EUV imaging performance and challenges of 10nm and 7nm node Logic

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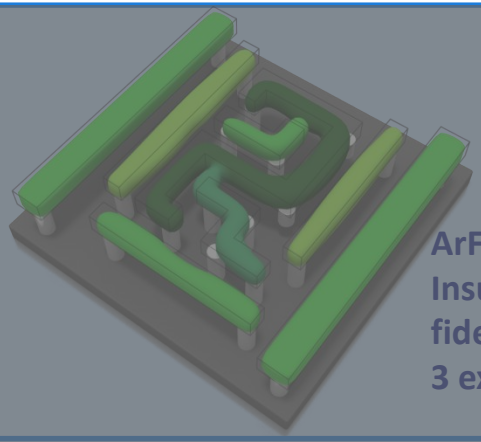
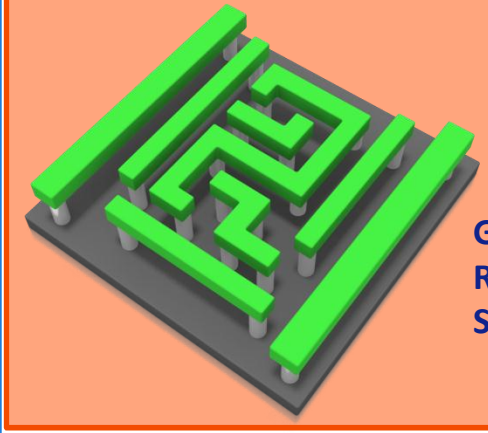
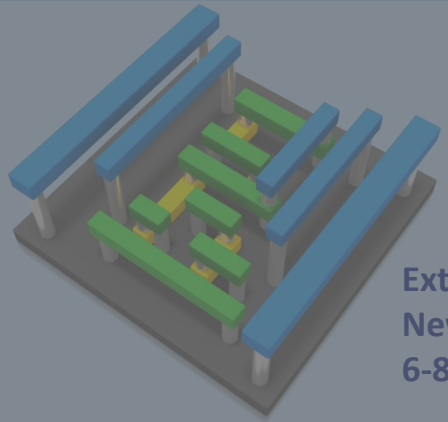
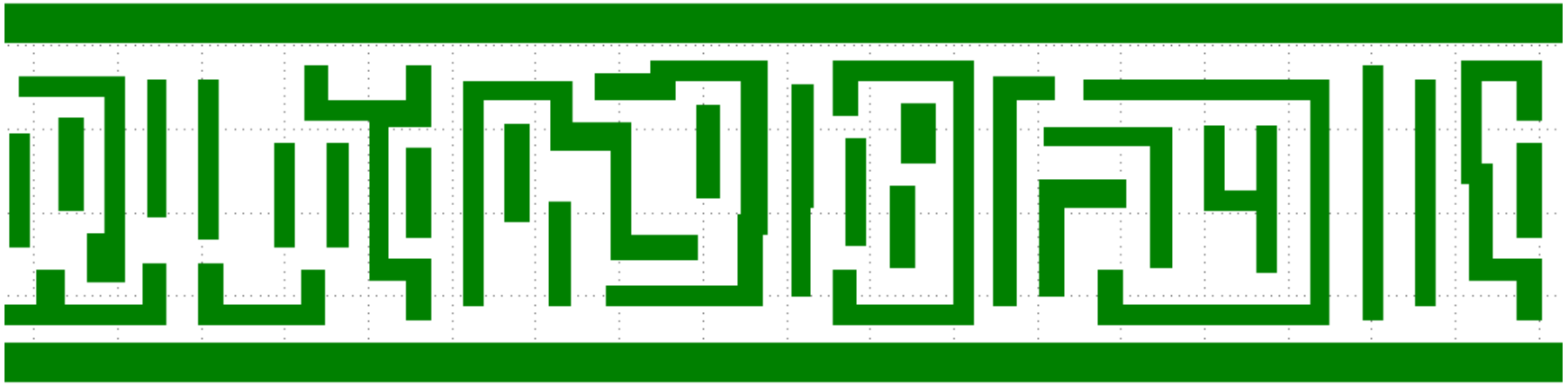
ST Microelectronics: Vincent Farys

International Symposium on Extreme Ultraviolet Lithography – October 27, 2014 – Washington, D.C.

Chipmakers are evaluating patterning solutions for coming Logic nodes

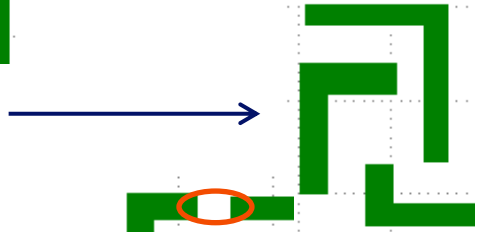
	ArFi	EUV
2D - Single layer solution	 ArFi multiple patterning Insufficient pattern fidelity 3 exposures	 Good pattern fidelity Re-use existing designs Single exposure
1D - 2-3 layers required	 Extra layers needed New integration scheme 6-8 exposures	

Logic M1 one of most challenging layers for lithography

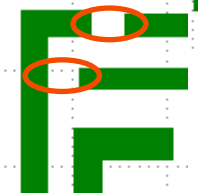


- Tightest pitch in design with lines from fully dense to (semi-)iso

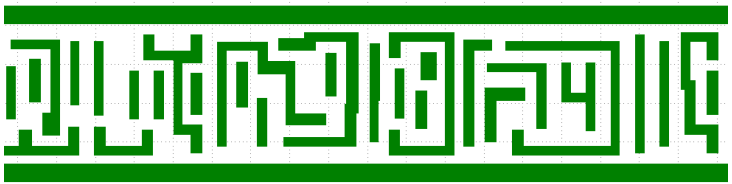
- 2D feature shapes (H and V combined), like elbows



- Many line-end features, like tip-to-tip and tip-to-space

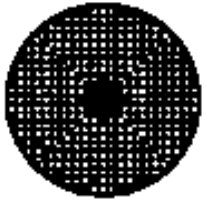


Logic M1 evaluated on ASML's NXE:3300B using conventional and Quasar illumination at low dose



	NXE:3300B
NA	0.33
Illumination	Conventional 0.9σ, 6 off-axis pupil settings
Resolution	22 nm
Dedicated Chuck Overlay / Matched Machine Overlay	3.0 nm / 5.0 nm
Productivity	55 - 125 Wafers / hour
Resist Dose	15 mJ/cm^2

	Logic M1 – 10nm node
Min. pitch	~ 42 – 48nm
CD control	~ 1.4-1.7nm (7% min. HP)
Min. Tip-to-tip	~35-50nm
Min. Tip-to-space	~28-35nm



R. Peeters et al, EUV Lithography - Industrialization Progress

Contents

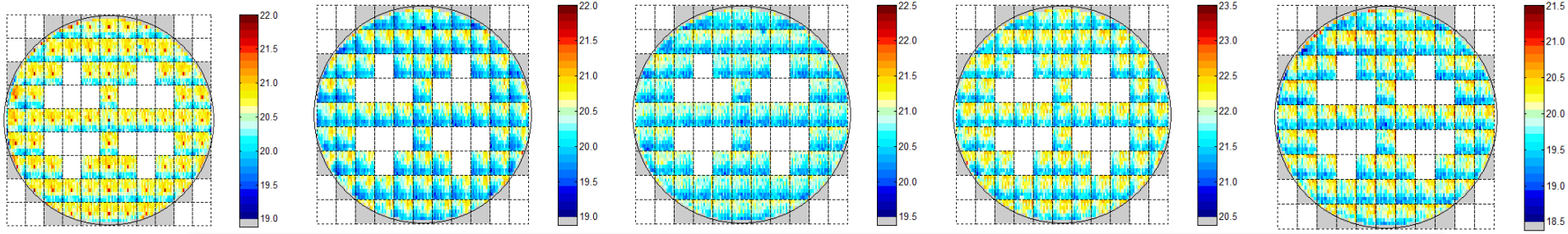
Multiple NXE:3300B systems show CDU below 1.5nm

dense and iso lines exposed at 16mJ/cm2 – conventional ill.

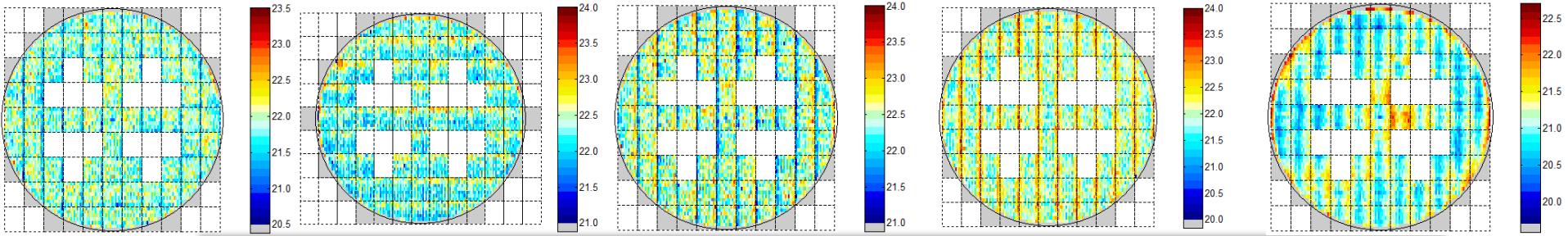
ASML

Public

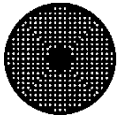
System A **System B** **System C** **System D** **System E**



22nm DLs: Full wafer CDU <1.2nm



22nm ILs: Full wafer CDU < 1.5nm

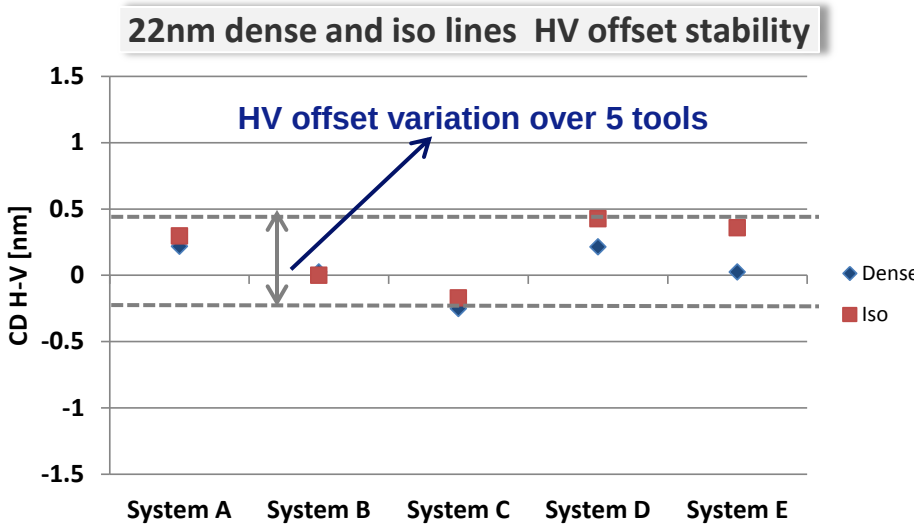


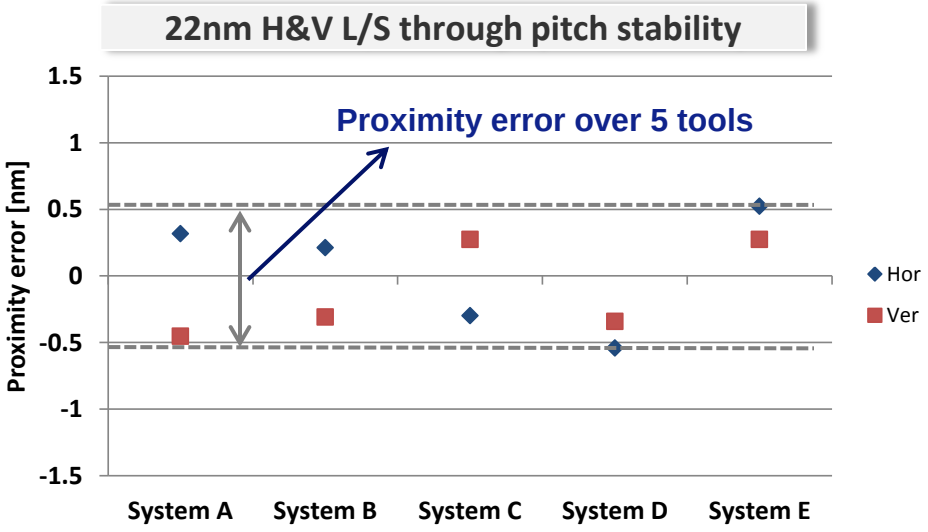
Data corrected for reticle errors and mask shadowing effect

CD measurements performed with YieldStar

NXE:3300B shows stable HV offset and CD through pitch control between systems

- HV offset variation over 5 tools within +/-0.35nm
- CD through pitch control over 5 tools within +/-0.55nm (< +/- 3% TargetCD)



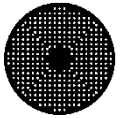


22nm H and V L/S, pitch 44 and 154nm

Reference pitch

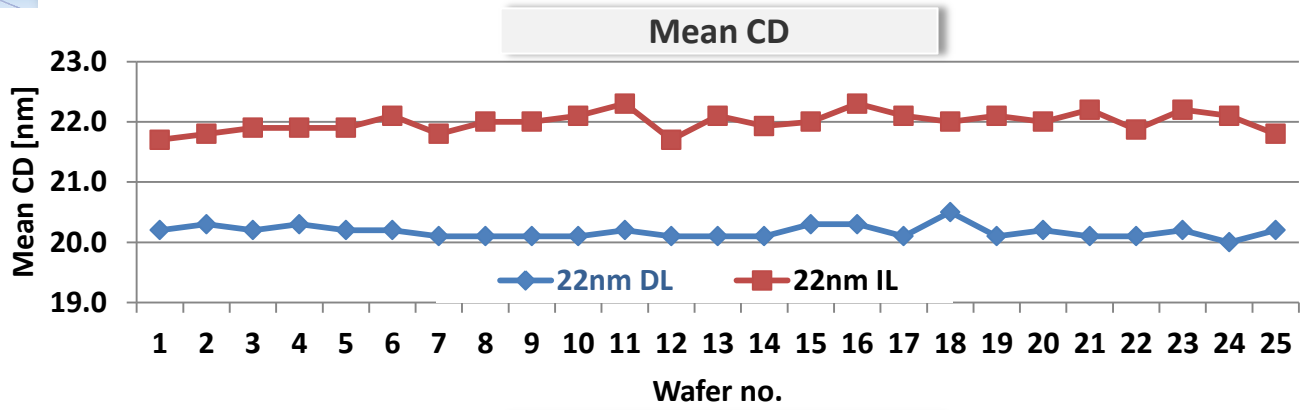
22nm L/S, pitch 44, 50.5, 57, 66, 88 and 154nm

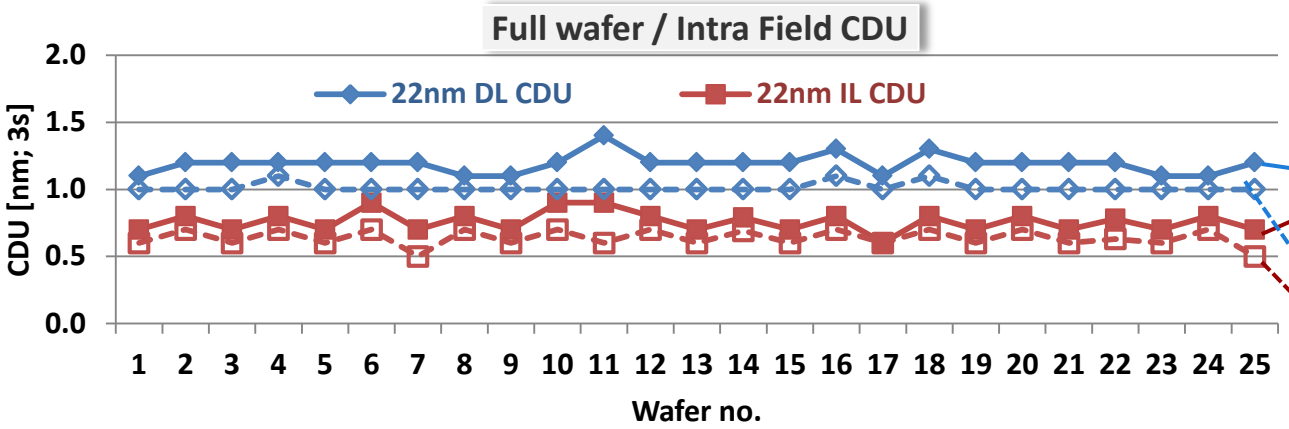
16mJ/cm²



NXE:3300B shows stable through lot performance

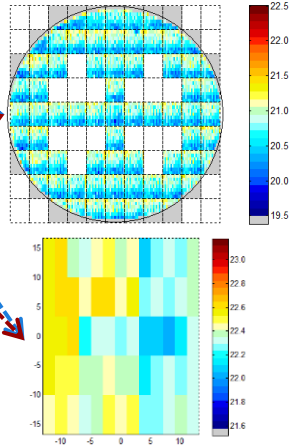
Courtesy of IBM

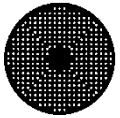




Through lot stability (HV pooled data):

- Mean CD: +/-0.3nm
- FW CDU: +/-0.15nm
- IF CDU: +/- 0.1nm

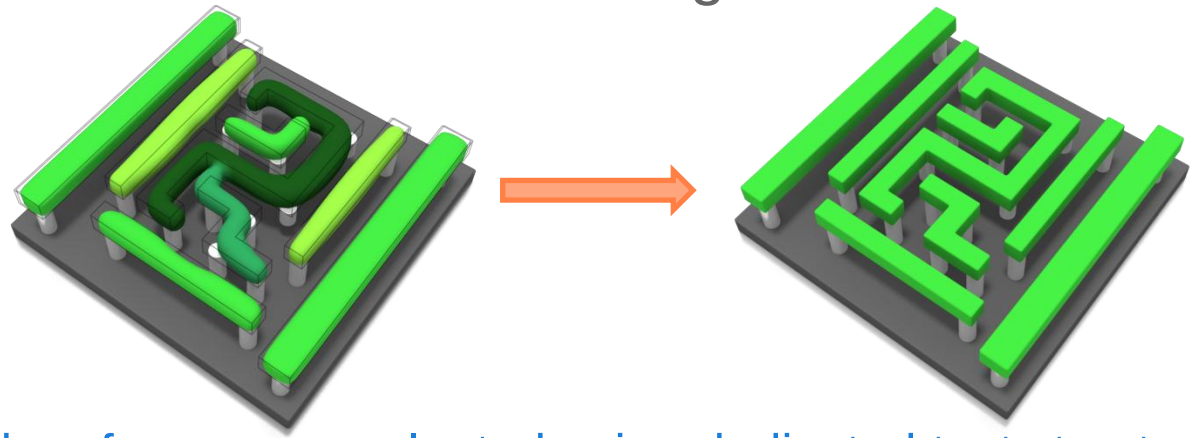




22nm H and V L/S, pitch 44 and 154nm @ 16.6mJ/cm²

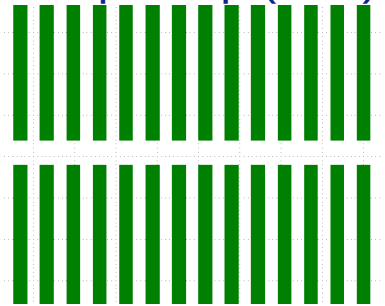
CD measurements performed with YieldStar

Good line-end control allows aggressive shrink of random 2D logic

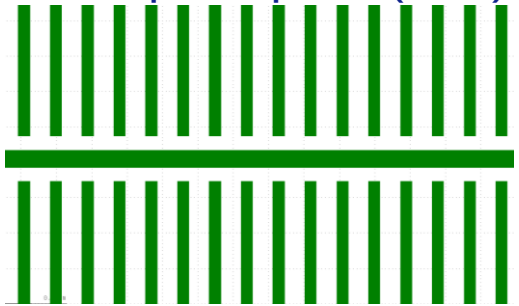


- Line end performance evaluated using dedicated test structures

Tip-to-tip (T2T)



Tip-to-space (T2S)

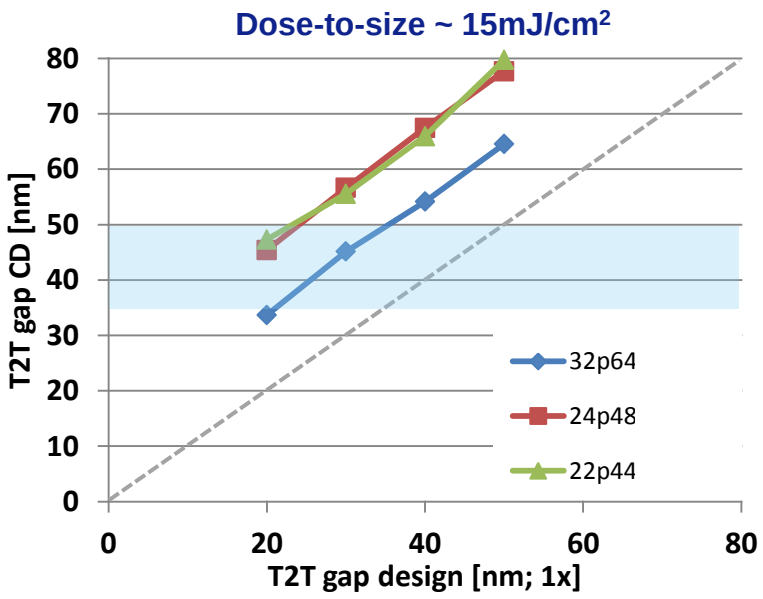


Dark field pattern → polygon = space

Logic M1 – 10nm node	
Min. pitch	~ 42 – 48nm
Min. Tip-to-tip	~35-50nm
Min. Tip-to-space	~28-35nm

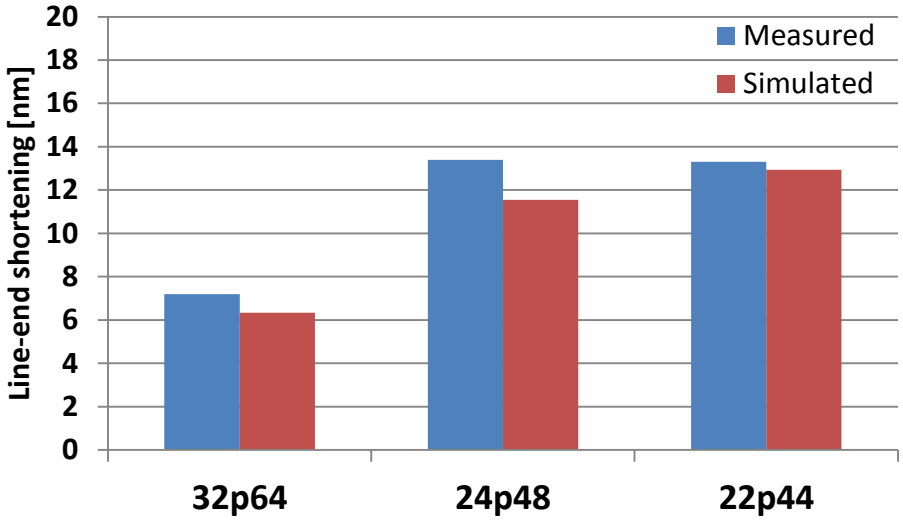
Resist shows significant Line-end-shortening of ~ 13nm for 24 and 22nm HP designs

Tip-to-tip



Conventional illumination

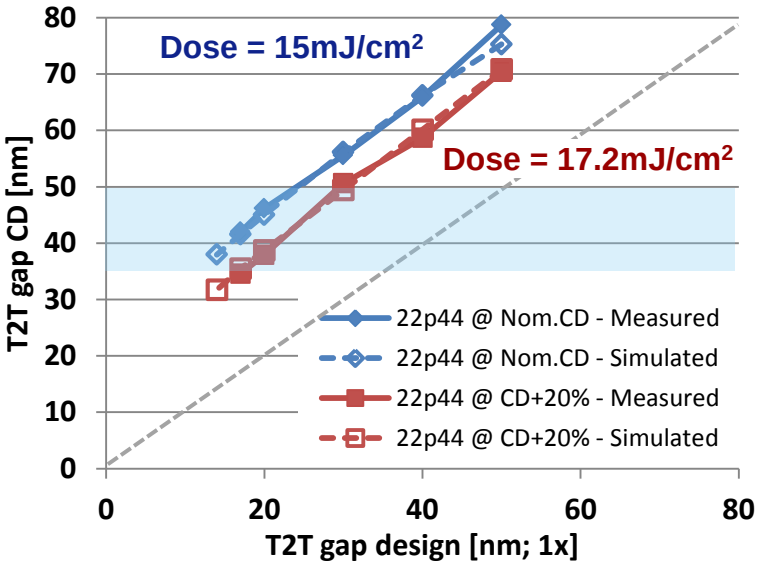
Line-end shortening



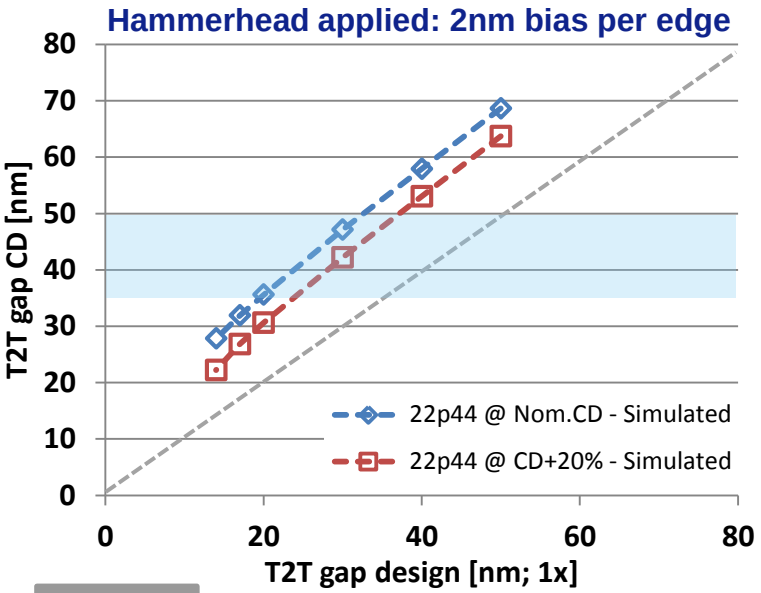
Rigorous simulation: 9nm resist blur + typical 3300 scanner

T2T < 25nm feasible at low dose by means of OPC and overexposure trench

Tip-to-tip – 22p44nm

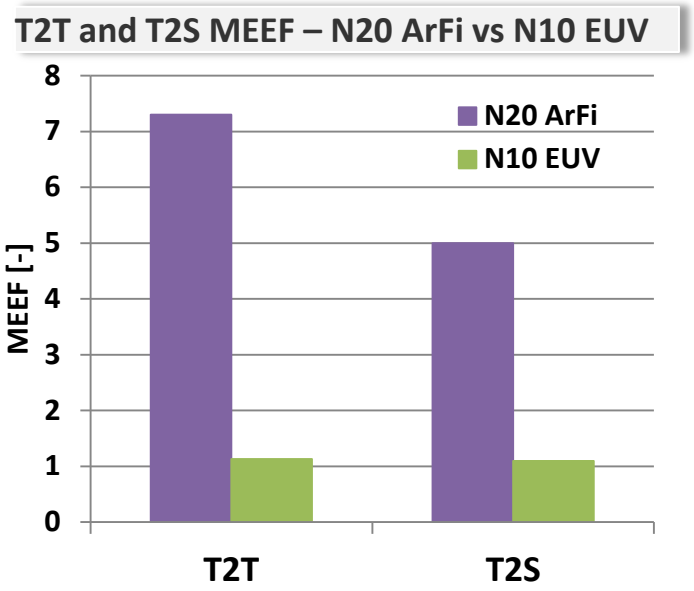


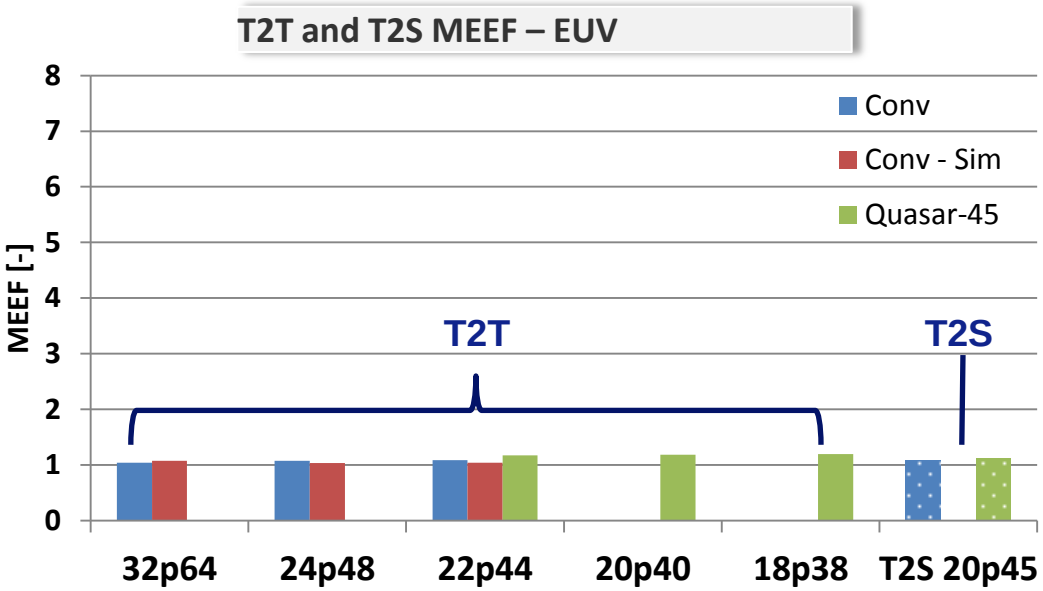
Tip-to-tip – 22p44nm w/ OPC



- T2T of 30nm feasible by lowering gap CD on mask to 14nm (1x) and overexposure trench (CD+20%)
- Simulations: OPC (eg. Hammerheads) enables < 25nm T2T at low dose

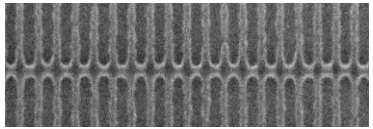
MEEF T2T/T2S close to 1 for N10. More than 5x improvement w.r.t. N20 performance with ArFi



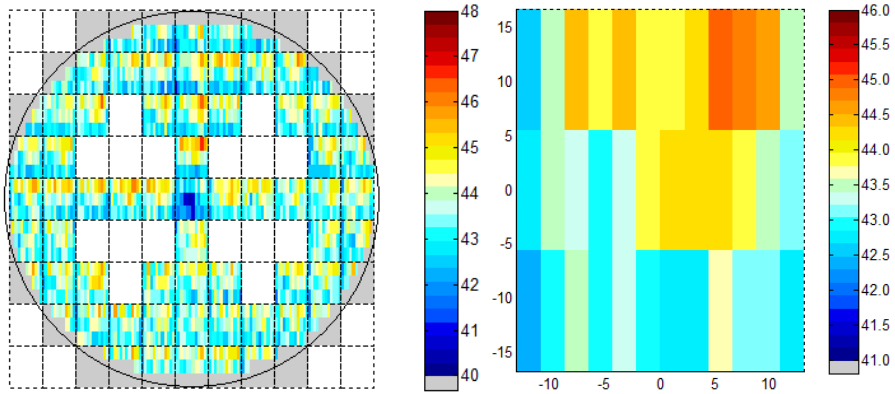


- Low Mask Error Enhancement Factor for gap CD for both T2T and T2S features for various grating pitches
  - Both for Conventional and Quasar illumination, supported by simulations
- Large improvement w.r.t. current performance at N20 using ArFi

Raw full wafer CDU T2T and T2S < 7% of targetCD at 18mJ/cm^2



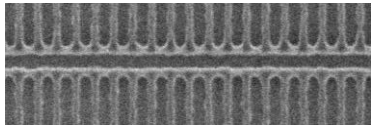
Tip-to-tip



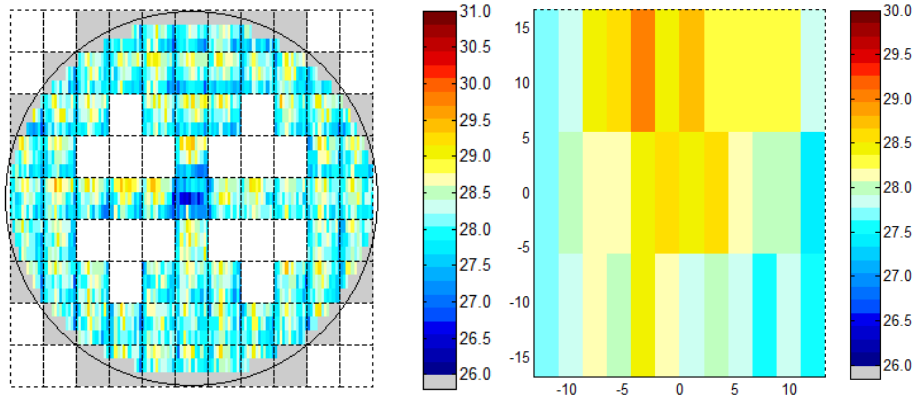
22nm dense L/S with 20nm gap (1x) @ 18mJ/cm^2

Including reticle fingerprint

T2T CDU	Mean gap CD	FW CDU	IF CDU
V trench	43.6nm	2.6nm	2.0nm
H trench	40.3nm	2.8nm	2.4nm



Tip-to-space

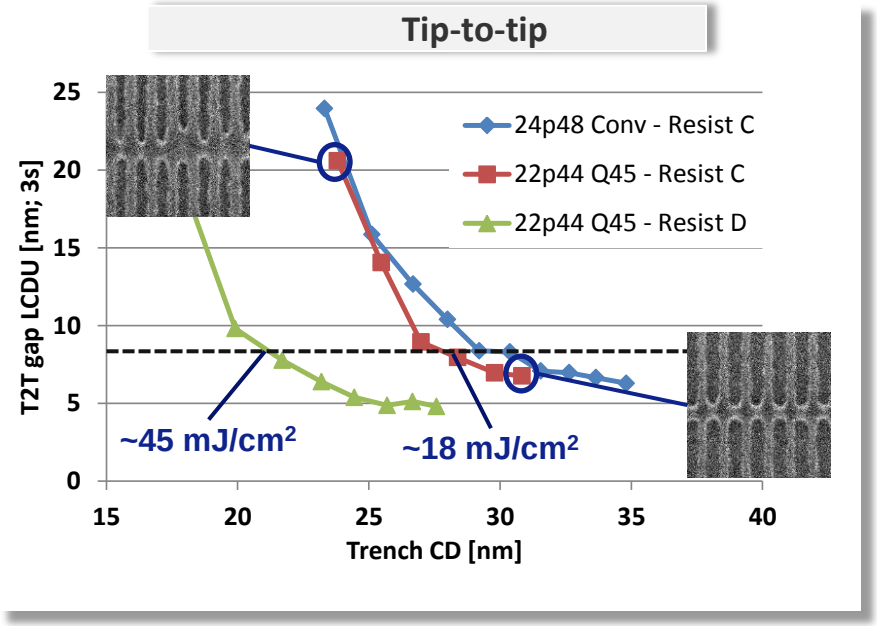


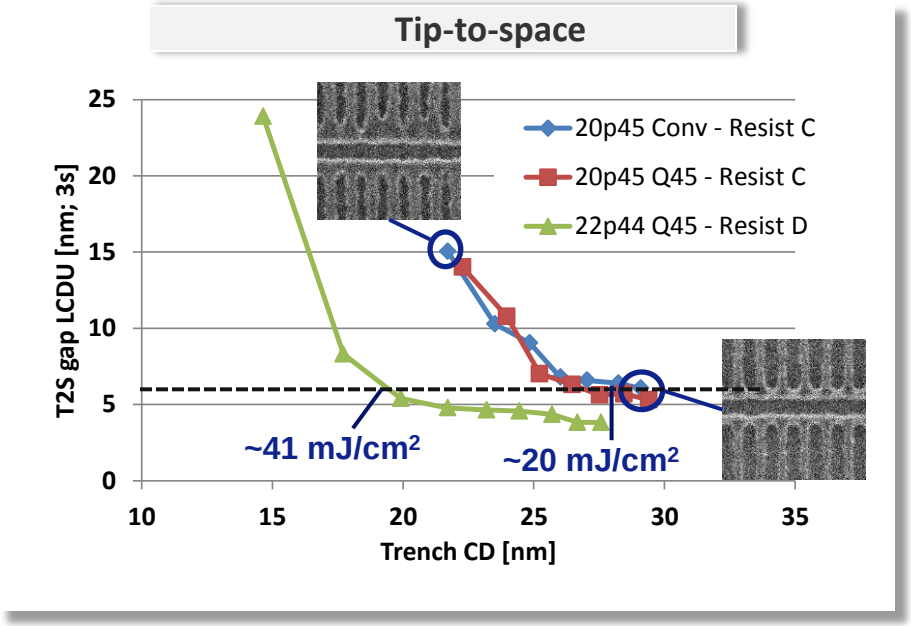
22nm dense L/S with 20nm gap (1x) @ 18mJ/cm^2

Including reticle fingerprint

T2S CDU	Mean gap CD	FW CDU	IF CDU
V trench	28.1nm	1.4nm	1.1nm
H trench	25.4nm	1.4nm	1.0nm

Local gap CDU dependent on trench width and resist contrast

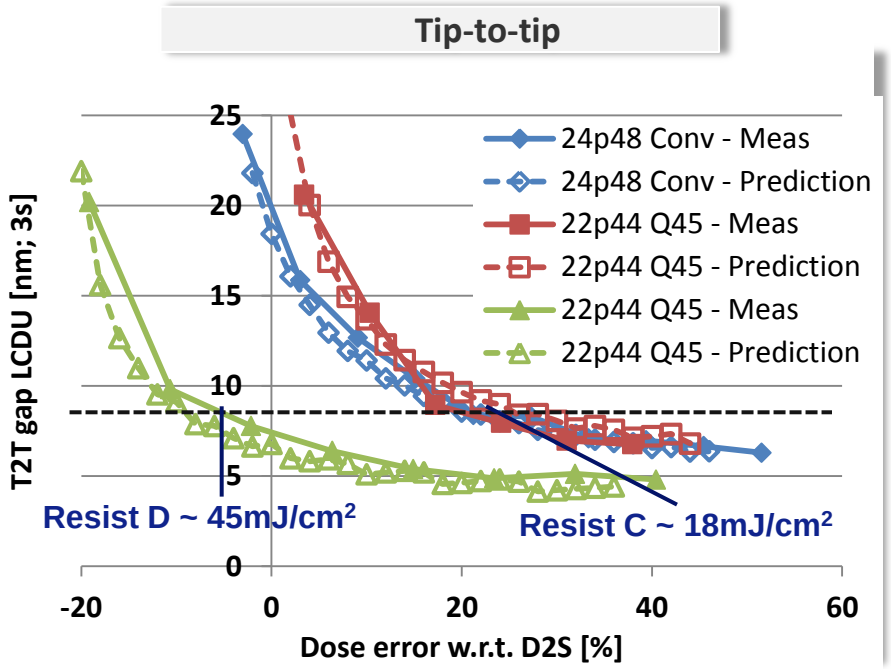


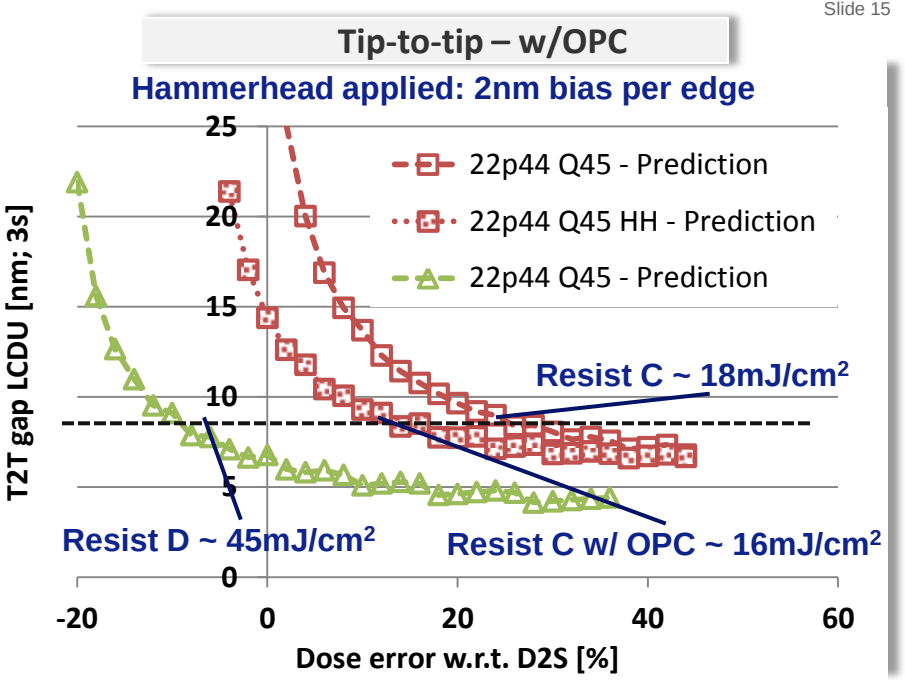


Logic M1	20nm node ArFi - Actual	10nm node EUV – Scaled from N20
Tip-to-tip LCDU	~11nm	<8nm
Tip-to-space LCDU	~7.5nm	<5.5nm

- Large LCDU at small trench width → More advanced OPC (Hammerheads) expected to reduce LCDU significantly

Local gap CDU driven by dose sensitivity and resist properties. OPC reduces LCDU





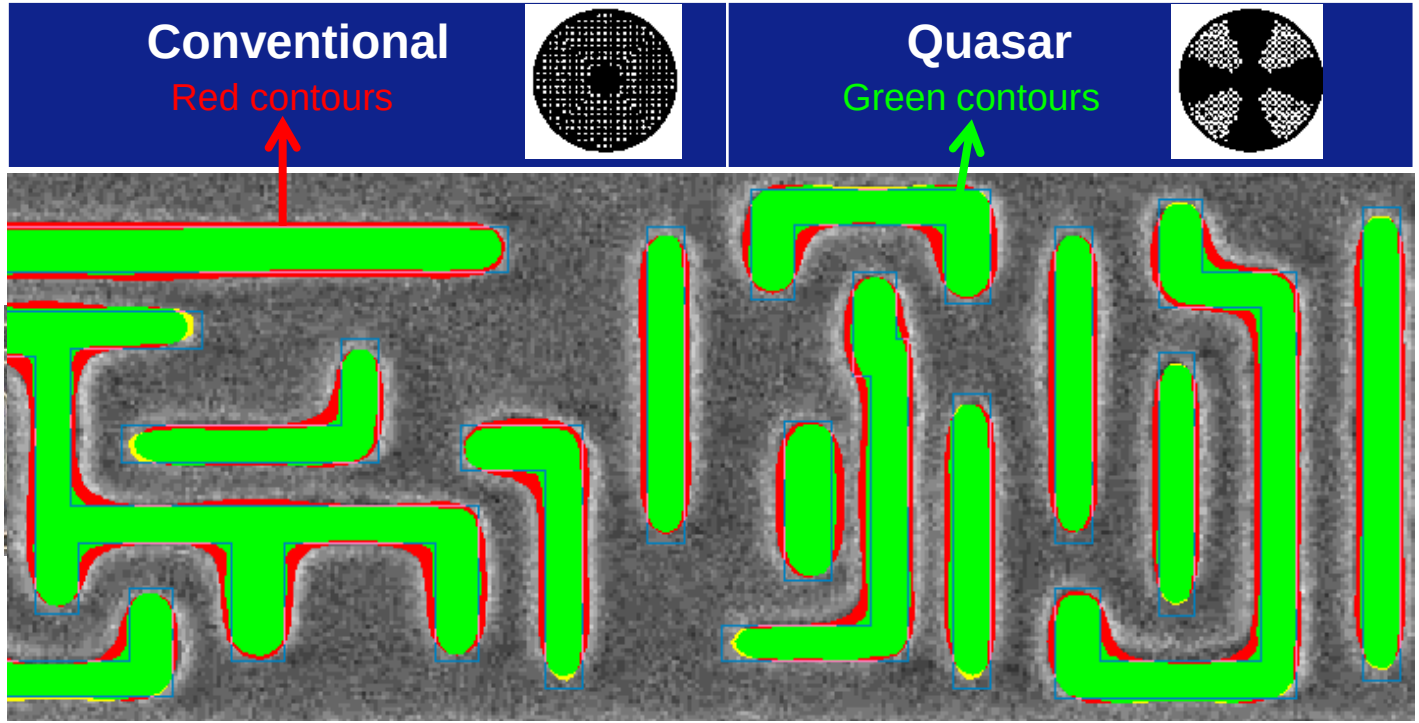
- LCDU prediction: LCDU ~ A * D*dCD/dD
  - A = resist dependent constant
- LCDU trend driven by dose sensitivity
- OPC (Hammerhead) reduces LCDU at same dose or allows dose reduction at same LCDU

Contents

Accurate Metal layer model for multiple illumination modes

Calibrated Tachyon NXE M3D+ model

Test mask without OPC - 20 mJ/cm²

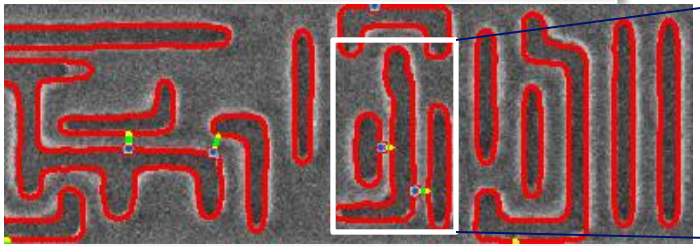


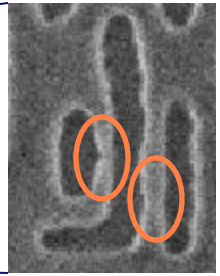
- Quasar-45 shows better pattern definition

NXE:3300, 10 nm logic metal 1 layer, 45 nm pitch

Tachyon Litho Manufacturing Check (LMC) & M3D+ correctly predicts bridge- and neck-defects through focus

Focus = -60nm

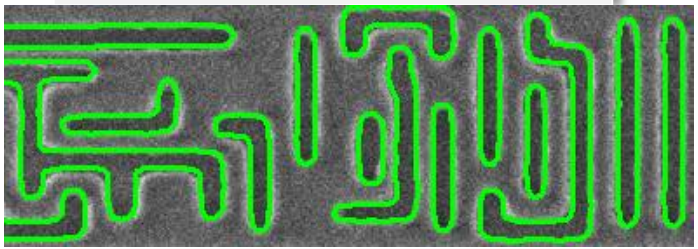




Test mask without OPC

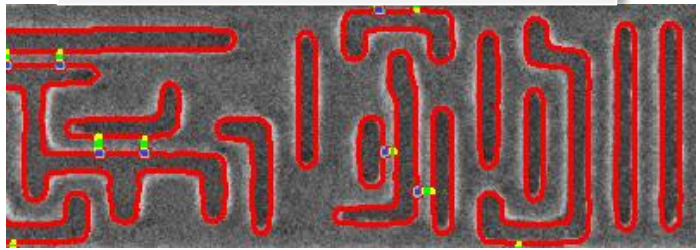
20 mJ/cm^2

Nominal Focus



No bridge- and neck-defects expected at nominal conditions → in line with observations

Focus = 60nm



Potential bridge defects in defocus (+/60nm) highlighted by LMC → in line with observations

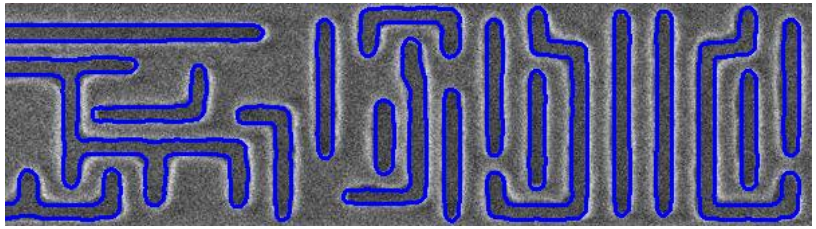
NXE:3300, 10 nm logic metal 1 layer, 45 nm pitch

Model predictions confirm good printability thru focus with Quasar and OPC

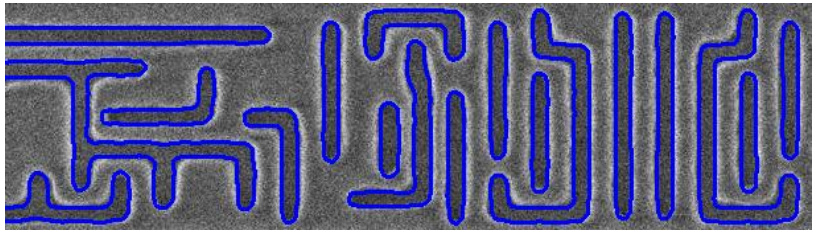
Calibrated Tachyon NXE M3D+ model

Focus

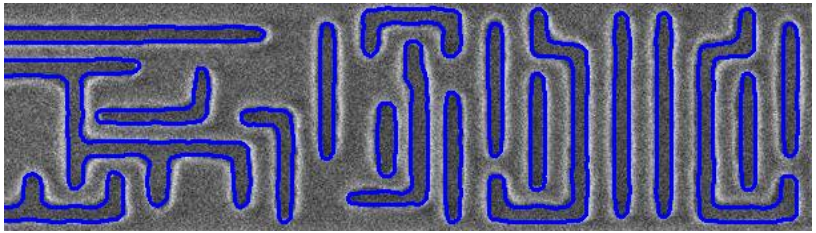
-60nm



0nm

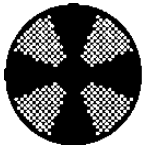


60nm



Test mask with basic OPC

20 mJ/cm²



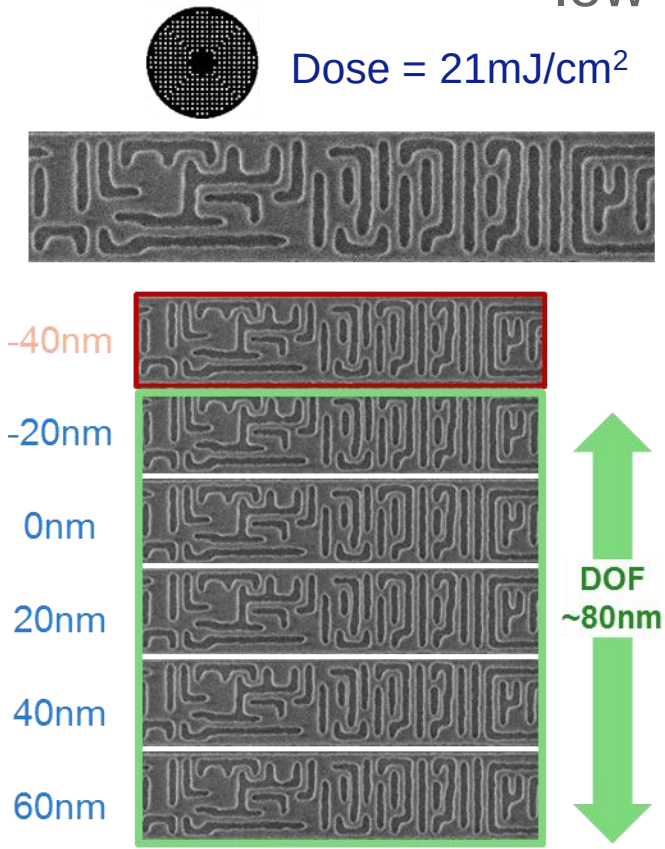
Early process results:

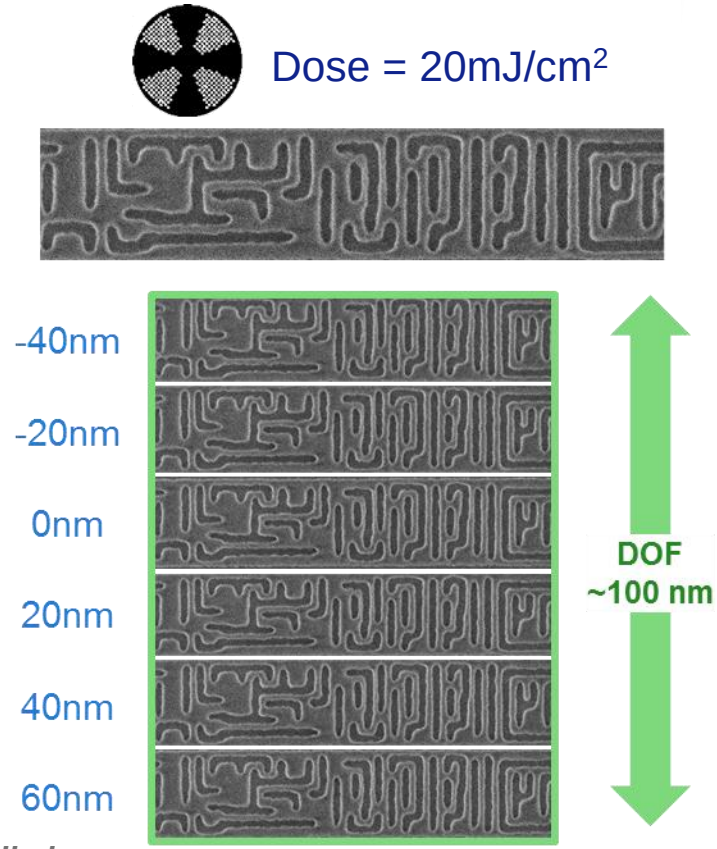
Predicted contours (blue) match well SEM contours

NXE:3300, 10 nm logic metal 1 layer, 45 nm pitch

life.augmented

OPC enables scaling to sub-N10 (40nm) min. pitch at low dose





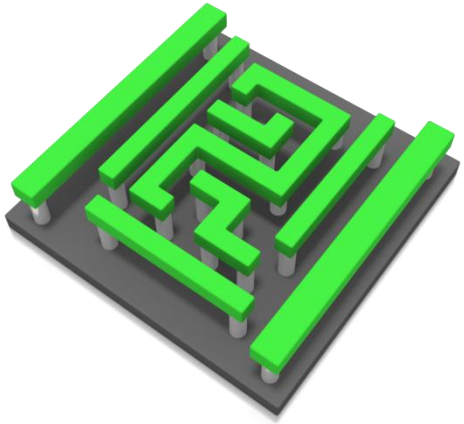
Basic OPC applied

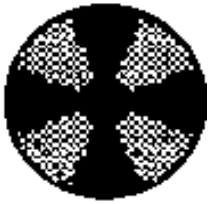
NXE:3300, 10 nm logic metal 1 layer, 40 nm pitch

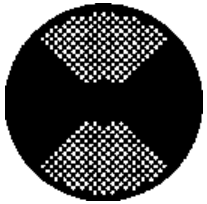
Contents

Initial evaluation of N7 Logic M1 done on ASML's NXE:3300B using Quasar and Dipole illumination

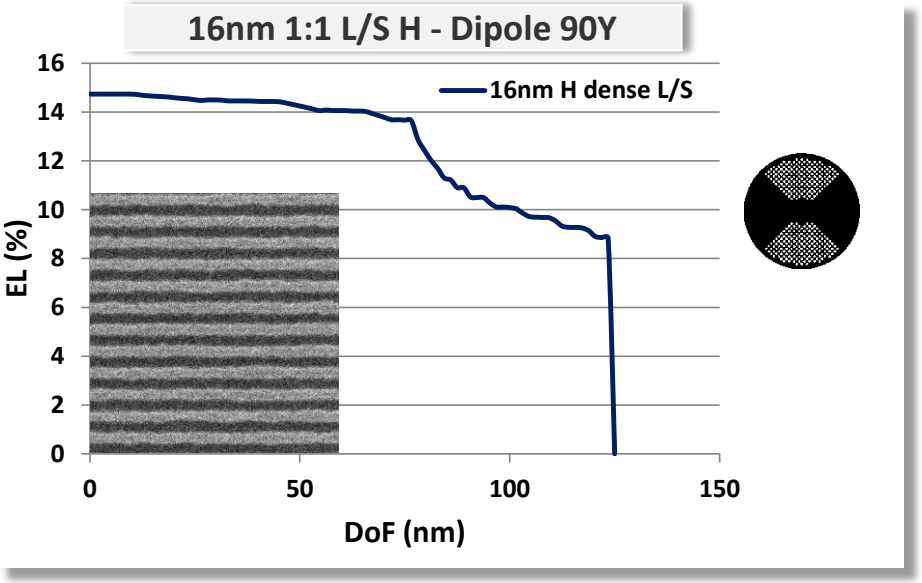
	Logic M1 – 7nm node
Min. pitch	~ 32 – 36nm
Min. Tip-to-tip	~25-35nm
Min. Tip-to-space	~18-25nm

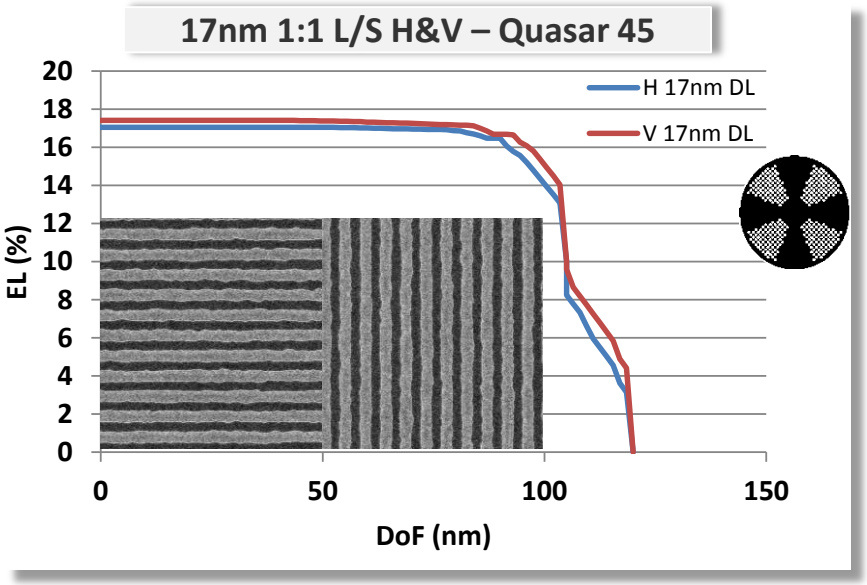






Large PWs on NXE:3300B for minimum pitch N7 design



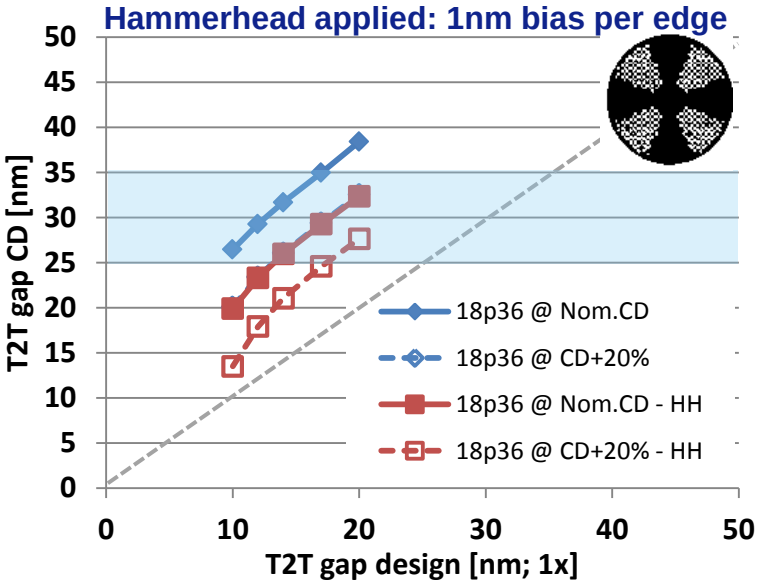


Dose-to-size ~ 55mJ/cm^2

- Sufficient resolution and process window for N7 development
- Further resist development required to lower dose
- NOTE, no mask optimization done

Simulations show T2T ~20nm feasible for 7nm node resolution – Further optimization by means of FlexPupil

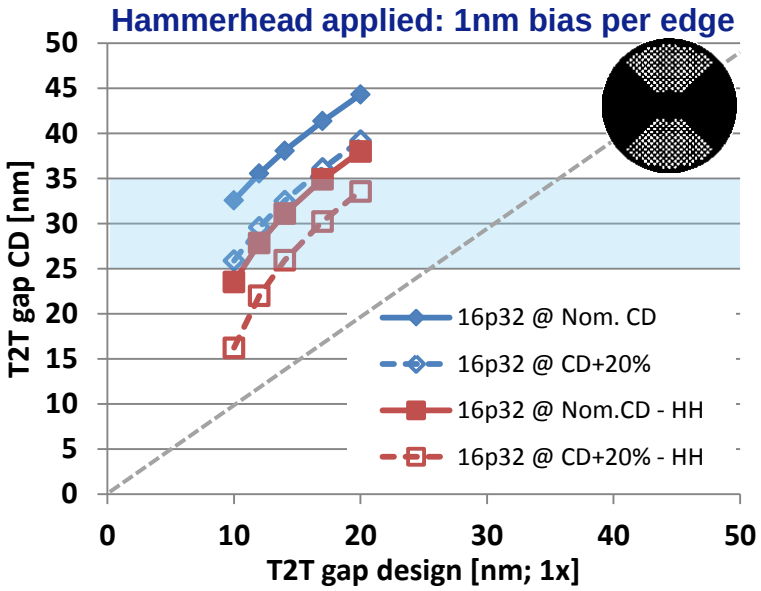
Tip-to-tip – 18p36



- OPC enables 20nm T2T at 36nm and 32nm pitch using std. off-axis illumination
- MEEF ~ 1 in region of interest

Rigorous simulation: 6nm resist blur + typical 3300 scanner

Tip-to-tip – 16p32

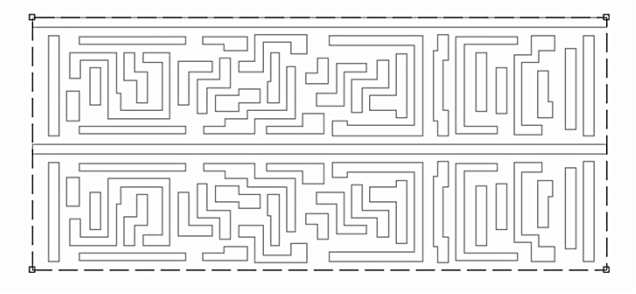


- Further optimization possible by means of FlexPupil

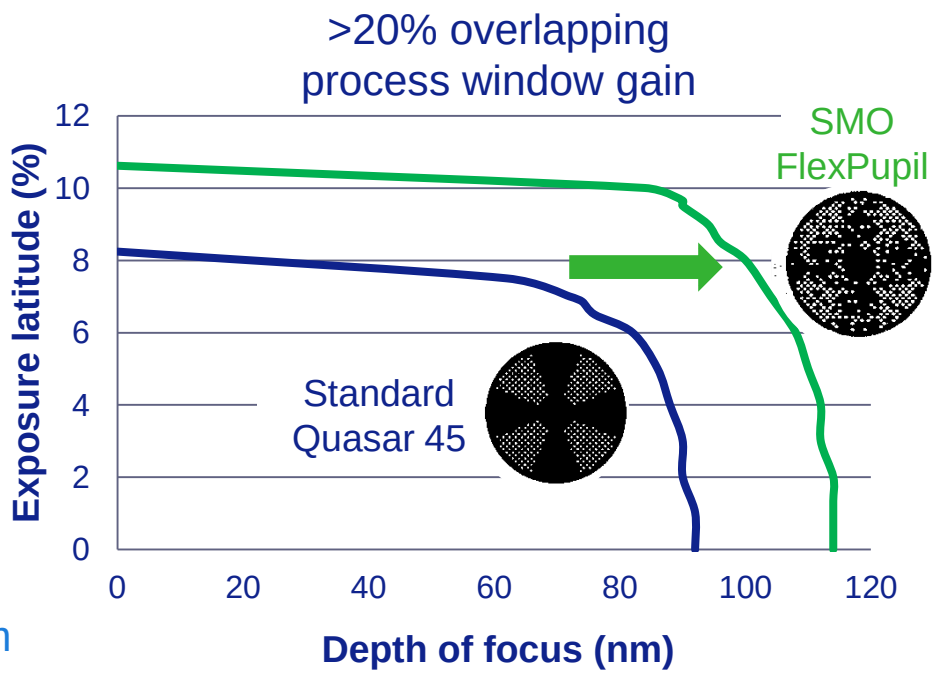
Rigorous simulation: 5.3nm resist blur + typical 3300 scanner

SMO & FlexPupil can greatly improve process window

SMO FlexPupil shape vs. best standard pupil: 7 nm node metal 1 example



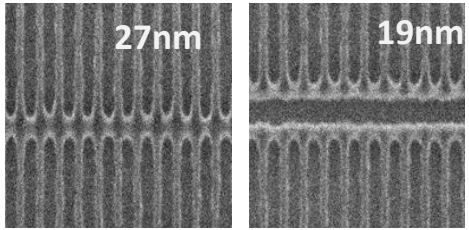
- 7 nm node logic metal 1 layer
- Logic standard cells, dark field
- Tachyon NXE M3D+ model used
- NXE:3300 K1 = 0.39
- Min pitch = 32 nm, min feature 16 nm



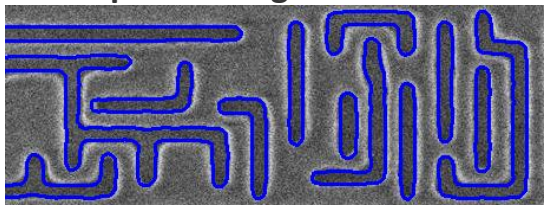
Contents

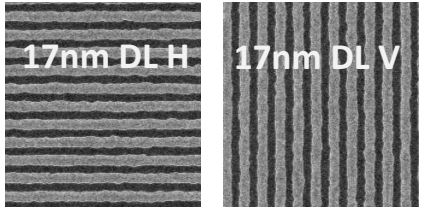
Summary and conclusions

- **NXE:3300B** evaluated for N10 and N7 logic performance
  - CDU, HV and proximity performance meet N10 requirements
  - Line-end performance for N10 (~45nm pitch) allows aggressive T2T and T2S design at low dose
    - T2T down to 30nm, T2S down to 20nm feasible
    - OPC required to mitigate line-end shortening and local line-end variations - Validated by rigorous simulations
  - OPC enables scaling to sub-N10 (40nm) min. pitch at <20mJ/cm^2 with 100nm DOF
    - Tachyon NXE OPC+ model calibrated for conventional and Quasar illumination showing good contour overlap
    - LMC correctly predicts bridge- and neck-defects through focus
  - Initial imaging performance evaluation for N7 logic started
    - 17nm HP resolution for H &V achieved with Q45
    - Rigorous simulations and calibrated Tachyon model shows ‘2D-style’ N7 logic M1 feasible
    - SMO and FlexPupil can greatly improve process window

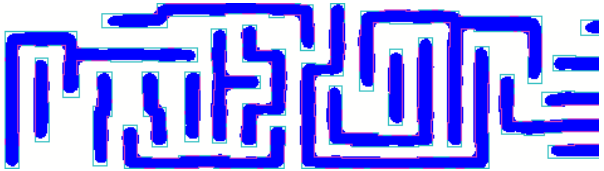


p45 nm Logic M1





p35 nm Logic M1



Acknowledgements

Special thanks to:

- Jean Galvier

- Dan Corliss
- Chris Robinson

- Patrick Wong
- Jing Wang

ASML demo group
- Maarten van Dorst
- Peter Rademakers
- Cynthia van den Akker

ASML Albany
- Bart Kessels
- Brian Lee

ASML D&E Imaging Applications
- Cristina Toma
- Natalia Davydova
- Andre van Dijk
- Frank Horsten
- Ijen van Mil
- Gijsbert Rispens
- Vadim Timoshkov

ASML

Thank you for your attention !