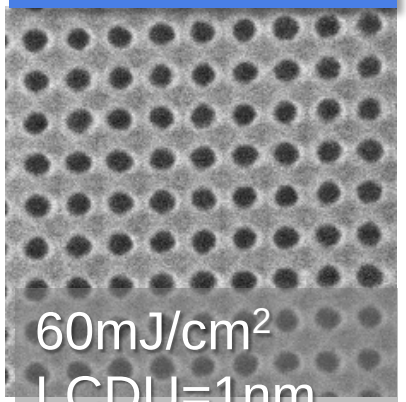


60°Dipole
σ0.81/0.43



Quasar ill
σ0.81/0.51

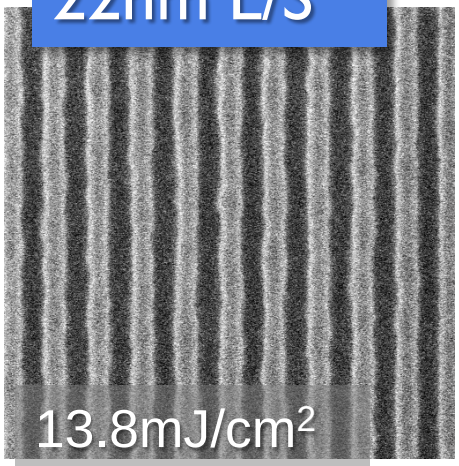
24nm CH



60mJ/cm²
LCDU=1nm

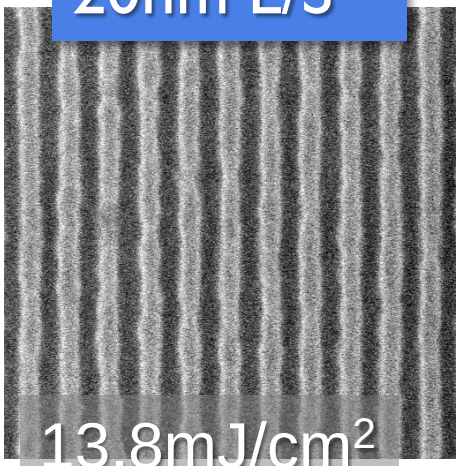
Resist M

22nm L/S

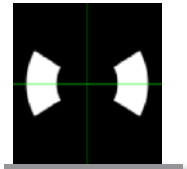


13.8mJ/cm²
LER = 3.1nm

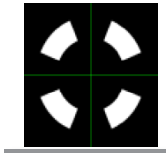
20nm L/S



13.8mJ/cm²

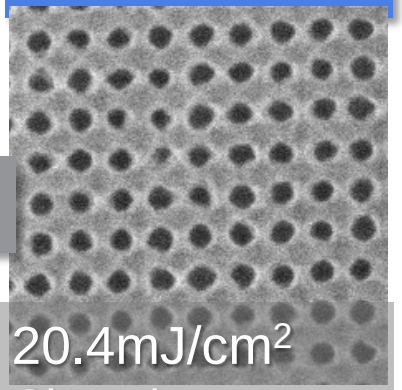


60°Dipole
σ0.81/0.43



Quasar ill
σ0.81/0.51

24nm CH



20.4mJ/cm²
Closed contacts

© IMEC 2012

SUMMARY

Line width roughness and local CD variation of CH are challenging – trade-off with dose requirements is still remaining the major issue

LS resist performance with dipole

- Pattern collapse is resolution limitation. Firm rinse is beneficial for both pattern collapse and LER reduction.
- Resist M is almost meets the target specs for 22nm
- With extreme dipole 30, 16nm resolution capability demonstrated in slow resist R.

CH resist performance with quasar

- L-CDU and CER are effective metrics to judge the CH performance
- 26nm CH is challenging with regard to LCDU and CER, but acceptable to wide processing window can be achieved
- 24 nm CH resolution demonstrated with good LCDU in high dose resist

© IMEC 2012

ACKNOWLEDGMENTS

ASML

- NXE team at imec

TEL

- Kathleen Nafus, Hideo Shite, Koichi Matsunaga

IMEC

- Eric Hendrickx, Jan Hermans, Geert Vandenberghe and Kurt Ronse

Material suppliers

- For supplying the samples and useful discussions

Part of this work was sponsored by CATRENE through the project CT301 EXEPT

ASPIRE
INVENT
ACHIEVE

imec

intel Micron Panasonic ideas for life SAMSUNG tsmc ELPIDA hynix Semiconductor Powerchip SONY FUJITSU