Mask patterning challenges for EUV N7 and beyond

Date: 2018/02/27

Outline

- EUV tech drivers and mask roadmap
- N7 mask process status
- Mask and mask process characterization
- Process improvements toward N5

EUV technology drivers

Type	2017	2018	2019	2020
Logic	10nm	7nm	5nm	
DRAM	1x	1y	1z + new architectures	
3D NAND	Gen 2	Gen 3	Gen 4 + new architectures	

- **Roadmap drives scanner and subsequent mask improvements**
  - Minimum feature resolution-main & SRAF
  - Pattern fidelity & LER
  - CD control-MTT, CDU, linearity, etc
  - Pattern placement
  - 3D effects
  - Black border (including OOB suppression)

PHOTRONICS

EUV Mask capability roadmap

Target for mask readiness

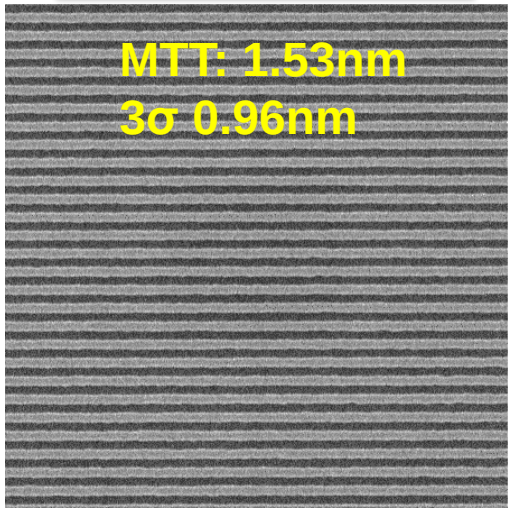
EUV N7 → N5 → N3

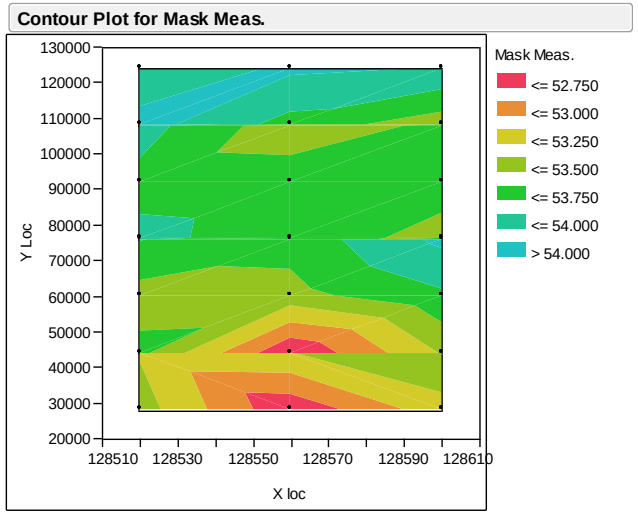
Attribute	2017	2018	2019 & beyond
Main CD (nm)	52	44	30
SRAF (nm)	40	30	24
CD Uniformity (3σ, nm) Spec/LS Capability	3.0/1.5	2.5/1.3	2.0/1.1
Registration(3σ, nm)	3.0	2.0	1.5
Linearity (nm) (50nm – 500nm; IL, IS DL)	≤ 5	≤ 4	≤ 3
Roughness: LER/LWR (3σ, nm)	≤ 3.0	2.5	2.0
3D Effects-Blank Materials	• Ta-based Abs. • 60nm Thick	• Ta-based Abs. • 55nm Thick	• Alternate Abs. material • 30-35nm to support high NA
Black Border	≤0.05% reflectivity (λ from 12.80 - 14.2nm) <2% Out of band reflectivity ((λ from 100 - 280nm)		

PHOTRONICS

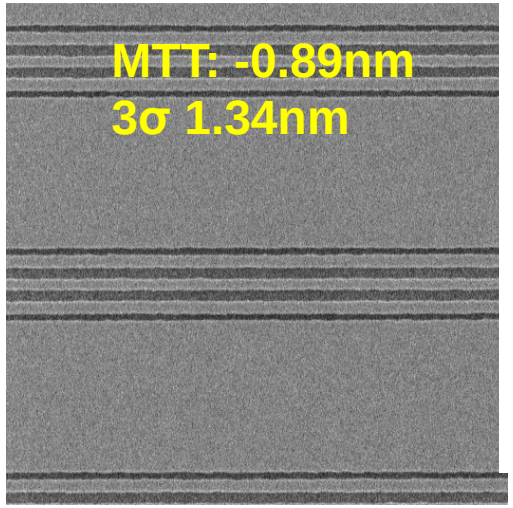
N7 process performance

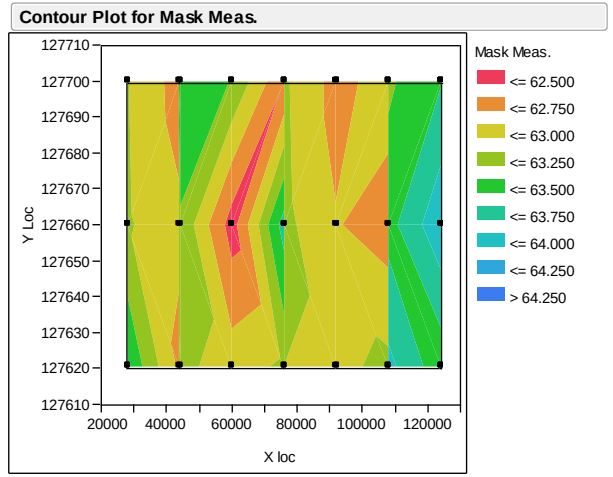
52nm Dense Line

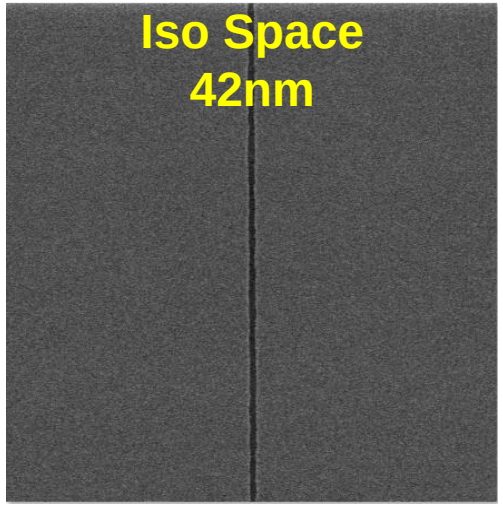


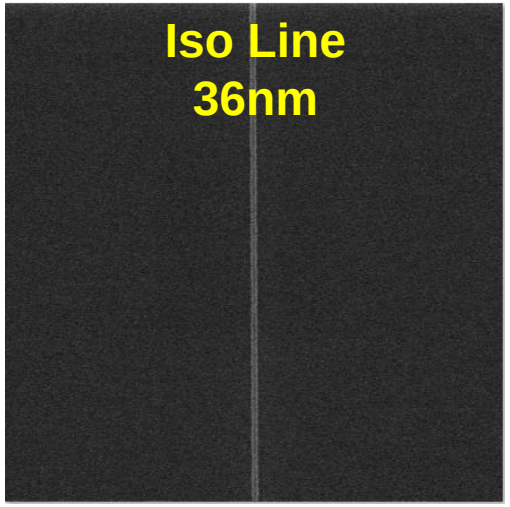


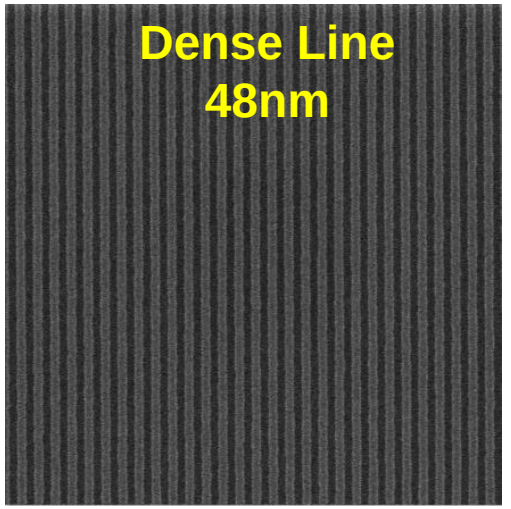
64nm Space/40nm SRAF







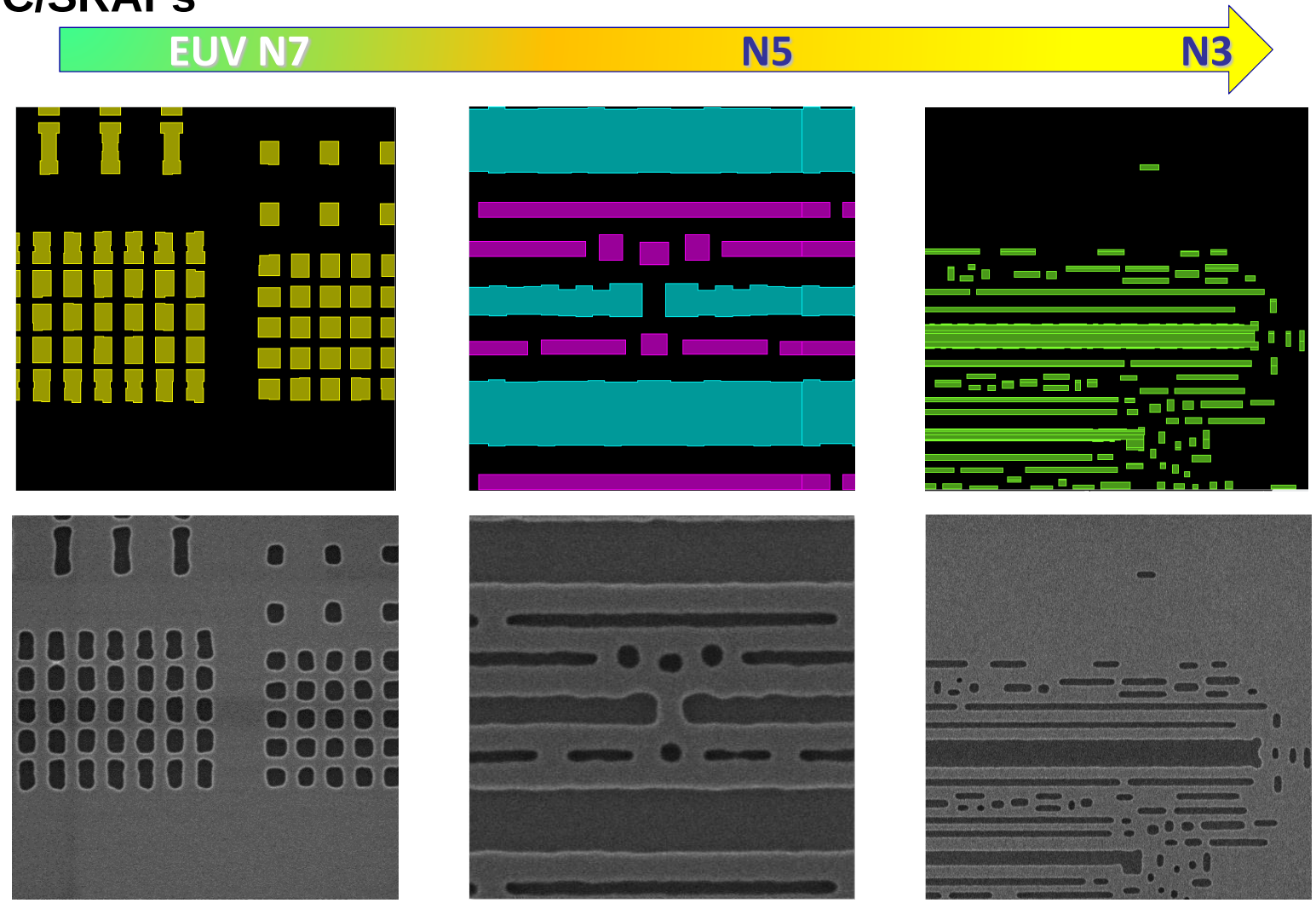




PHOTRONICS

Challenge: increasing pattern complexity

- 2D structures are critical at N7 and increase in complexity through N5 with increasingly aggressive OPC/SRAFs



Characterizing pattern fidelity

▶ Edge roughness & other mask process-induced error

Low frequency LER on mask - high impact on wafer

⟶ Mask LCDU is critical

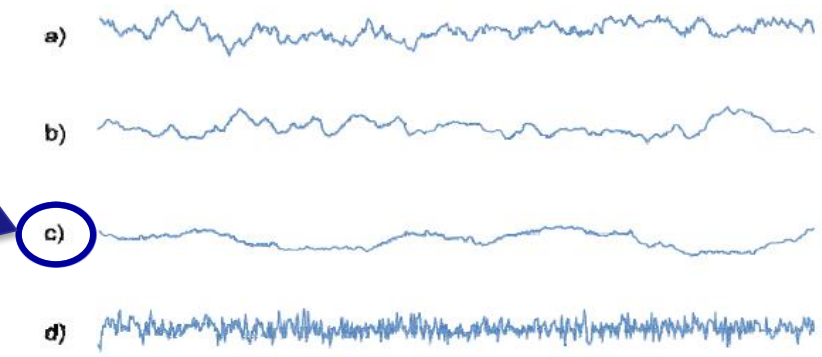
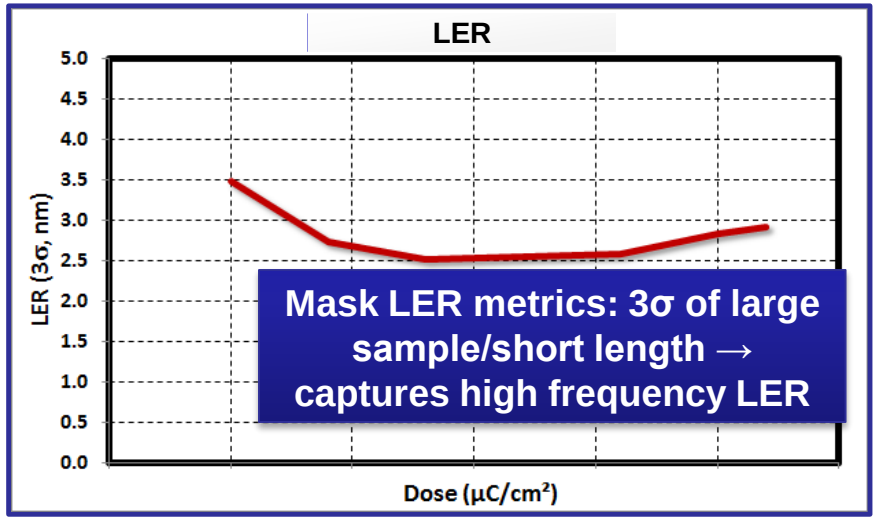
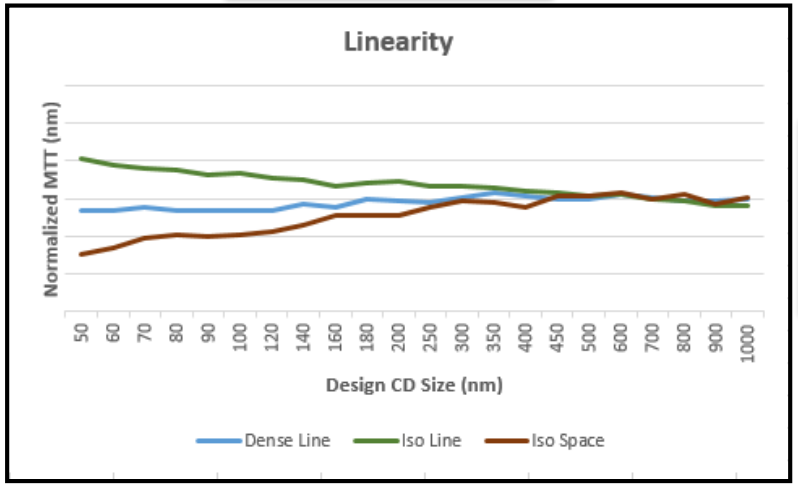


Figure 1. These four randomly rough edges all have the same standard deviation of roughness, but differ in the frequency parameters of correlation length (ξ) and roughness exponent (H): a) $\xi = 10$, $H = 0.5$, b) $\xi = 10$, $H = 1.0$, c) $\xi = 100$, $H = 0.5$, d) $\xi = 0.1$, $H = 0.5$.

[C. Mack, Proc. of SPIE Vol. 10450 104500P-2]

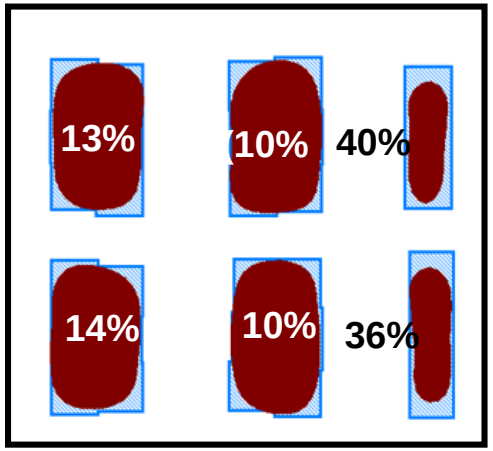


1D Metrics



Mask Process Error Characterization

2D Metrics - mask contour



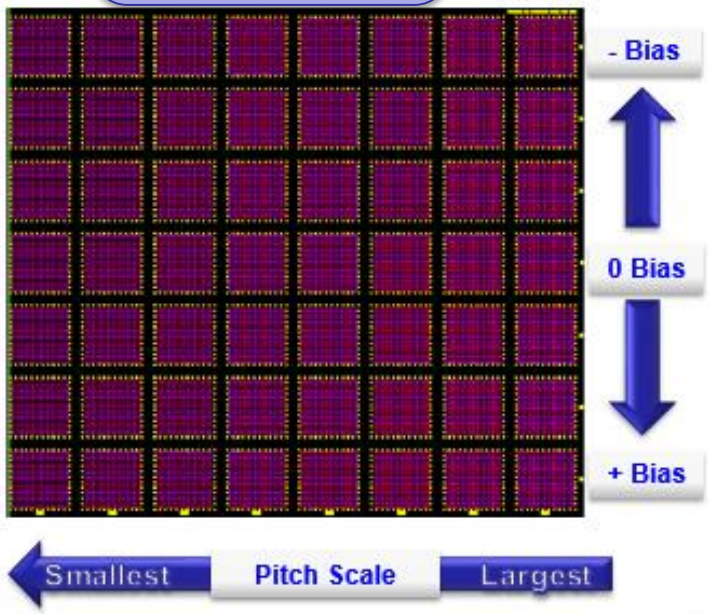
Area loss vs design or other EPE metrics

Mask process development and mask process error correction

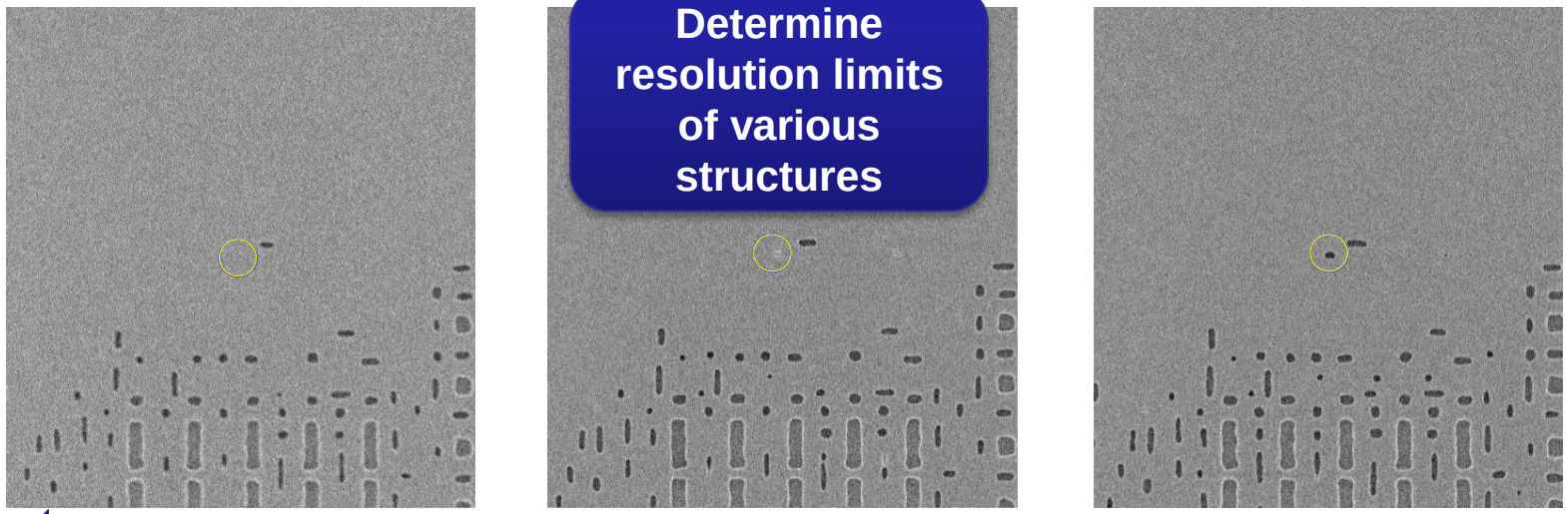
PHOTRONICS

Defining process capability

Device-like test chip w/ aggressive OPC features

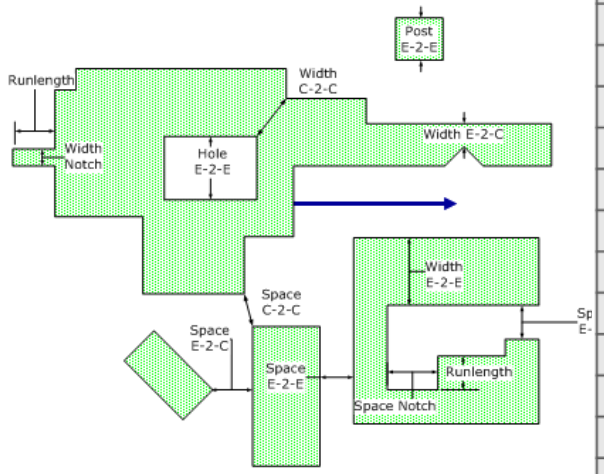


Determine resolution limits of various structures



Clear Shrink

Associate geometries with MRC Rules



Rule
Min Width Edge-2-Edge
Min Width Edge-2-Corner
Min Width Corner-2-Corner
Min Notch Width (runlength)
Min Post Width Edge-2-Edge
Max Post Aspect Ratio
Min Space Edge-2-Edge
Min Space Edge-2-Corner
Min Space Corner-2-Corner
Min Notch Width (runlenth)
Min Hole Edge-2-Edge
Max Hole Aspect Ratio

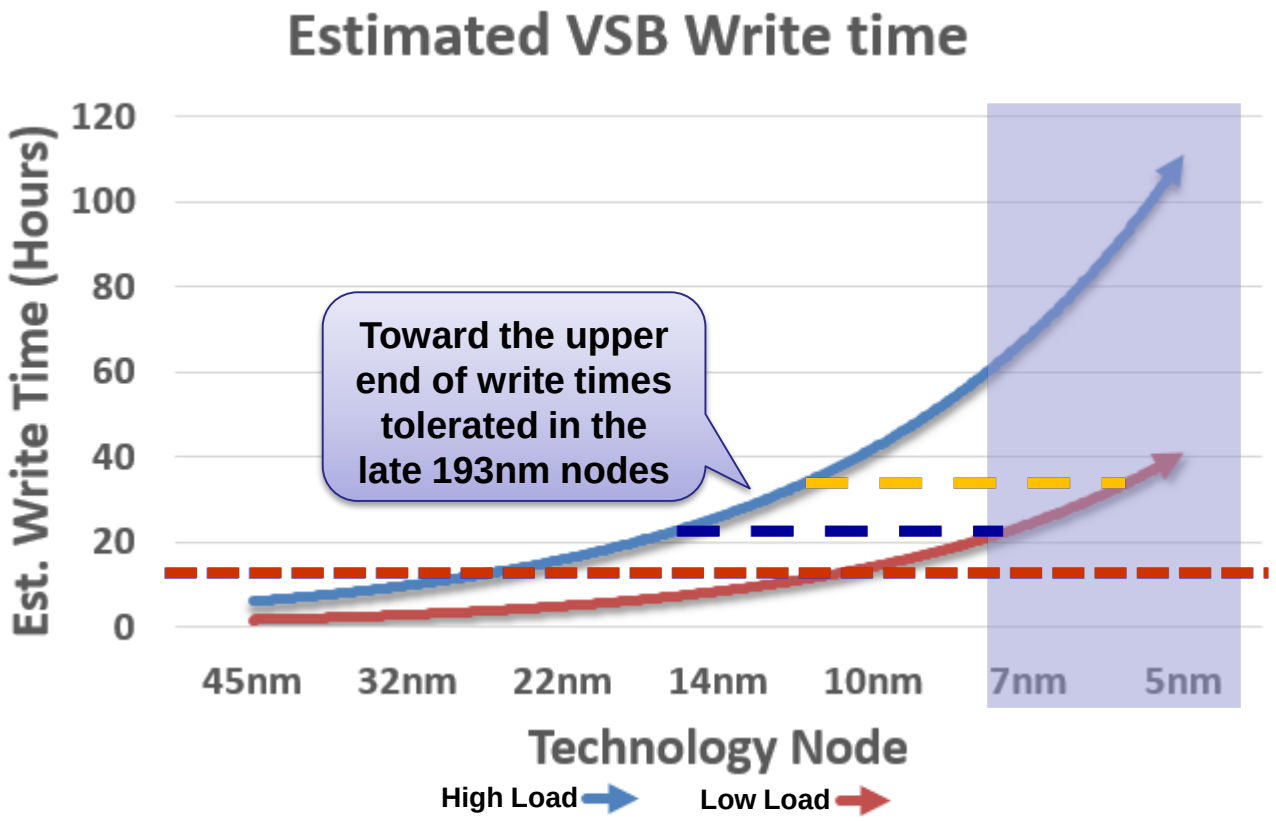
PHOTRONICS

Improving pattern fidelity

Improved LER/Pattern fidelity needed for N5

$$LER \propto \frac{1}{\sqrt{DOSE}}$$

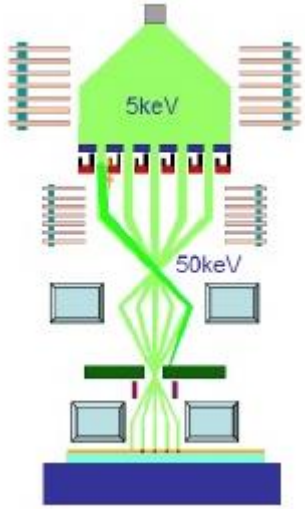
Low sensitivity-High Dose Resists



High dose CARs or chain scission type resists 60-150μC/cm²

>4pass VSB writing feasible for some applications - low load or small field test masks

Ultimate solution for N5 HVM: MBMW



[IMS Nanofabrication]

PHOTRONICS

Optimizing the blank material

Minimize M3D effects → shrink the absorber stack

Faster etching, thinner films → enable thinner resist → improved minimum resolution

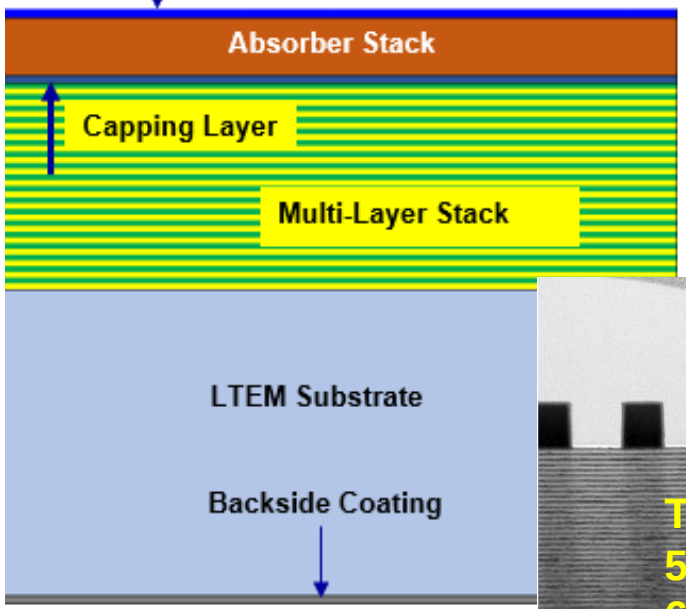
EUV N7 → N5 → N3

60nm

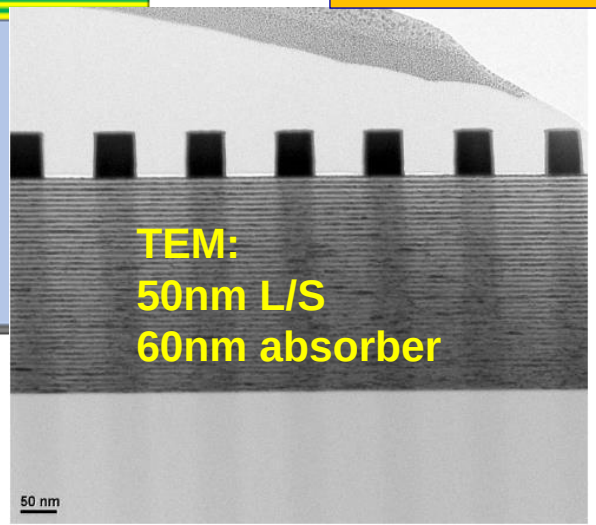
55nm

30-35nm

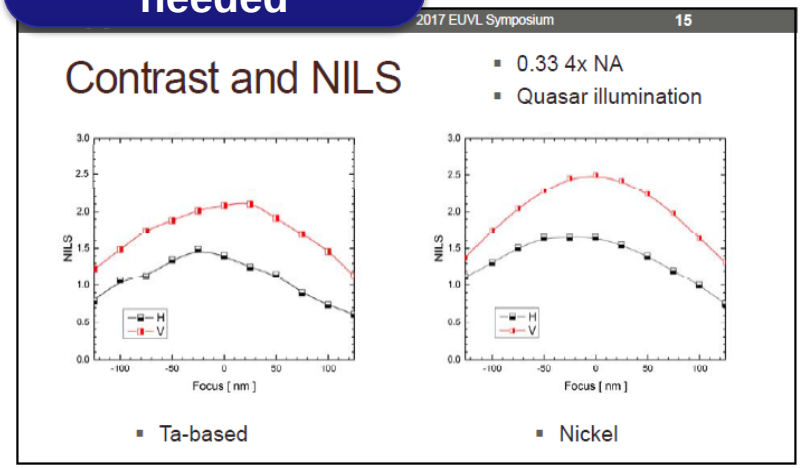
High NA litho sub-N5



Limitation of current Ta formulations



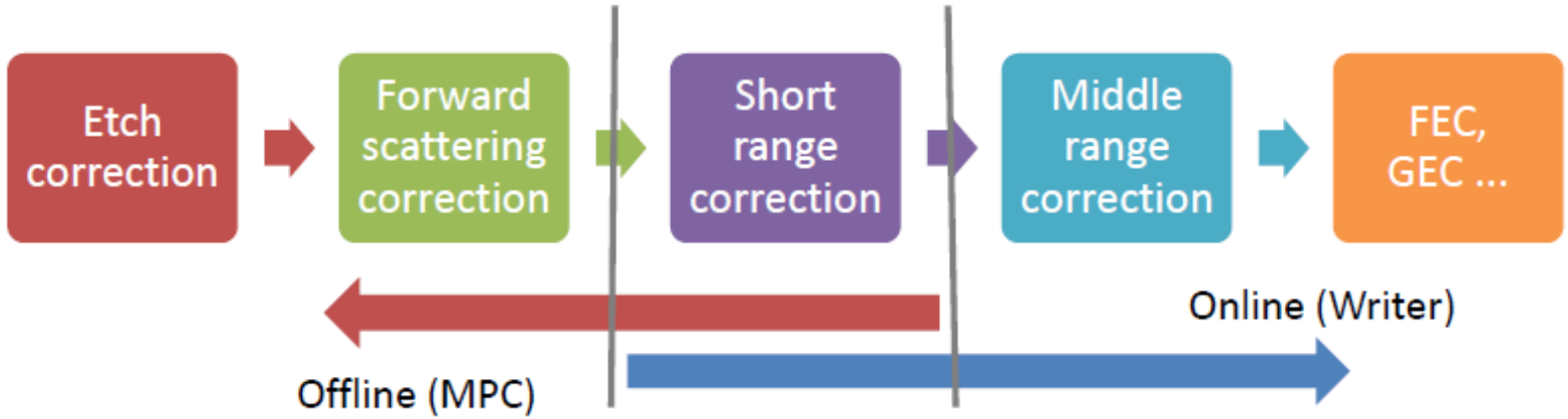
Litho benefits from shrink → alternate material needed



[M Benk et al, Proc. of SPIE Vol. 10450 104500Y-1]

Data solutions-MPC

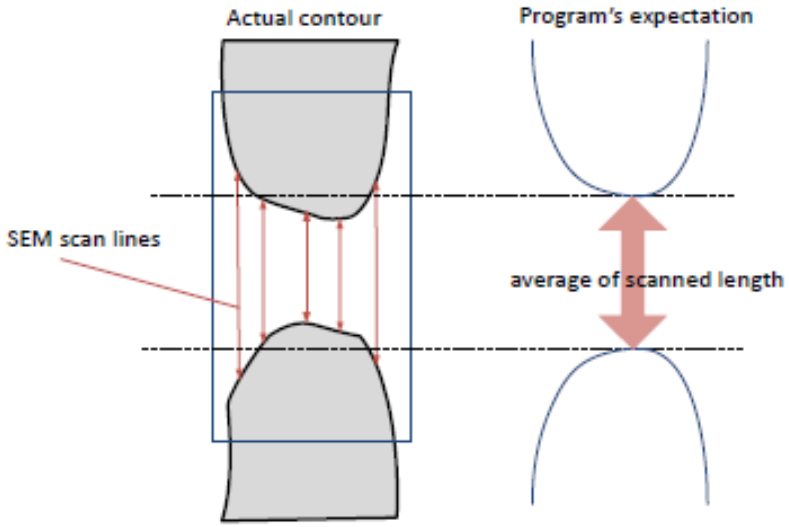
Account for inherently different proximity effect in EUV blanks-short range backscatter



Provide more accurate MPC models

- Additional component to capture local/proximity effect
- Decouple the effects which should not be considered in model
- *VSB/MBMW specific effect*

Account for 2D structures using actual mask contours for model building



We use contour images for 2D because using the measured CD may not duplicate the actual CD at line ends.

Courtesy of NCS

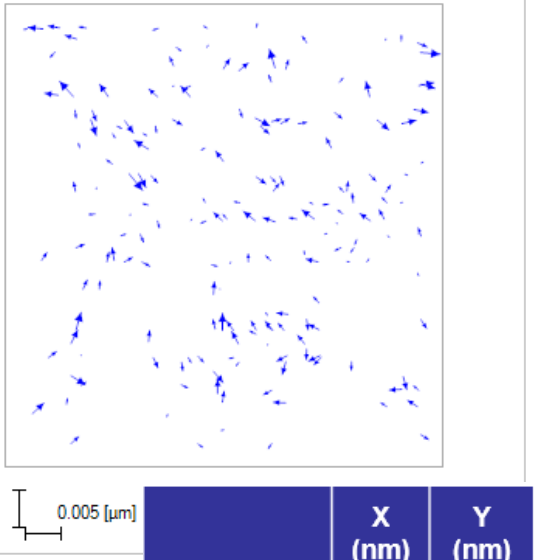
PHOTRONICS

Pattern placement

N7 Class EUV Mask

Solutions toward N5 & beyond

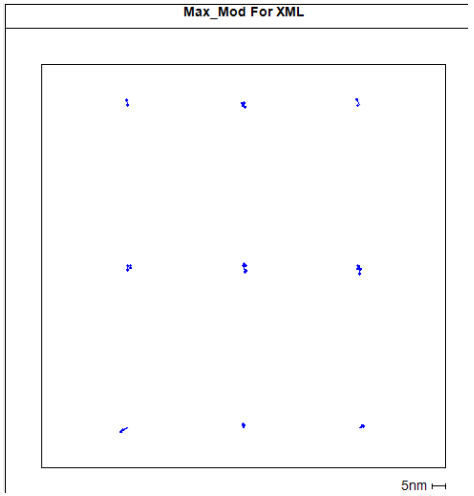
EUV N7 → N5 → N3

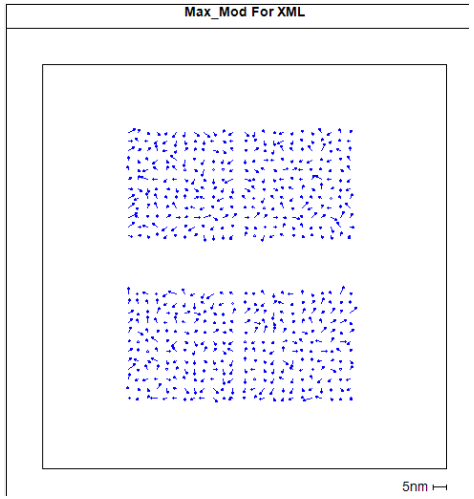


	X (nm)	Y (nm)
Max 3σ	2.95	2.91
Min	-2.09	-2.24
Max	2.80	2.52

In die metrology for larger sample size and accurate custom writing grids

Physical charging countermeasures → charge dissipation layers (CDLs)





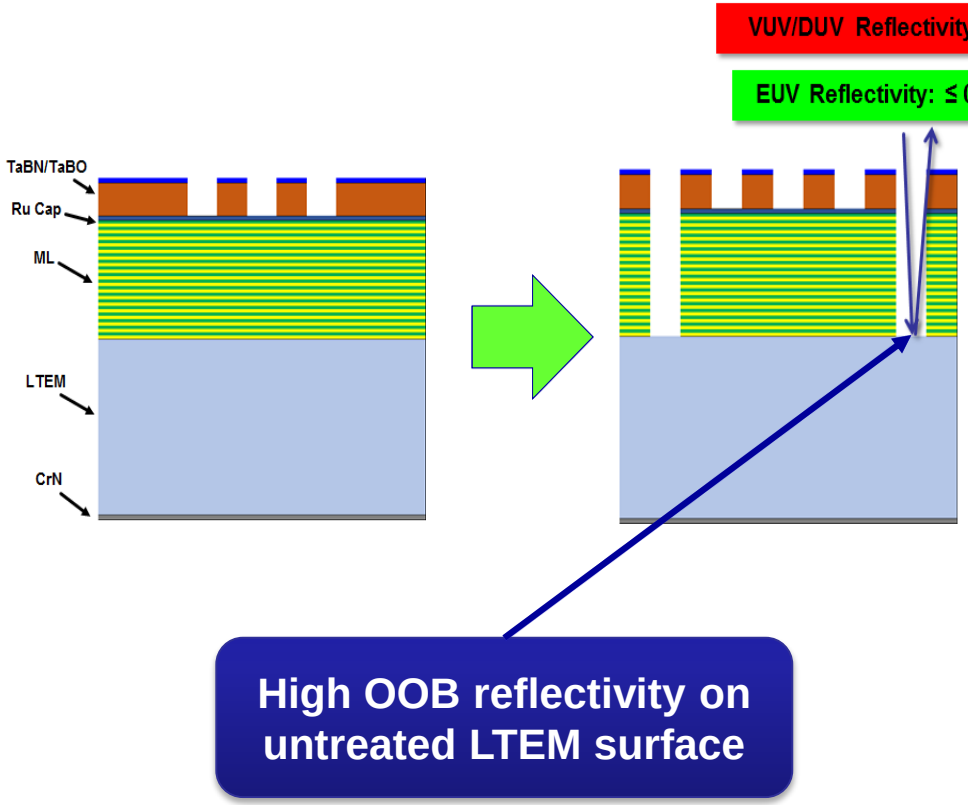
Improved computational methods for charging effect correction

Advanced writing platforms

PHOTRONICS

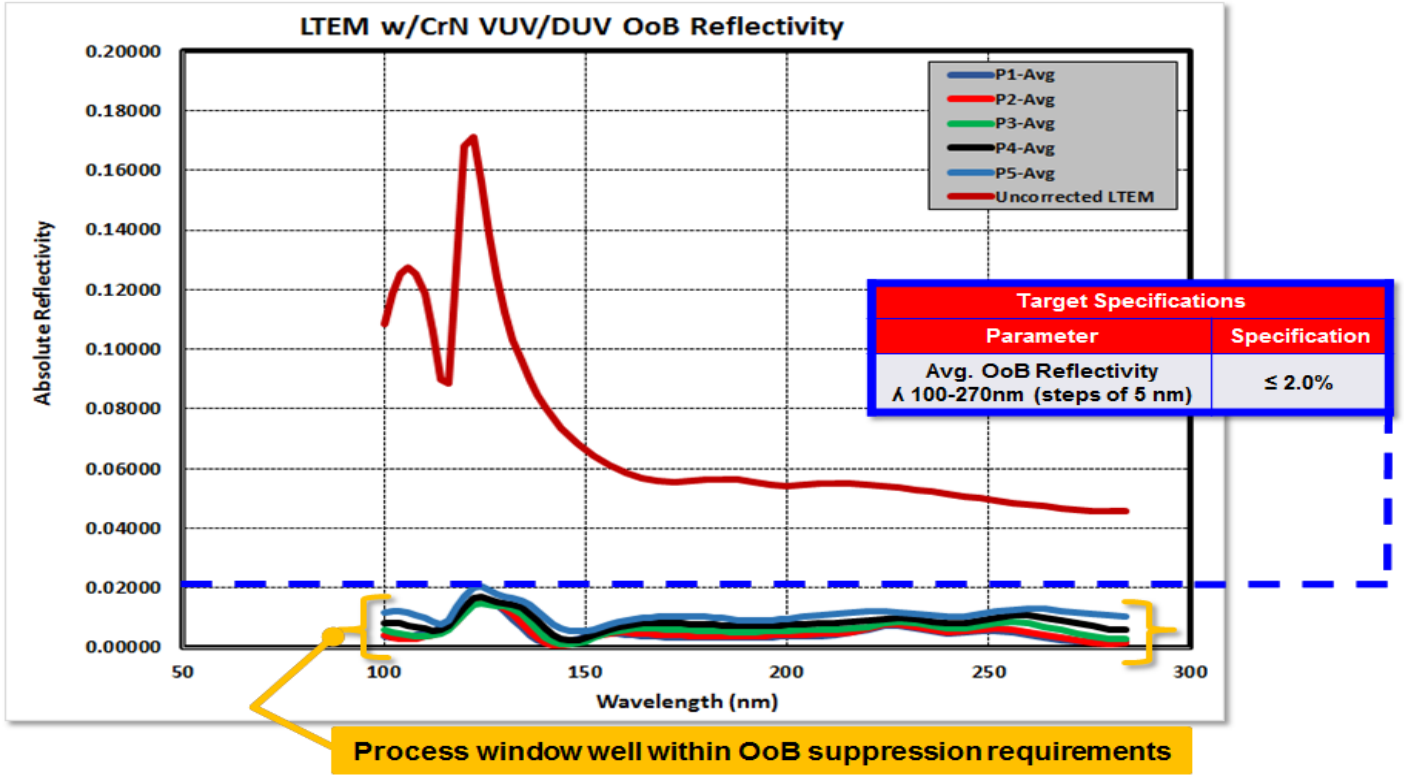
Black Border

- Need OOB suppression from 100nm - 280nm target <2% average reflectivity
- Photronics proprietary process



High OOB reflectivity on untreated LTEM surface

OOB Reflectivity after Photronics BB Process (measure at PTB, Germany)

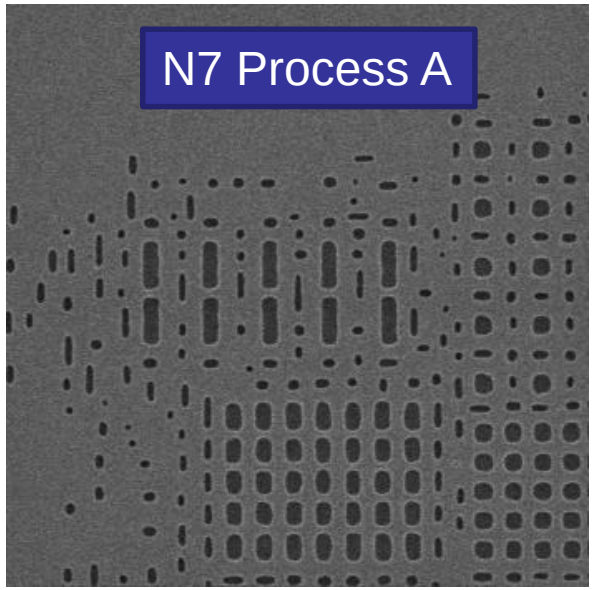


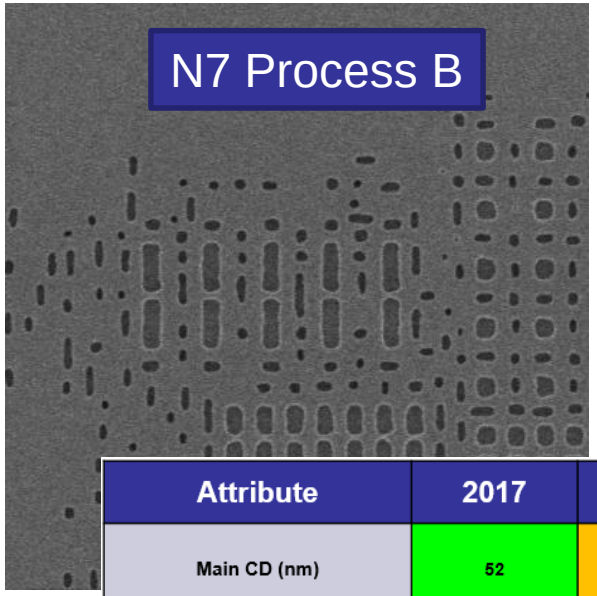
Process window well within OoB suppression requirements

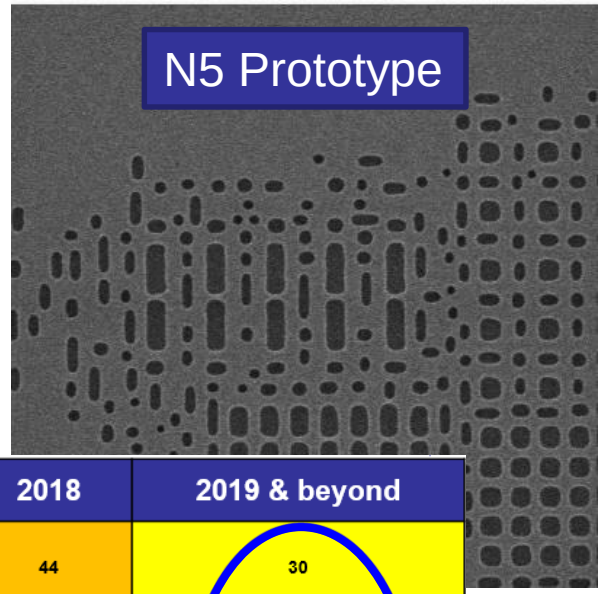
Putting it all together

Iterative process development toward N5

EUV N7 → N5 → N3







Target mask capability to support N5 and early N3 R&D within next 2 years

Attribute	2017	2018	2019 & beyond
Main CD (nm)	52	44	30
SRAF (nm)	40*	30	24
CD Uniformity (3σ, nm) Spec/LS Capability	3.0/1.5	2.5/1.3	2.0/1.1
Registration(3σ, nm)	3.0	2.0	1.5
Linearity (nm) (50nm – 500nm; IL, IS DL)	≤ 5	≤ 4	≤ 3
Roughness: LER/LWR (3σ, nm)	≤ 3.0	2.5	2.0
3D Effects-Blank Materials	• Ta-based Abs. • 60nm Thick	• Ta-based Abs. • 55nm Thick	• Alternate Abs. material • 30-35nm to support high NA
Black Border	≤0.05% reflectivity (λ from 12.80 - 14.2nm) <2% Out of band reflectivity ((λ from 100 - 280nm)		

PHOTRONICS

Summary

- **Processes for EUV N7 are known and in place across the industry**

- **N5 and beyond presents new mask patterning challenges**
  - Increased pattern complexity with proliferation of SRAFs
  - Escalating error contribution of mask 3D effects

- **Solutions moving forward**
  - Enhanced mask characterization
  - Lower sensitivity resists
  - Mask data manipulation for mask process error correction
  - Blank material innovations

PHOTRONICS