PROGRESS ON EUV RESIST MATERIALS AND PROCESSES AT IMEC

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OUTLINE

Introduction

CAR resist performance and challenges

Alternative resist materials and processes

Summary

Acknowledgements

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IMEC EUV LITHOGRAPHY
TOOL ROADMAP/ RESIST ACTIVITIES

2011 - now	2015-
ASML NXE:3100 - 0.25 NA 27nm LS: conventional 22nm LS: dipole	ASML NXE:3300 – 0.33 NA 22nm LS: Conventional 16nm LS: off-axis

Resist screening, benchmarking and alternative materials exploration

- Follow up the performance of EUV resist towards the yearly set targets requirements high resolution, RLS
- Select and optimize baseline resist processes to be installed on track for use in the imec EUV program (NXE3100 (27nm) → NXE3300 (22nm) and for device implementation
- Explore new ancillary materials for EUV and novel materials
- Fundamental understanding of statistical effects in EUV resists

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DETAILED EUV RESIST TARGETS 2014

Resist Performance Target on NXE3100 (0.25NA)	Q1-Q3 2014
CH screening with quasar ill Resolution Contacts 1:1 (nm) Dose-to-size (at 20% bias) DOF@10%EL LCDU at 24nm HP (3σ) Resist thickness	**24nm** **20 mJ** (<40mJ) **>100nm** **<3.0nm** **60nm**
LS dipole 60 ill/ TM11 reticle Resolution L/S 1:1 (nm) DOF@10%EL dose-to-size target LWR on 18nm L/S (3σ) Resist thickness	**18nm** **>100nm** **20mJ** (<40mJ) **4.2nm** **30-40nm**
Ultimate resolution for LS With dipole 30	**16nm**
Iso trench (conv ill 0.51) dose-to-size target Trench width roughness (TWR) Resist thickness	**20nm** **20mJ** (<40mJ) 4.0 nm 45nm

Resist Performance Target on NXE3300 (0.33 NA)	Q4 2014
CH conventional ill/quasar Resolution Contacts 1:1 (nm) Dose-to-size (at 20% bias) DOF@10%EL LCDU at 24nm HP (3σ) Resist thickness	**24-22nm** **30 mJ/cm²** **>100nm** **<3.0nm** **60nm**
LS dipole 90 Resolution L/S 1:1 (nm) DOF@10%EL dose-to-size target LWR on **16nm** L/S (3σ) Resist thickness	**16nm** **>100nm** **30mJ/cm2** **3.5nm** **30-35nm**
Ultimate resolution for LS Extreme dipole (tbd)	**13nm**
Iso trench (dipole 90) dose-to-size target Trench width roughness (TWR) Resist thickness	**20nm** 20mJ (<40mJ) 4.0nm 45nm

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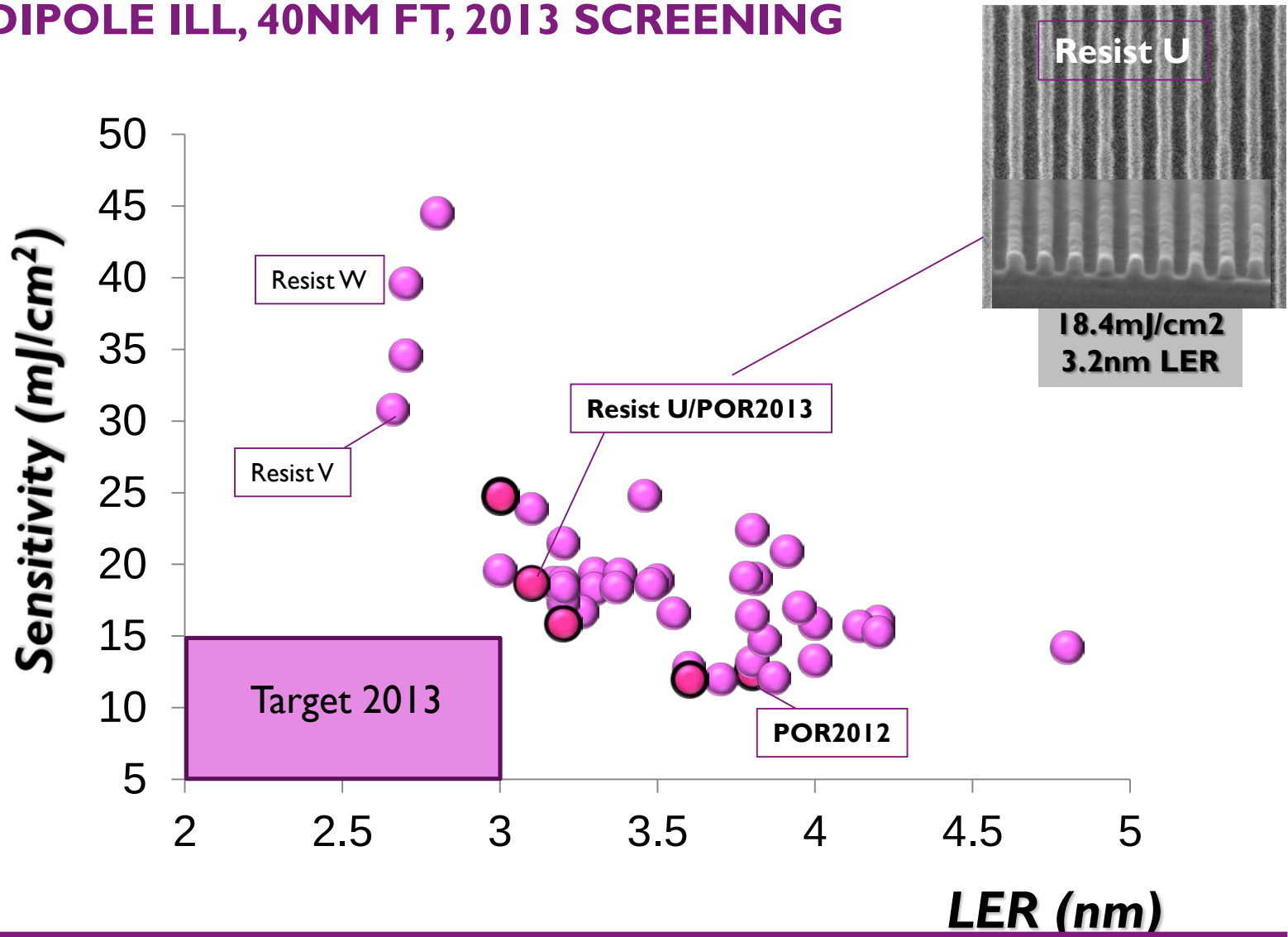
22NM LS SCREENING ON NXE3100 IN 2013

DIPOLE ILL, 40NM FT, 2013 SCREENING



Resist U was selected as new POR/baseline for 22nm LS, and for 26nm CH
Resist W was the only resist capable of resolving also 18nm LS HP

OUTLINE

Introduction

CAR resist performance and challenges

- Resist screening for 18nm LS, 24nm CH on NXE3100
- Verification of 16nm performance on NXE3300

Alternative resist materials and processes

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18NM LS SCREENING ON NXE3100 AT IMEC

Goal

- Identification of a high resolution resist for 16nm LS qualification on 3300/3350

Strategy

- Screening with dipole illumination on the 3100 targeting at 18nm
- Promising material testing on /3300 demo

Challenges for 18-16nm LS

- Resolution, LWR, DTS, pattern collapse
- OoB sensitivity
- Compatibility with rinse materials

Performance and selection criteria

- *Resolution, LWR, dose, Process window, OoB sensitivity*

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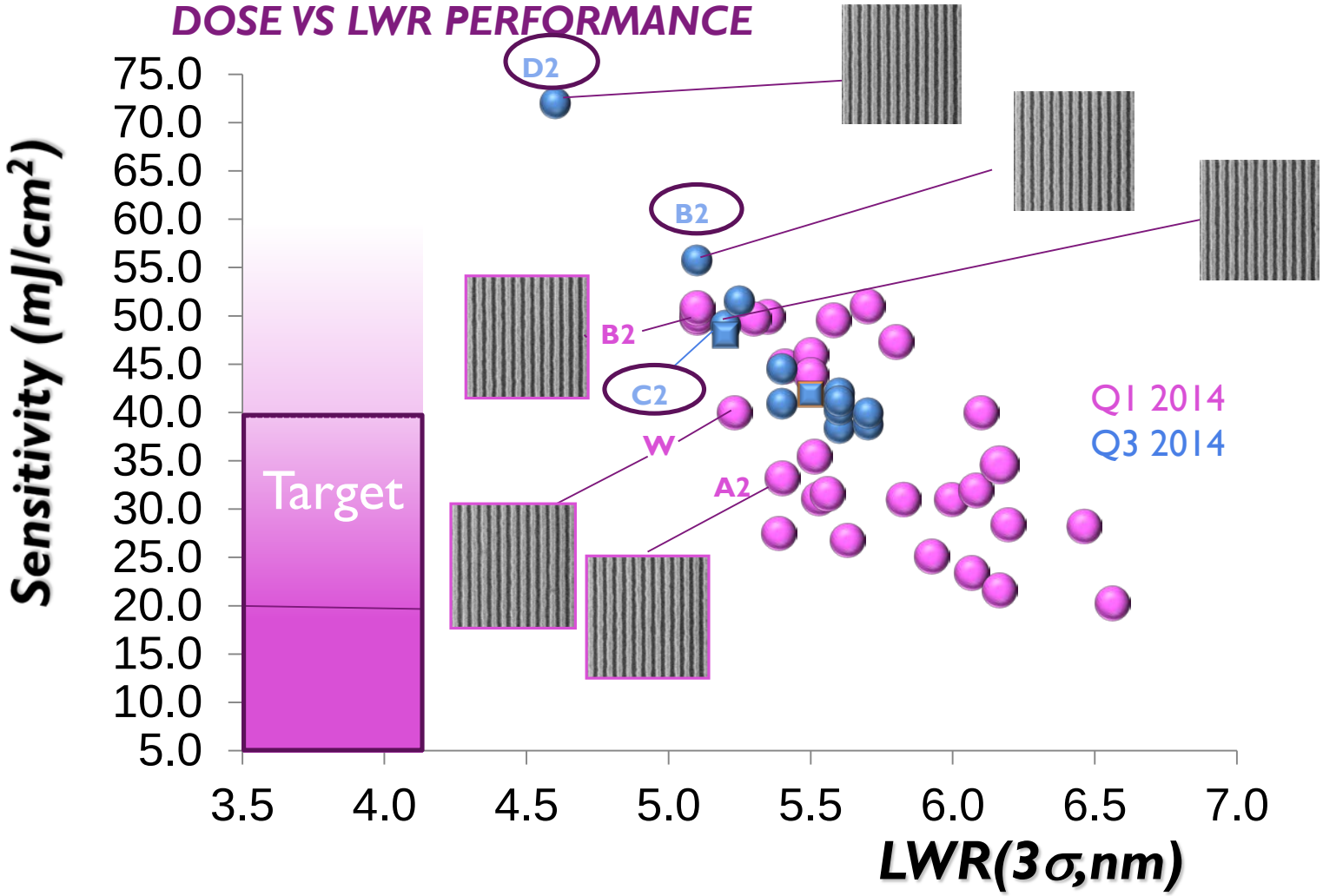
18NM LS EVALUATION ON NXE3100

(DIPOLE60 ILLUMINATION, 35NM FT, FIRM EX10 RINSE)

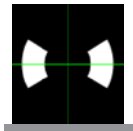
DOSE VS LWR PERFORMANCE



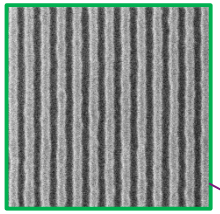
No resist is meeting the 4.2nm LWR at 40mJ dose target. Trend towards higher dose to get lower LWR and wider process windows.

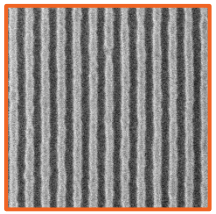
PROCESS WINDOW 18NM

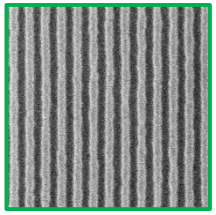
RESIST B2, 35NM FT, FIRM EX10 RINSE

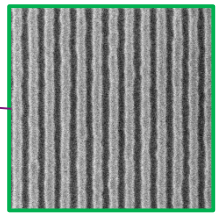


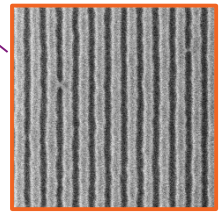
60° Dipole
σ0.81/0.43



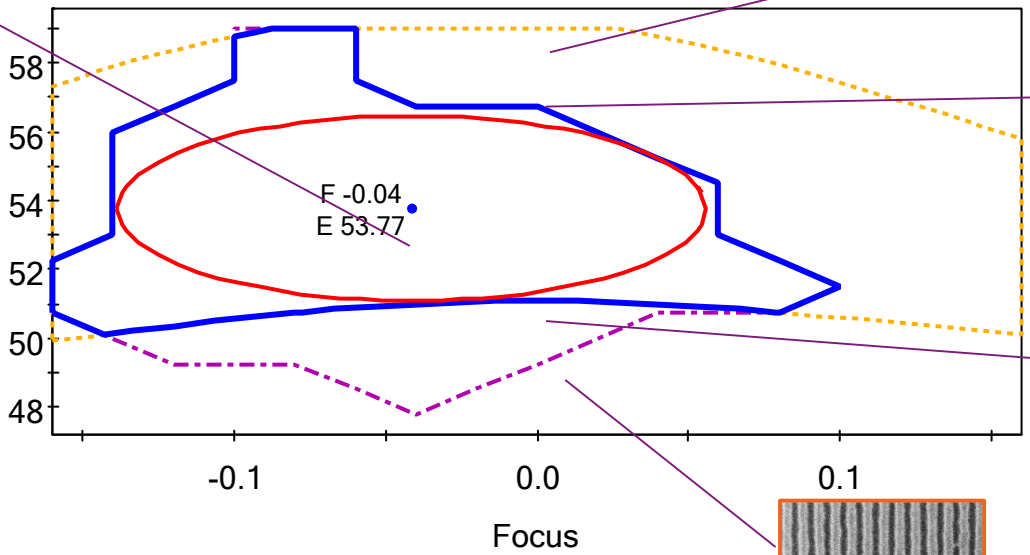


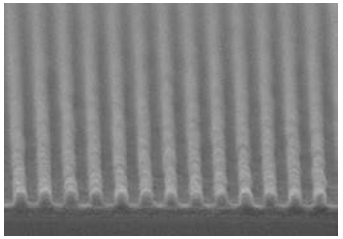






DTS (mJ/cm2)	55.7
LWR 3s (nm)	5.1
Max EL (%)	11%
Max DOF (nm)	240
DOF@10% EL	190





Process window limitation is resist top loss/pinching

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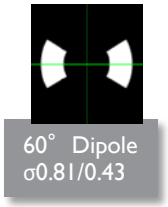
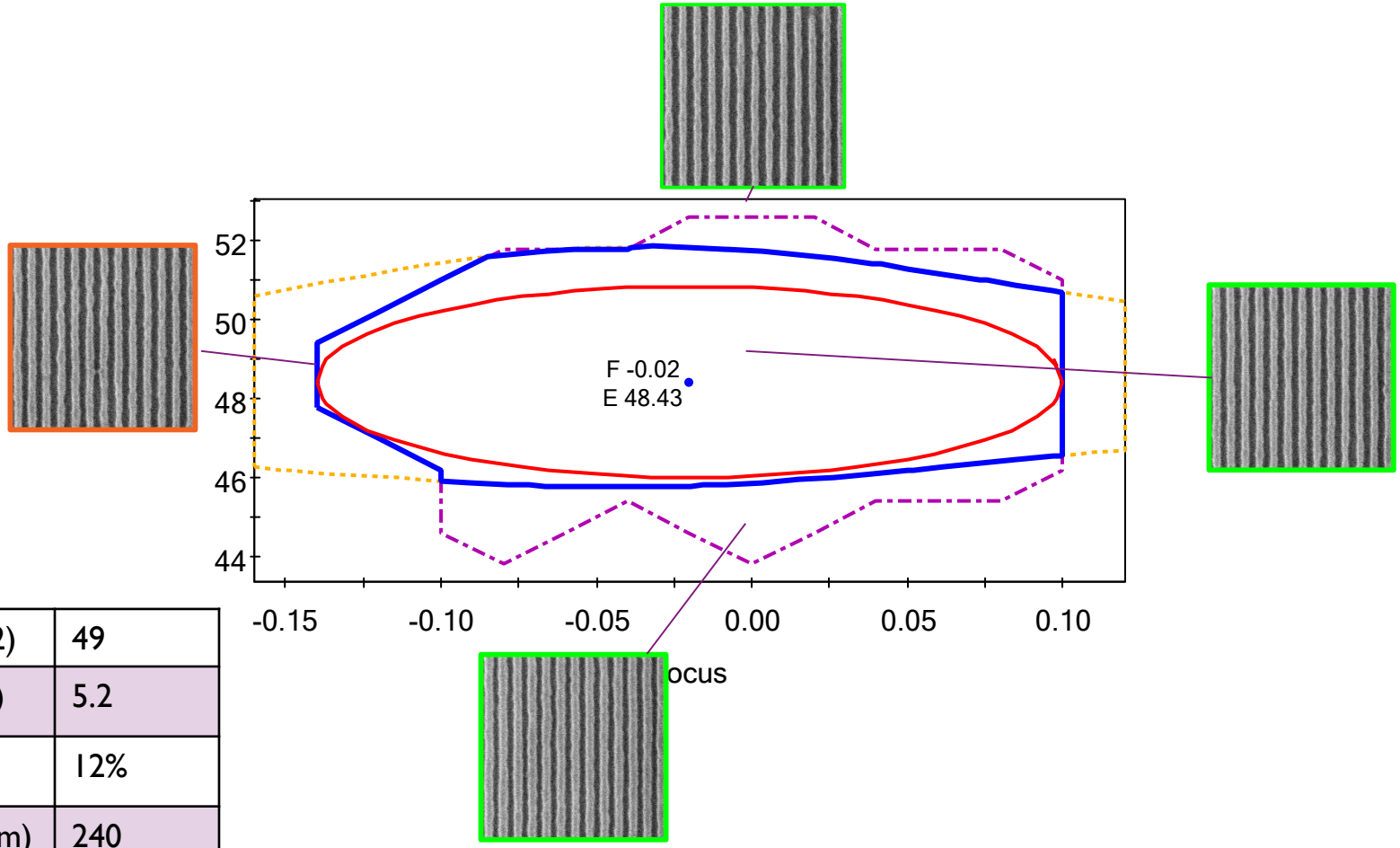
PROCESS WINDOW 18NM

RESIST C2, 35NM FT, FIRM EX10 RINSE





DTS (mJ/cm2)	49
LWR 3s (nm)	5.2
Max EL (%)	12%
Max DOF (nm)	240
DOF@10% EL	240

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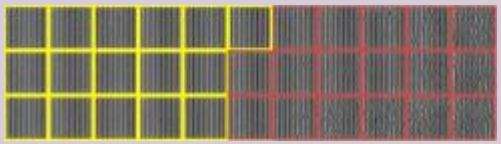
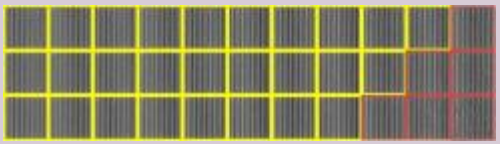
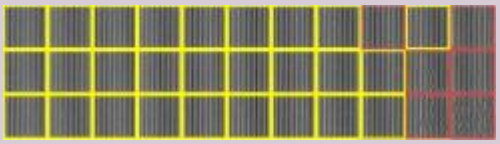
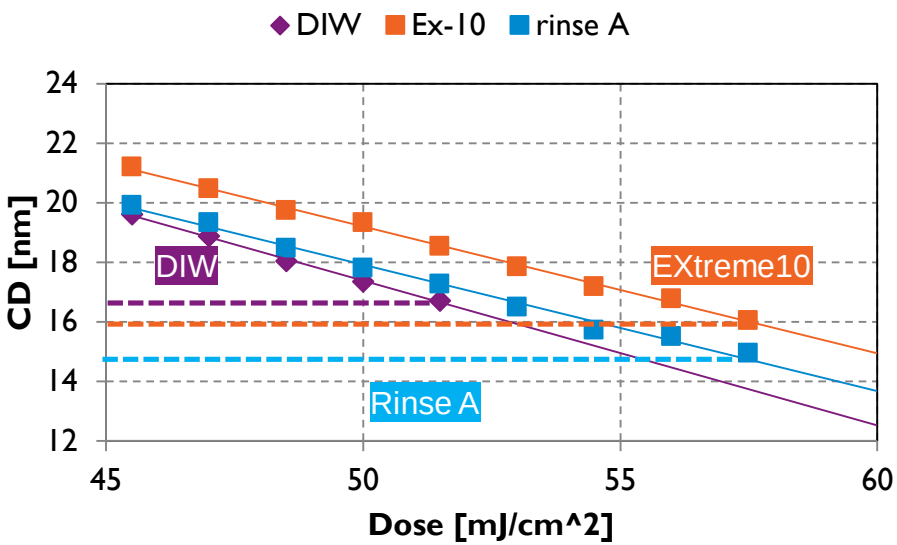
RINSE MATERIAL EVALUATION 18NM HP IN RESIST B2

Good pattern quality

No useful imaging (collapse, no resolution, melt)

	DIW	Extreme™10	Extreme™ A
Process window Dose → ↓ Focus	 good pattern quality : 16	 Good pattern quality :27	 Good pattern quality: 27



	Minimum standing CD [nm]	⊿CD from DIW [nm]	LWR 3σ [nm]
DIW	16.7	-	6.9
Extreme™10	16.0	1.7	6.4
Extreme™ A	**14.9**	**0.4**	6.9

See Poster P-PE-01

Rinse A has improved performance over Extreme10.
Minimal CD increase by the rinse A. Rinse A compatible with several resists

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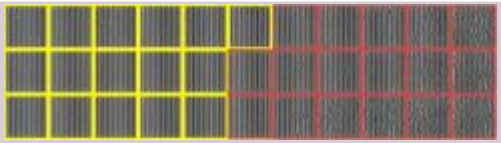
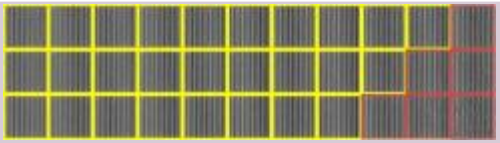
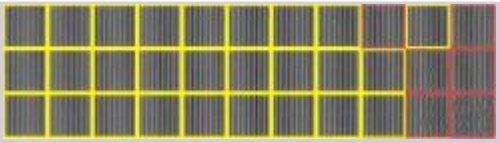
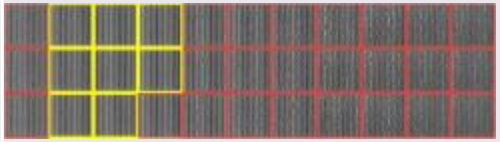
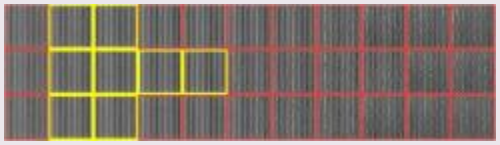
RINSE MATERIAL EVALUATION SUB -18NM HP

No collapses

Unavailable pattern (collapse, no resolution, melt)

Half pitch / Resist	DIW	Extreme™10	Extreme™ A
HP 18nm / Resist B2 (Dose →, Focus ↓)			
HP 17nm / Resist W (Dose →, Focus ↓)			

- **Extreme™ A shows pattern collapse mitigation for**
  - Below 20nm
  - Several resist materials (resist robustness)
  - No CD increase

		Miniumum standing CD [nm]	⊿CD from DIW [nm]	LWR 3σ [nm]
HP 18nm / Resist B2	DIW	16.7	-	6.9
	Extreme™10	16.0	1.67	6.4
	Extreme™ A	**14.9**	**0.4**	6.9
HP 17nm / Resist W	DIW	16.2	-	8.5
	Extreme™10	17.6	1.2	8.0
	Extreme™ A	**15.2**	**0.1**	8.2

See Poster P-PE-01

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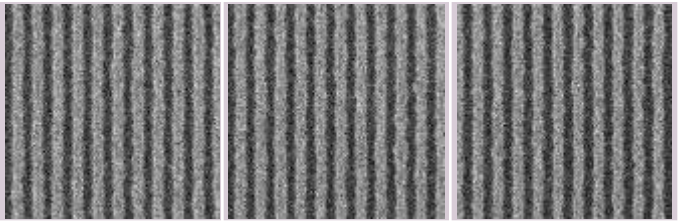
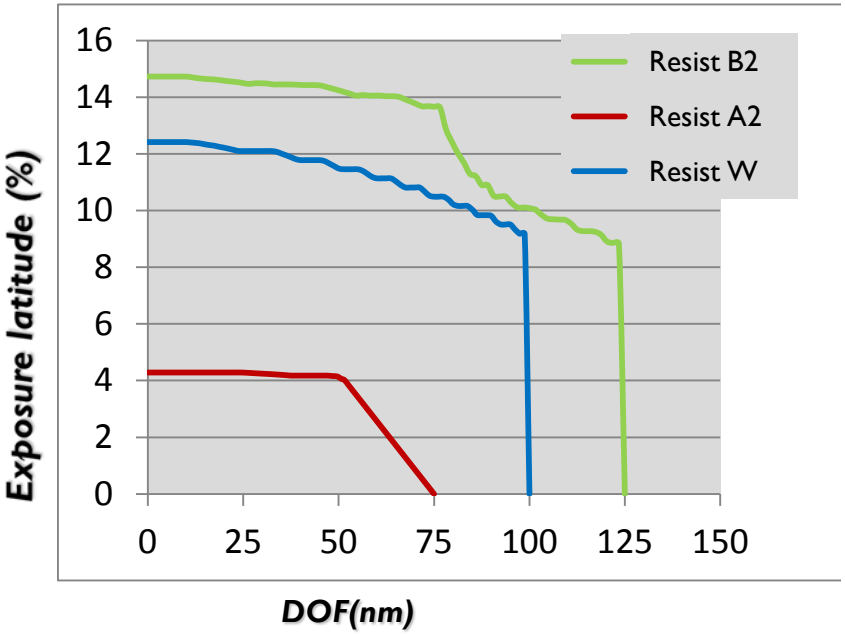
16NM HORIZONTAL LS ON NXE3300

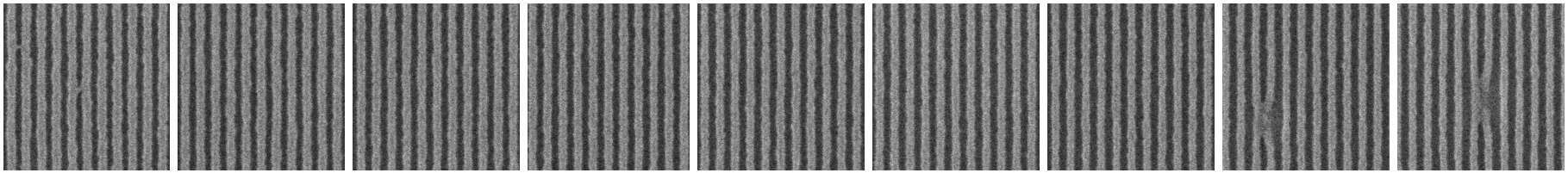
DIPOLE90Y ILLUMINATION, 35NM FT, FIRM RINSE EXTREME12

	Resist W	Resist A2	Resist B2
Dose to size (mJ/cm^2)	47.0	36.1	58.2
LWR 3σ	4.2nm	4.7nm	4.0nm
Max EL (%)	12.4%*	4.5%	14.7%
Max DoF (nm)	100nm	75nm	125nm
SEM image @BE/BF			



18.0nm 17.5nm 16.9nm 16.5nm 16.0nm 15.6nm 15.1nm 14.7nm 14.3nm

B2

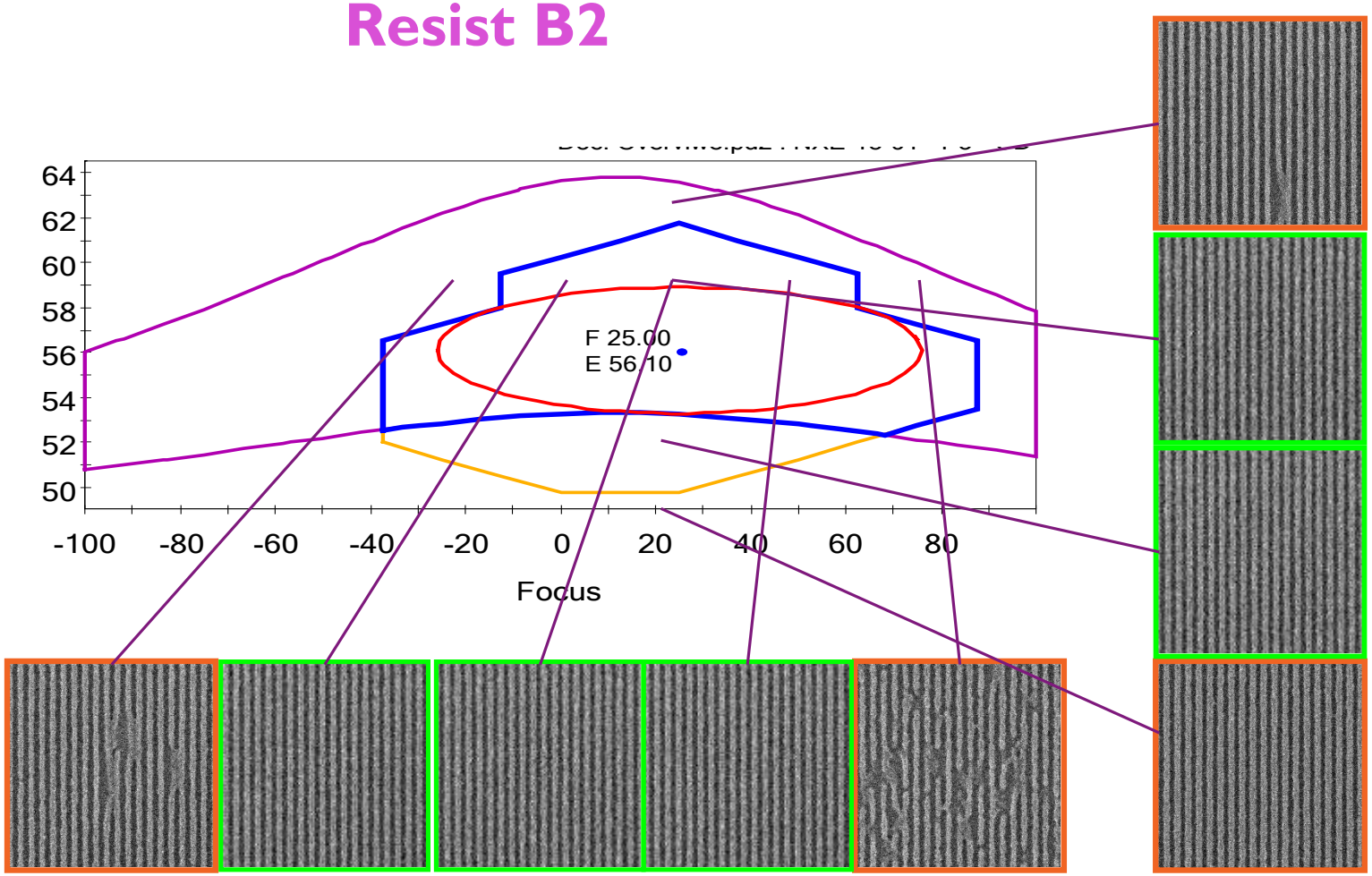


Demonstration of 16nm LS performance on the NXE3300 using dipole 90

16nm DL PROCESS WINDOW ON NXE3300

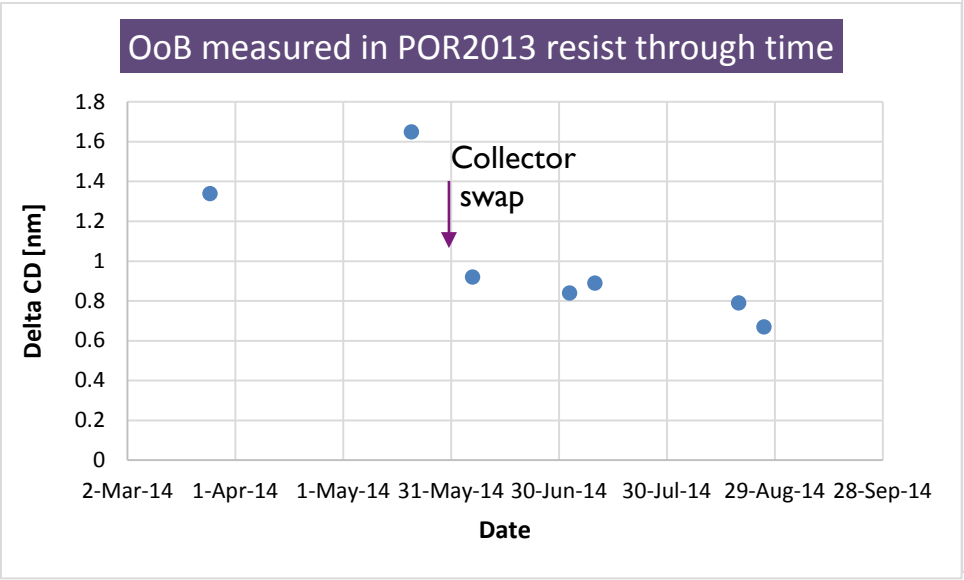
DIPOLE90Y ILLUMINATION, 35NM FT, FIRM RINSE EXTREME12

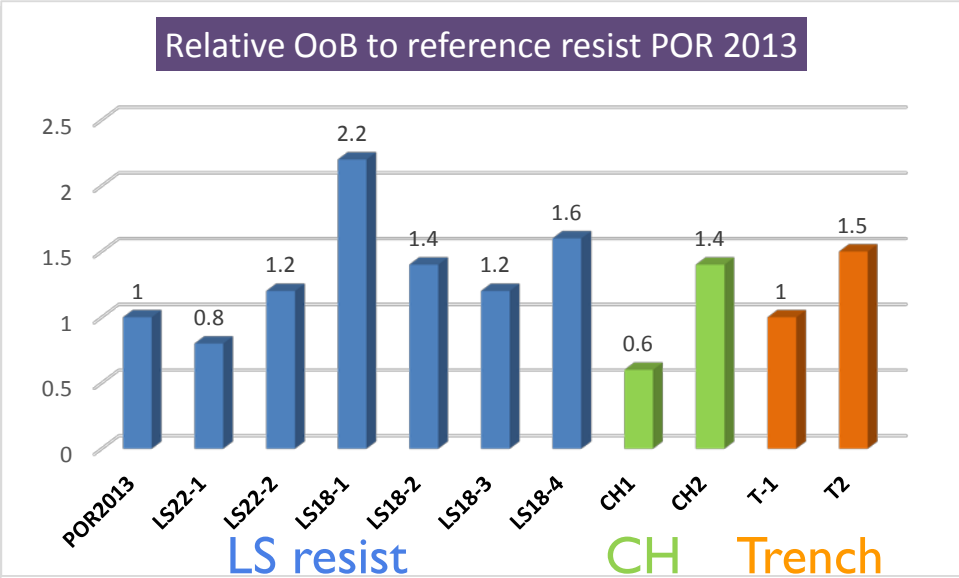
Resist B2



Process window with over >10% EL and 125nm DOF, collapse at smaller CD

RESIST OOB SENSITIVITY
DELTA CD METHOD





18nm LS resist candidates can have a factor of 2 higher OoB sensitivity over the 22nm POR 2013. Resist OoB sensitivity will be included as one of the selection criteria of the resists besides RLS and PW

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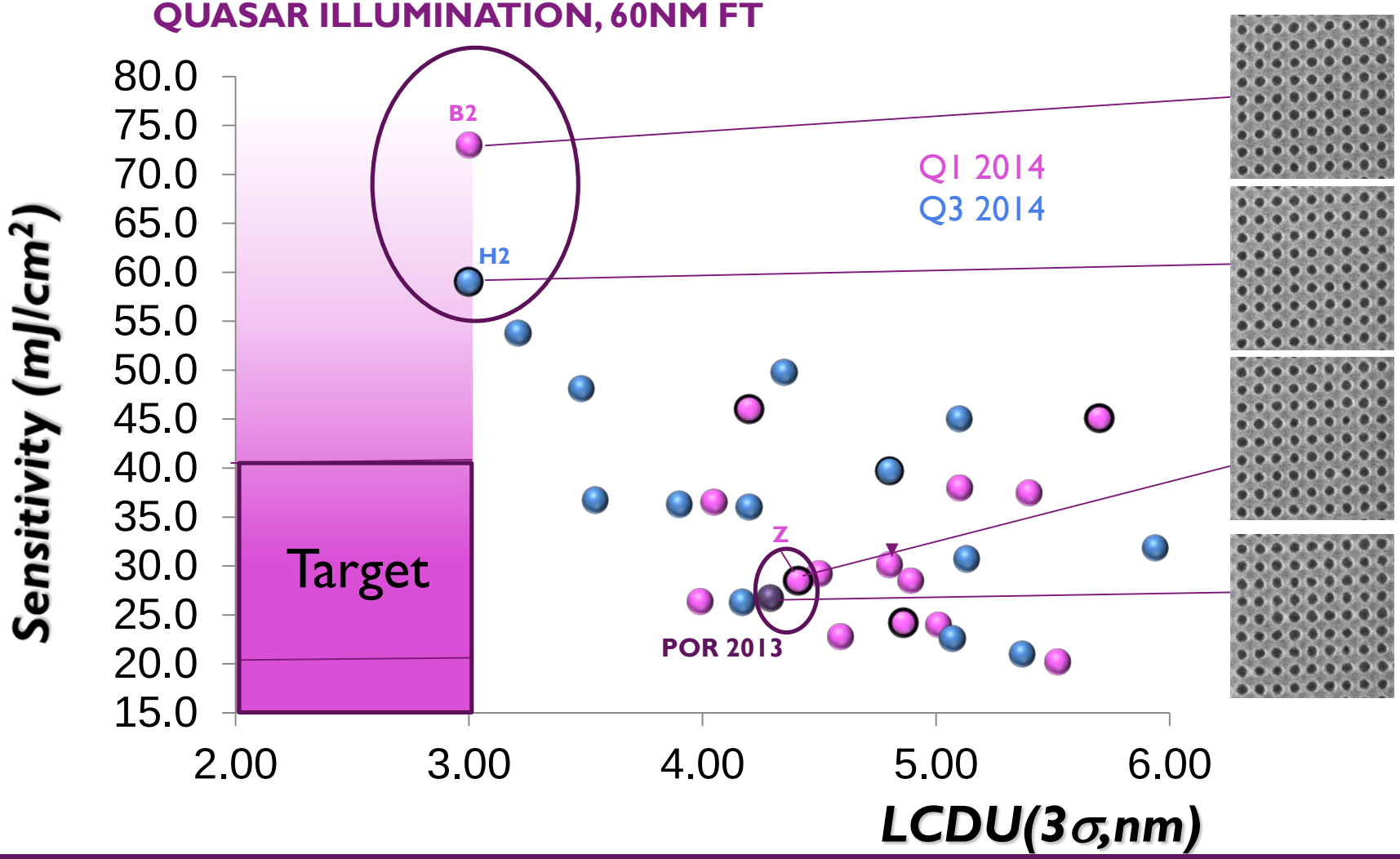
24NM CH SCREENING ON NXE3100

QUASAR ILLUMINATION, 60NM FT



Resist POR2013 and Z have competitive performance at 27mJ/cm^2. Resist H2 is meeting the LCDU target but at too high dose (60 mJ/cm^2)

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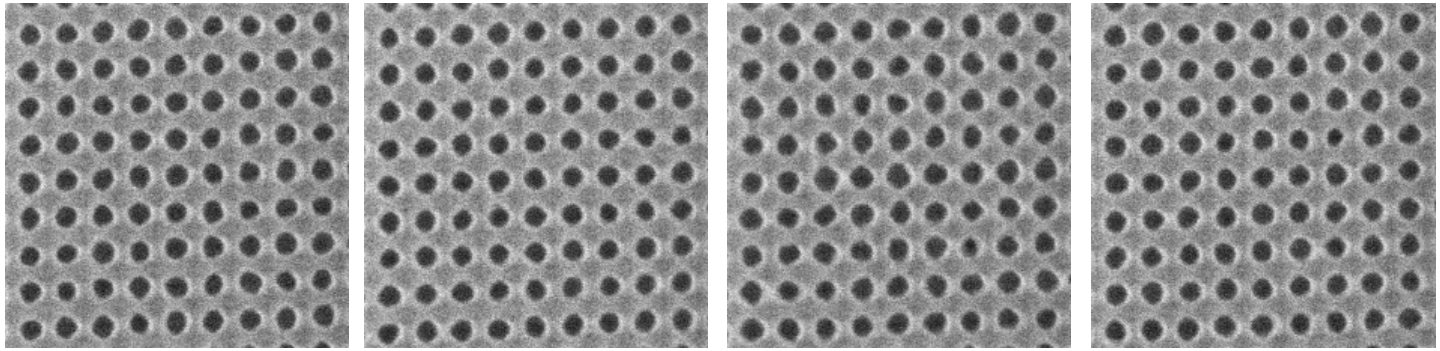
24nm HP CONTACT HOLES
60NM FT (C29P48), QUASAR ILLUMINATION

	Resist B2	Resist H2	POR 2013	Resist Z
Dose-to-size	73mJ/cm2	59mJ/cm2	26.7mJ/cm2	28.5mJ/cm2
3 sigma LCDU (3nm)	3nm (249/250)	3nm (250/250)	4.3nm (245/250)	4.4nm (250/250)
3 sigma CER	1.23nm	1.21nm	1.43nm	1.2nm
Max Exp latitude	15.9%	16.9%	13.9 %	14%

60nm Resist thickness

CD on reticle: C29P48



High dose resists have the largest EL and best LCDU and CER
Resist POR2013 and Z are good compromise LCDU-dose

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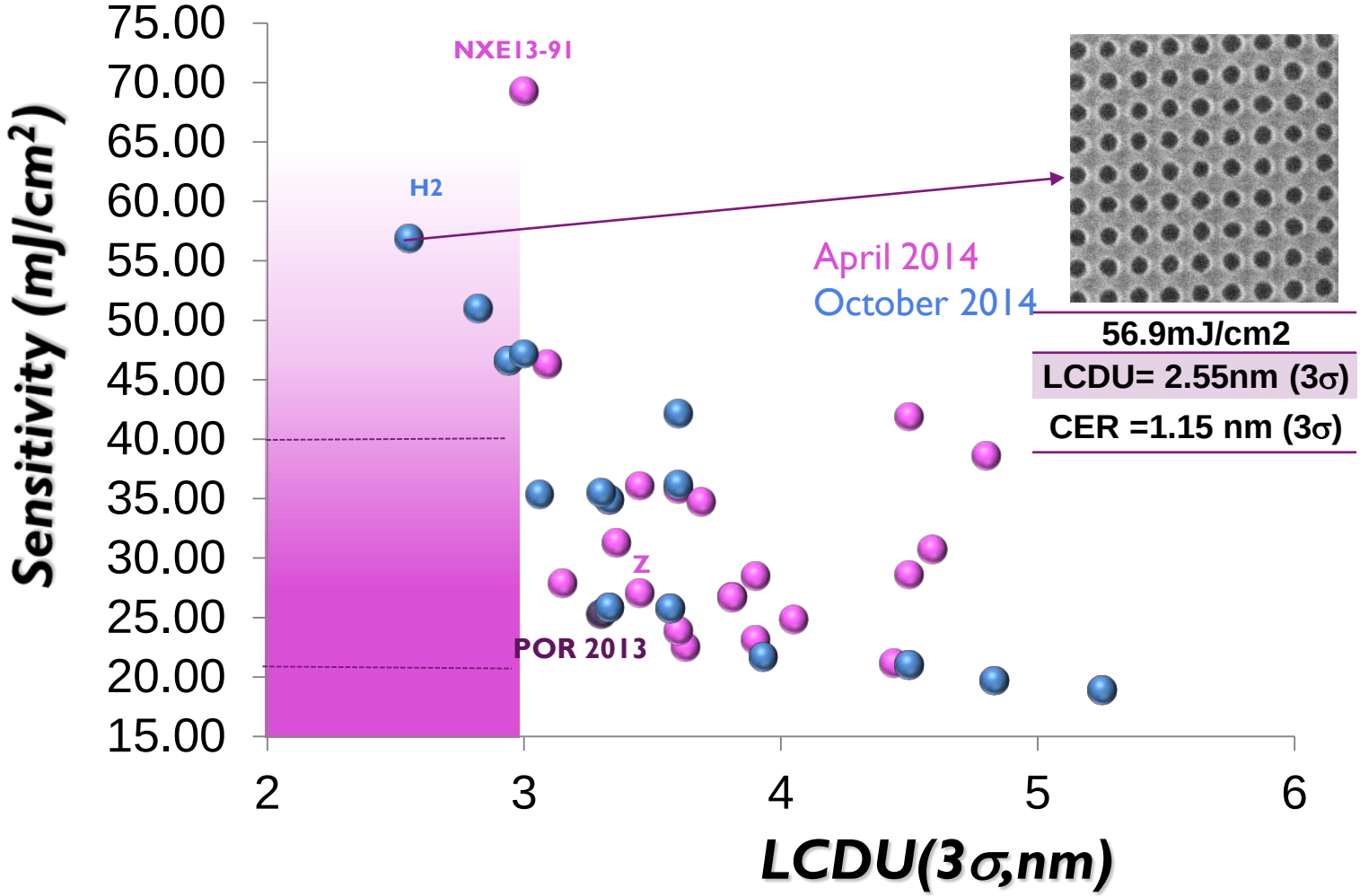
26NM HP CONTACTS IN 2014

QUASAR ILLUMINATION, 60NM FT

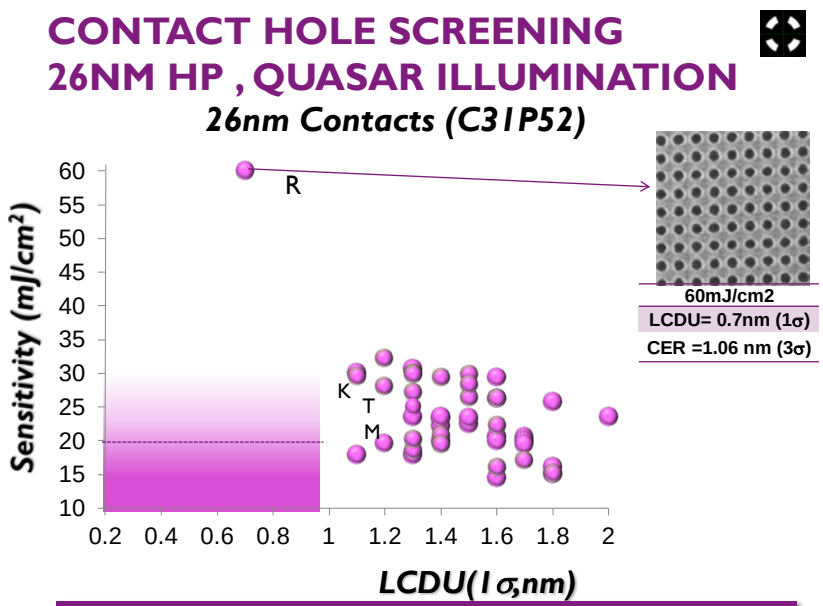


LCDU values lower than 3nm are achieved at doses 45mJ/cm^2 and up

RESIST PROGRESS

26NM CONTACTS ON NXE3100

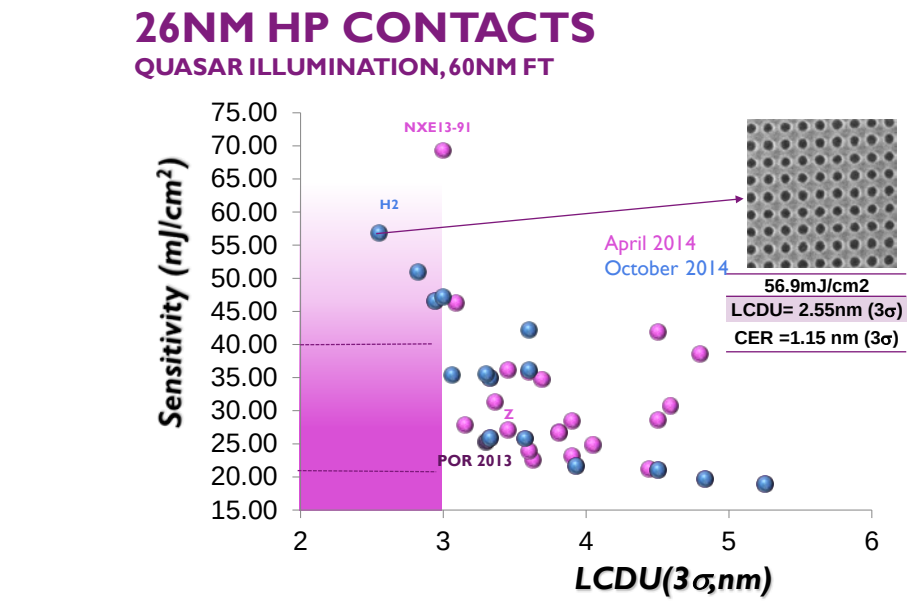
EUVL Brussels October 2012



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

M. Goethals, EUVL 2012, Brussels, October 1

EUVL 2014



LCDU values lower than 3nm are achieved at doses 45mJ/cm² and up

imec © IMEC 2014 M. GOETHALS, EUVL-2014, WASHINGTON, OCTOBER 27 22

Resist performance improvement mainly comes from relaxing the dose requirements
No notable progress in resist wrt RLS in the last 2 years !

OUTLINE

Introduction

CAR resist performance and challenges

Alternative resist materials and processes

- EUV CAR enablers
  - Negative tone imaging materials
  - Dry development rinse material
- Novel material concept
  - Metal containing resist

Summary

Acknowledgements

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CURRENT CAR PERFORMANCE LIMITERS VS. ALTERNATIVE EUV MATERIALS

= expected

Empty box = unknown / to be assessed

RLS – 1st priority

	Material type	Sensitivity	LWR LCDU	Resolution	Pattern collapse	Etch resistance	DUV Out-of-Band	Outgassing / Chemical flare	HVM compatibility (contam., defect, shelf-life)
Reference	Conventional CAR	●	●	●	●	●	●	●	●
Novel EUV materials (Long term solution)	Metal oxide resist			○		○			
	Nano particles	○				○			
	Fullerene based			○		○			
	Molecular glass		○						
EUV enables (Near term solution)	CAR+DDRM			○	○				
	CAR+NTD	NTD could enable specific applications [complementary to CAR-PTD]							
	CAR+Top Coat						○	○	
	CAR+ Smoothing		○						

Novel materials can show better figure of merit w.r.t. to CAR resists, but are longer term solution. CAR enablement processes could make the CAR materials meeting the requirements in short term.

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IMEC ALTERNATIVE MATERIALS FOR EUV
EXPLORATORY AREAS

- **EUVL enablement**
  - Roughness smoothing (post processing, ..)
  - **Negative tone imaging**
  - DUV Out-of-Band suppression (new resist, top coat)
  - Pattern collapse mitigation (**DDRM**, rinse, ..)
  - Defect reduction (rinse, filtering,..)

- **Novel inorganic / organic resist materials**
  - Bring university / research institute products from ***lab to fab***
  - Check manufacturing viability (contamination)
  - Integrate most promising in patterning module

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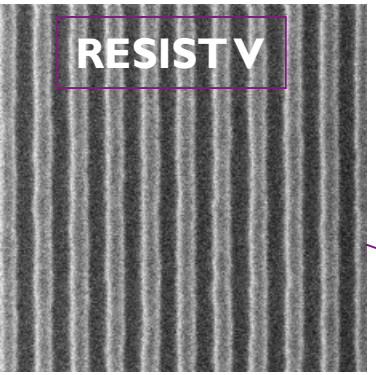
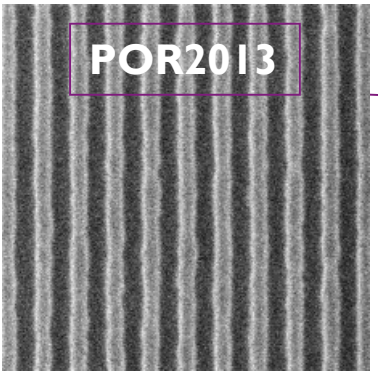
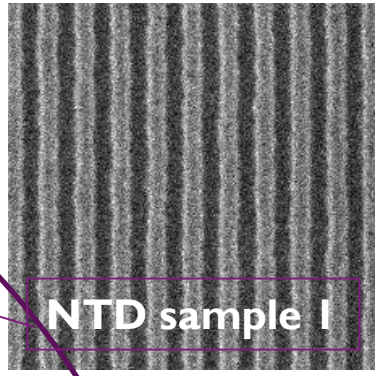
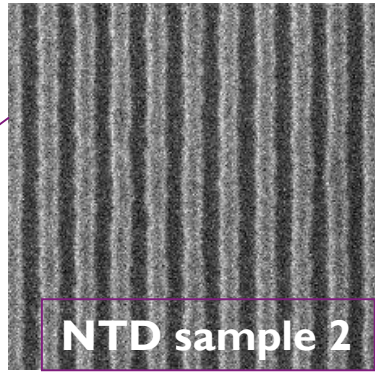
22 nm HP EUV RESIST LS PERFORMANCE

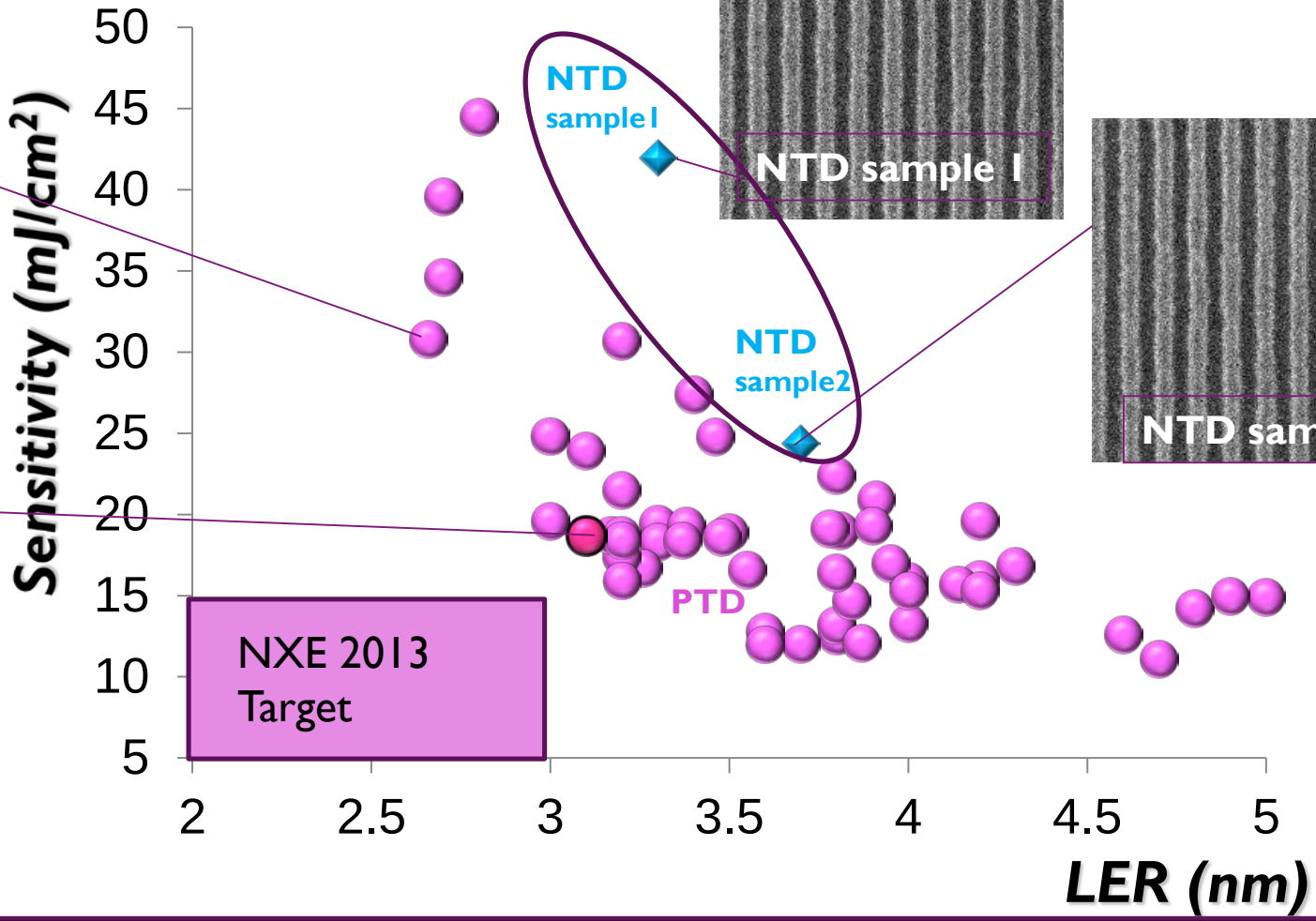
NTD vs. PTD











Currently Sensitivity and LER of NTD materials are in the same PTD trend.

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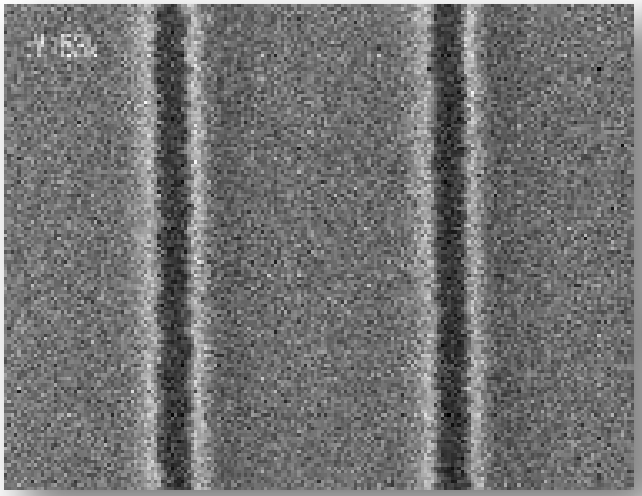
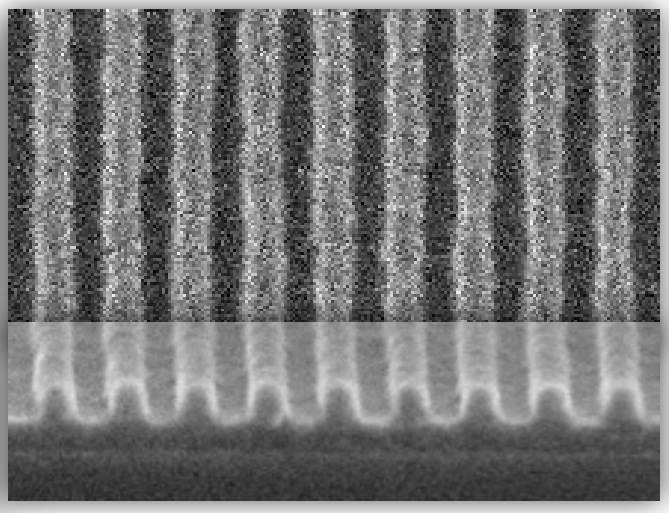
NEGATIVE TONE DEVELOPMENT RESOLUTION

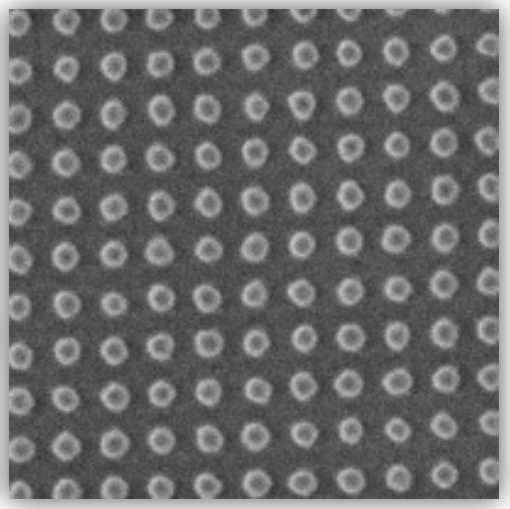
Conventional
iso trench 20nm
Dose 34.1 mJ/cm²



Dipole60
HP 20nm
Dose 40 mJ/cm2



Quasar45
HP 26nm
Dose 32.5 mJ/cm²



key challenge for NTD today:

- **Resolution LS (ultimate resolution today is 20nm HP)**

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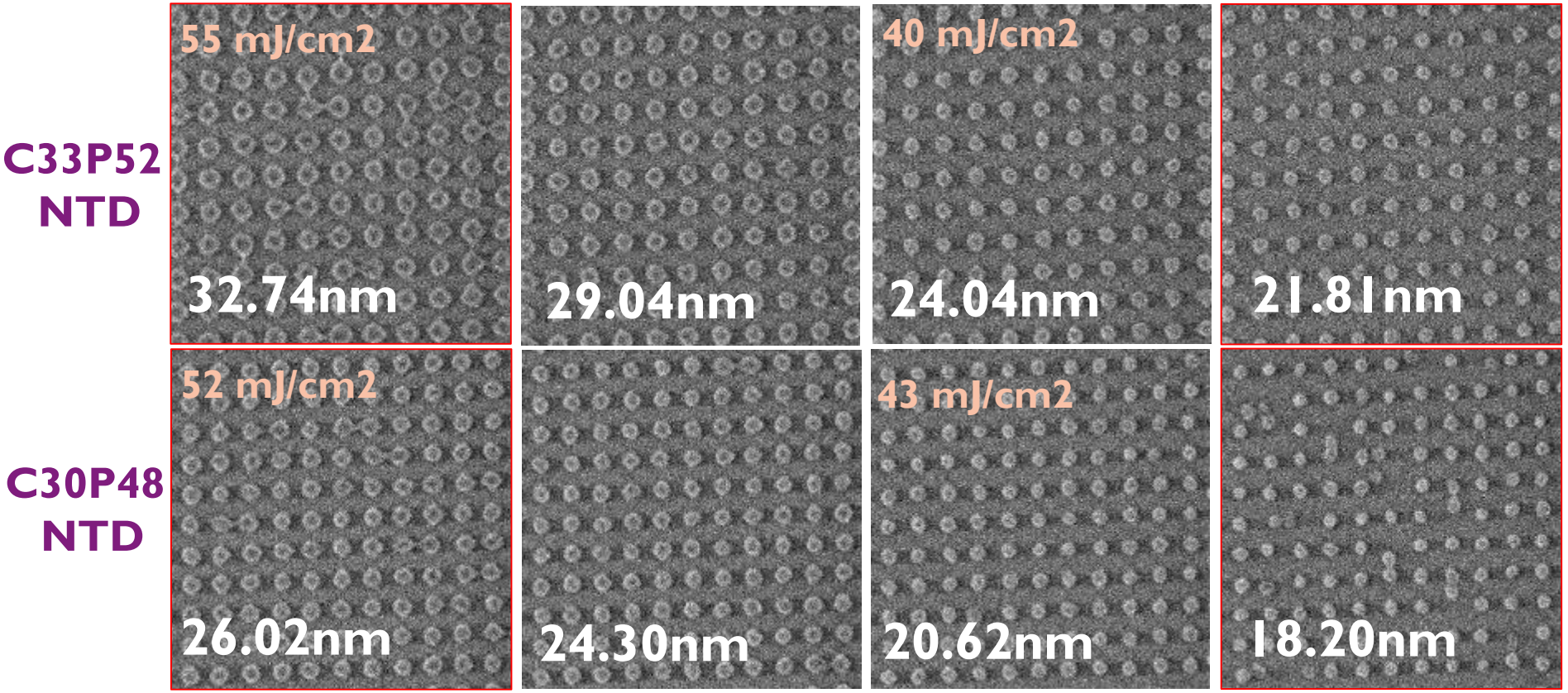
NTD PILLARS PATTERNING
QUASAR ILLUMINATION



NTD is able to print very small pillars. Sensitivity has to be improved.

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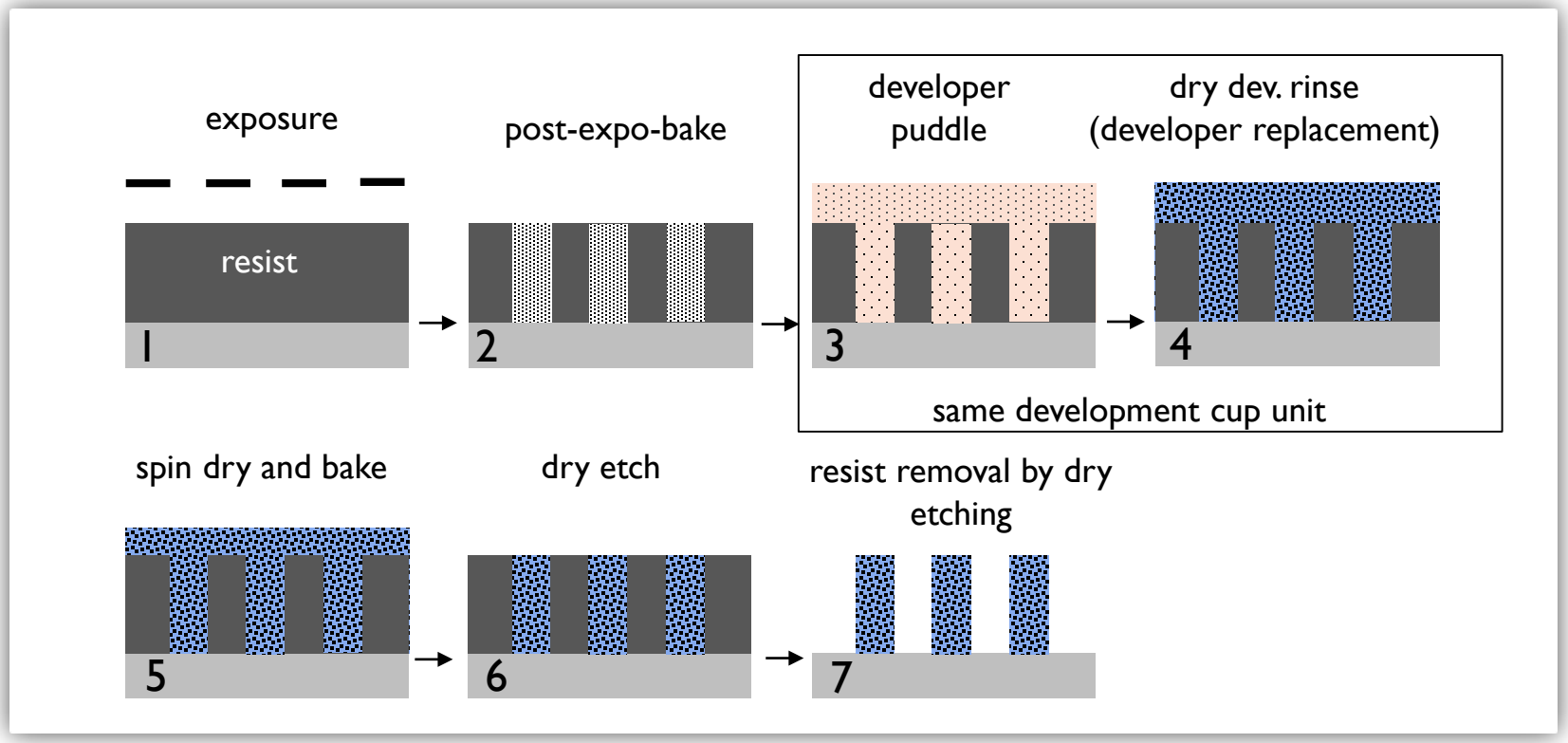
DRY DEVELOP RINSE MATERIAL CONCEPT

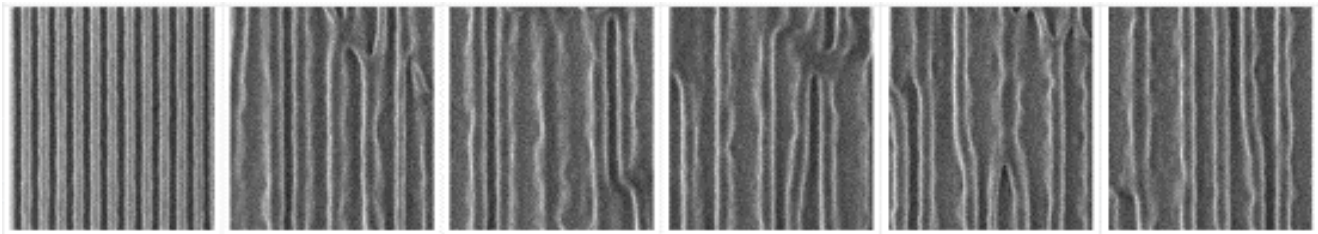


Strengths: Line collapse reduction, etch resistance improvement
Peculiarity: reversed patterning process

DDRM PROOF-OF-CONCEPT 19NM L/S

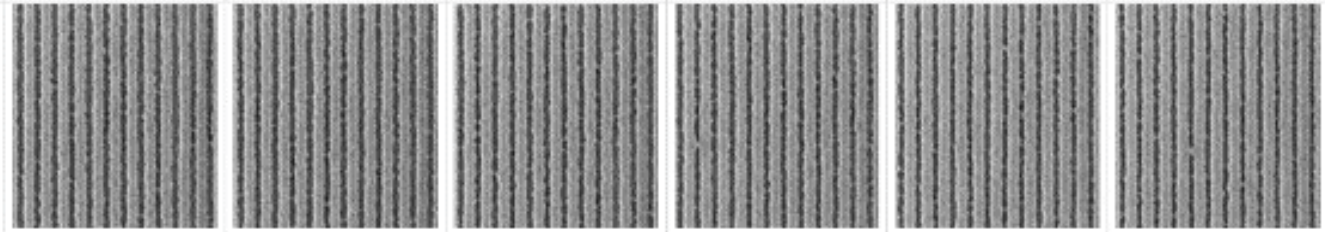
DRY DEVELOPMENT RINSE MATERIAL
by Nissan Chemical

Reference process



Dose increasing

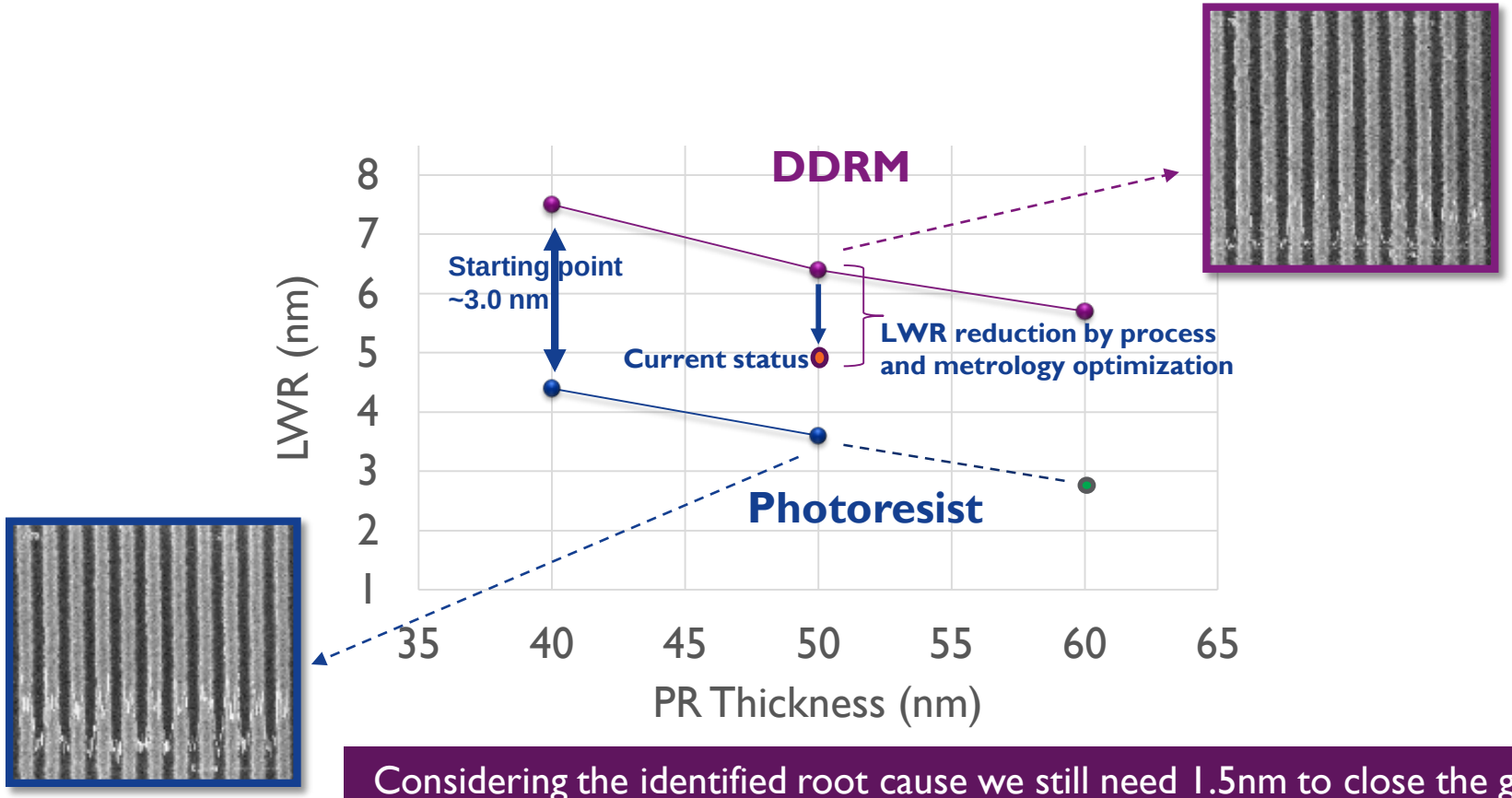
DDRP



Strong improvement in pattern collapse

DRY DEVELOPMENT RINSE PROCESS LWR INVESTIGATION

- Target: $LWR_{DDRM} \leq LWR_{PR}$
- at the starting point LWR for DDRM Lines was ~3.0 nm worse than those of PR



Considering the identified root cause we still need 1.5nm to close the gap
Further paths of improvement are today under investigation

NOVEL MATERIAL PATH FINDING
IMEC'S ROLE

Early Exploratory Research (Universities, Research Institutes, New startup, resist vendors)

Technology R&D
Assessment and mitigation of process risk

Not done at imec today

imec

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Lab → **Lab-to-Fab Cross-Over** → **Fab**

- Synthesis
- Simple Patterning (MET, PSI, EB)
- Coupon Processing
- Primitive Steps

- Advanced Patterning
- Process Development
- Integration in stable Modules

- Enables pipeline between risky exploratory research & Fab process enablement

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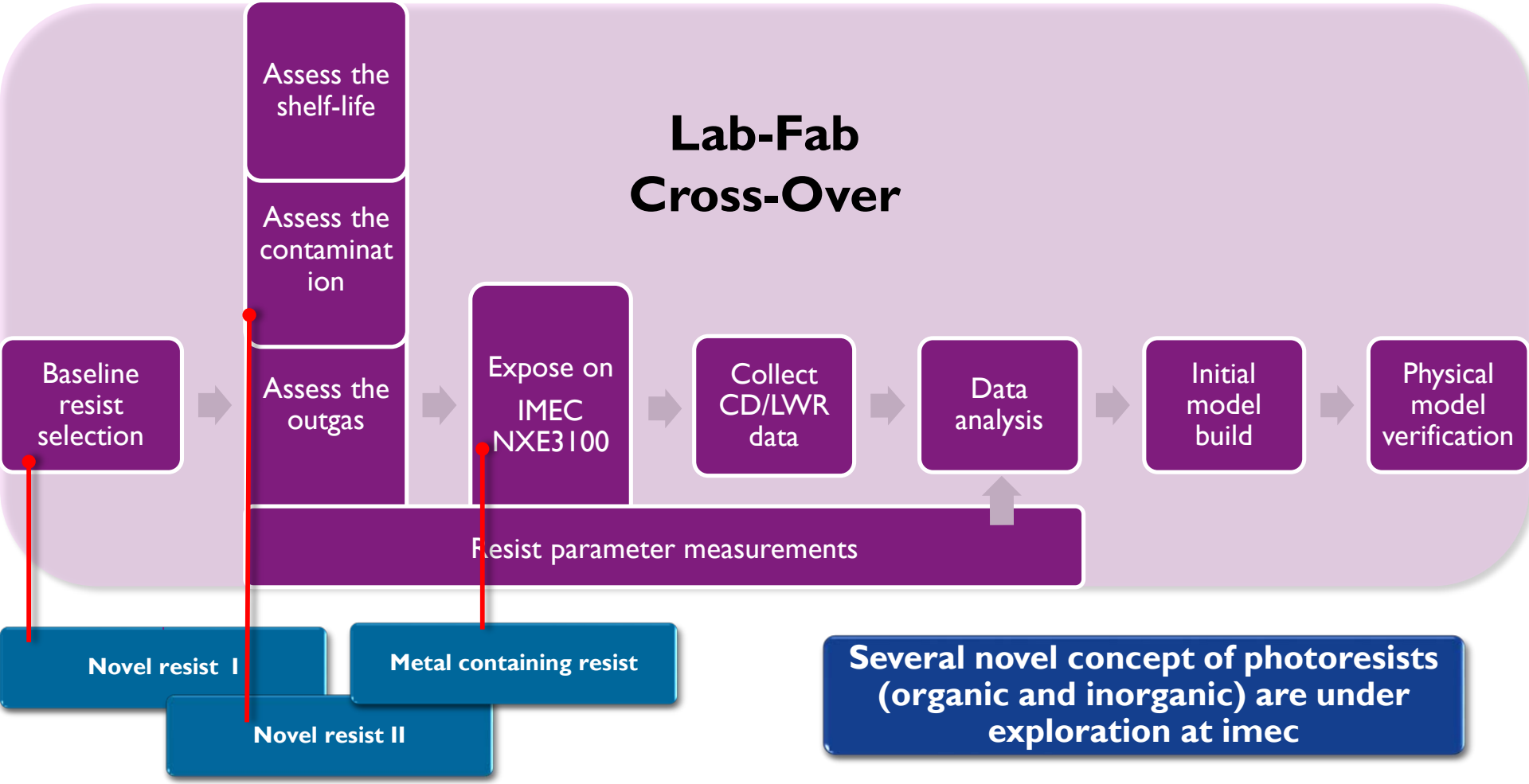
NOVEL EUV MATERIALS
LITHO CHARACTERIZATION
BASIC PROCESS FLOW IN THE LAB2FAB PHASE



Several novel concept of photoresists (organic and inorganic) are under exploration at imec

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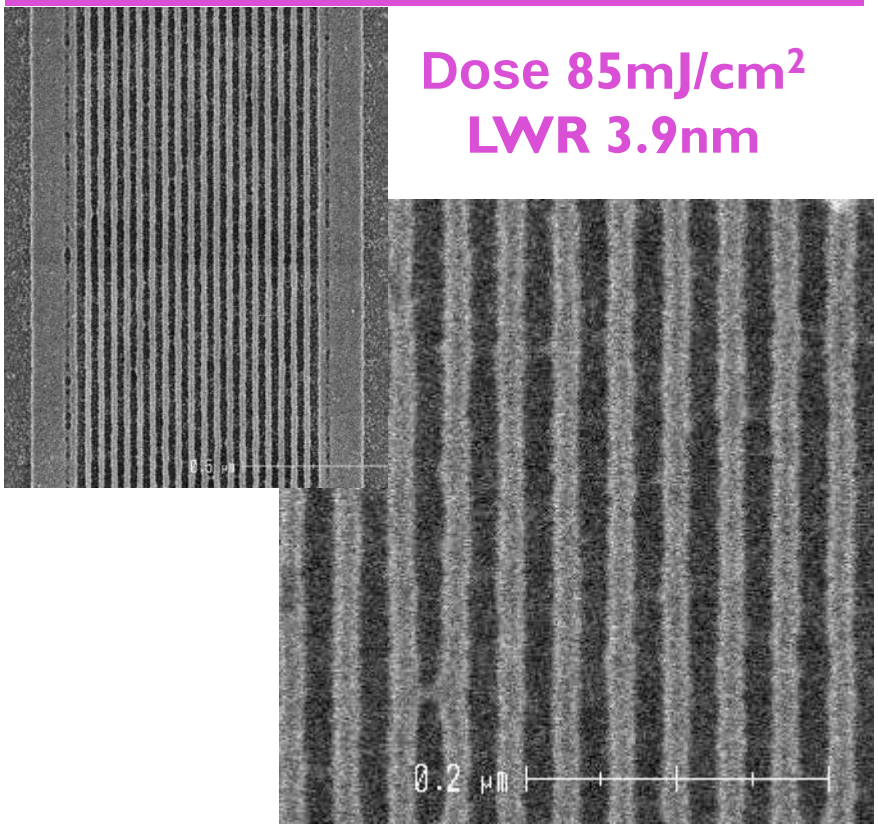
INORGANIC EUV RESIST IMAGING ON NXE3100

Photo condensable Metal oxide resist BY INPRIA

18nm LS

Dipole 60 illumination, TM11 mask

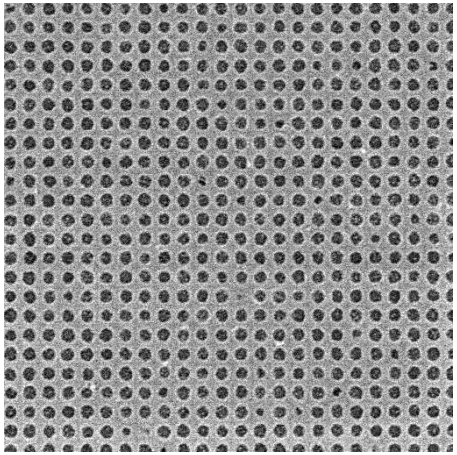


Dose 85mJ/cm²
LWR 3.9nm

24 -22nm Contacts

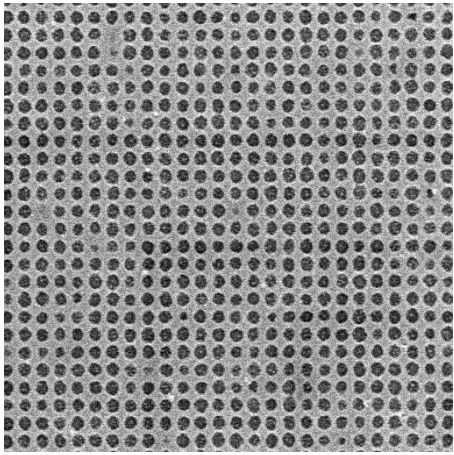
Quasar ill, TM10 mask

24nm dense CH C31.5P48



46 mJ/cm²

22nm dense CH C30.5P44



49 mJ/cm²

TM10 reticle not optimized for negative tone cell or characterized. Improved LCDU expected with reticle targetted for negative tone.

Promising 1st imaging results with Inpria resist demonstrated on NXE3100

OUTLINE

Introduction

CAR resist performance and challenges

Alternative resist materials and processes

Summary

Acknowledgements

SUMMARY-I

CAR resist status

LS resists are not meeting <4nm LWR 3σ and *high doses* are needed to resolve 18nm LS on /3100 and 16nm LS on /3300

CH resists – meeting <3nm 3σ LCDU spec at 24nm dense CH *at high dose*

Compatibility with Surfactinated rinse and OoB sensitivity of resist are important parameters in the resist process optimization

No progress in CAR resist performance wrt RLS in the last 2 year

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SUMMARY 2

New ancillary materials and/or Novel Material concept can potentially offer benefits in terms of resolution and LWR, line collapse and etch resistance

1st imaging results on the 3100 with Inpria resist obtained : 18nm LS (P36) and 24-22nm dense contacts.

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ACKNOWLEDGEMENTS

Marieke Meeuwissen en Rik Hoefnagels (ASML) for their contributions to the CA resist screening

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- Kenji Hoshiko, Andreia Santos (JSR)
- Takehito Seo (TOK)
- Ryuji Onishi (Nissan)
- Mike Koscis, Peter Deschepper (inpria)

All material suppliers for supplying resist samples, underlayers, rinse material and for the frequent discussions

TEL Team at imec and Japan

- Kuwahara Yuhei, Kathleen Nafus, and service team.

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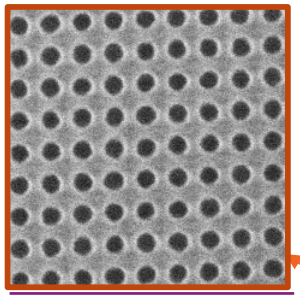
ASPIRE
INVENT
ACHIEVE

imec

GLOBALFOUNDRIES intel Micron Panasonic ideas for life SAMSUNG tsmc

ALTERA XILINX SK hynix SONY FUJITSU HUAWEI QUALCOMM

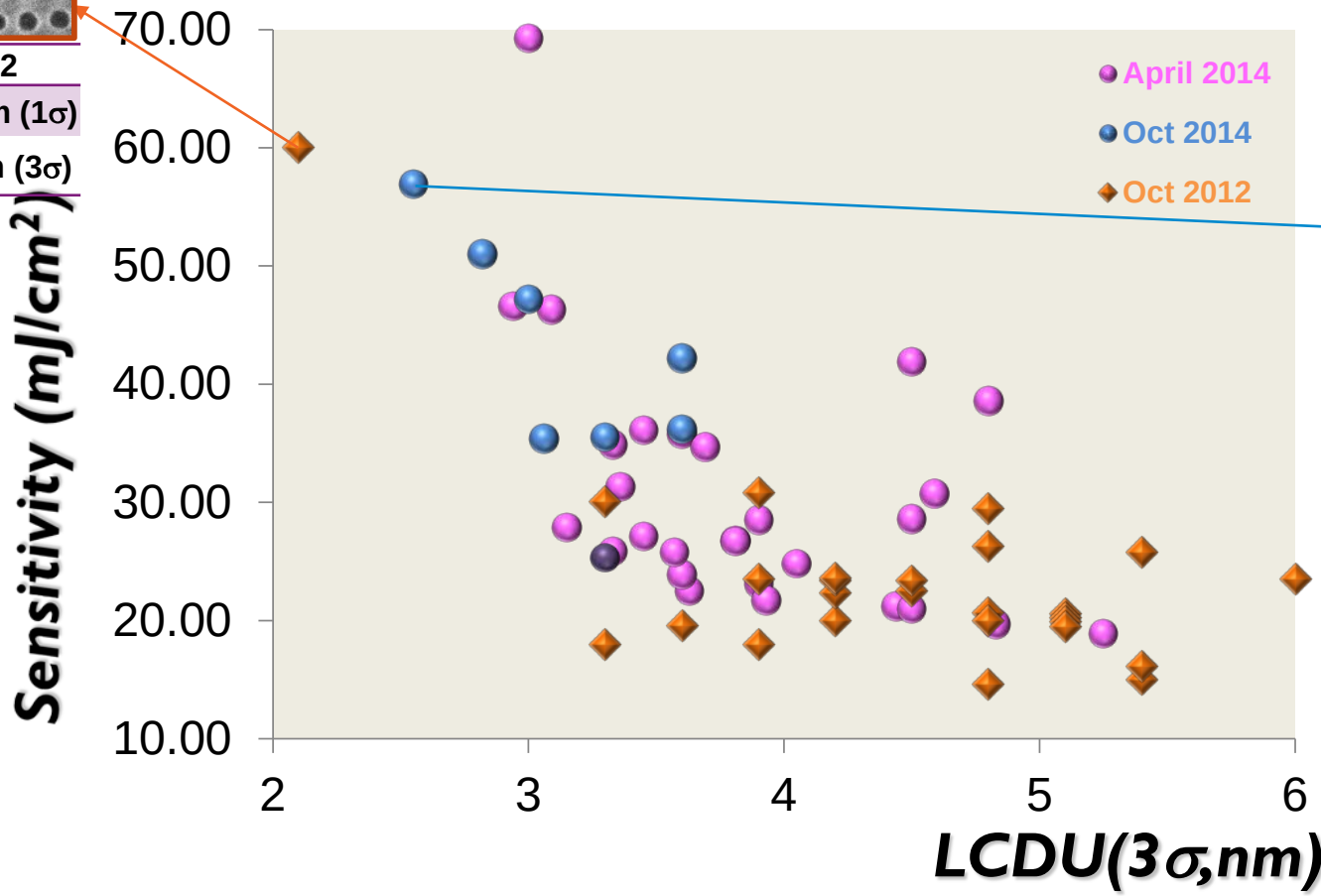
RESIST PROGRESS 2012-2014
26NM CONTACTS ON NXE3100

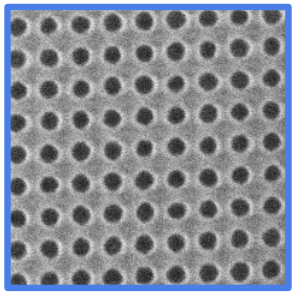


60mJ/cm2

LCDU= 2.1nm (1σ)

CER =1.1 nm (3σ)





56.9mJ/cm2

LCDU= 2.6nm (3σ)

CER =1.2 nm (3σ)

No notable progress in resist performance with regard to RLS in the last 2 years !

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