EUV MASK MANUFACTURING:

PATTERNING AND BLANK STATUS

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PHOTRONICS, INC.

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OUTLINE

Patterning Challenges

- Target Requirements
- Mask Manufacturing Modules
- Resist Process Selection and Results

Imaging Considerations

- EUV Reflectivity
- Black Border

EUV Blanks

- Evolution and Cost

Summary

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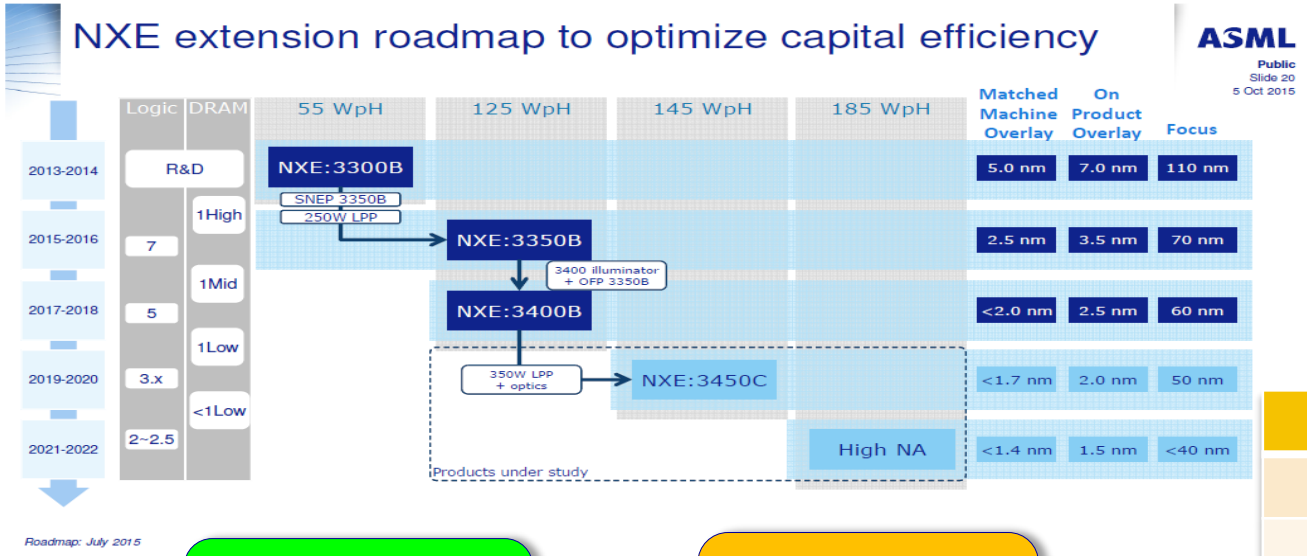
PATTERNING CHALLENGES



16P32 (1x)

64P128 (4X)

→

11P26 (1x)

44P104 (4X)

Tightening Mask Process Targets

Mask Attribute	Targets
CD (nm)	64 → 44
SRAF (nm)	~ 40 → ~ 25
CD MTT (nm)	3.0 → 2.0
Global CD Uniformity (nm)	2.5 → 1.5
Linearity Target (MFS to 500nm)	≤ 3
Proximity Target (1:1 to Iso; nm)	≤ 1.5
LER Target (3σ; nm)	≤ 2.5
Absorber SWA (°)	85° - 90°

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EUV MASK MANUFACTURING MODULES

Module	10nm → 7nm → 5nm
Blank Materials	• Defectivity • Absorber material & stack optimization
Blank Inspection	• Surfaces and backside • Native defect mitigation
Mask Patterning	• Resist materials and Etch • Resolution • CD control
Cleaning	• Absorber etch rate • Surface conditions • Backside Cleaning • Cleaning efficiency • Pattern damage • EUV Reflectivity (ML, Cap, Absorber)
Metrology	• Pattern Placement • CD, LER and SWA • EUV Reflectivity
Inspection	• DUV and ebeam • Inspection algorithms • Defect capture rate
Repair	• Mechanical, Ebeam, Ion beam • Repair accuracy
Defect Review	• Defect Repair Verification • Disposition process flow • Printability (wafer print, simulation)

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EUV MASK PATTERNING: PCAR PROCESS RESULTS

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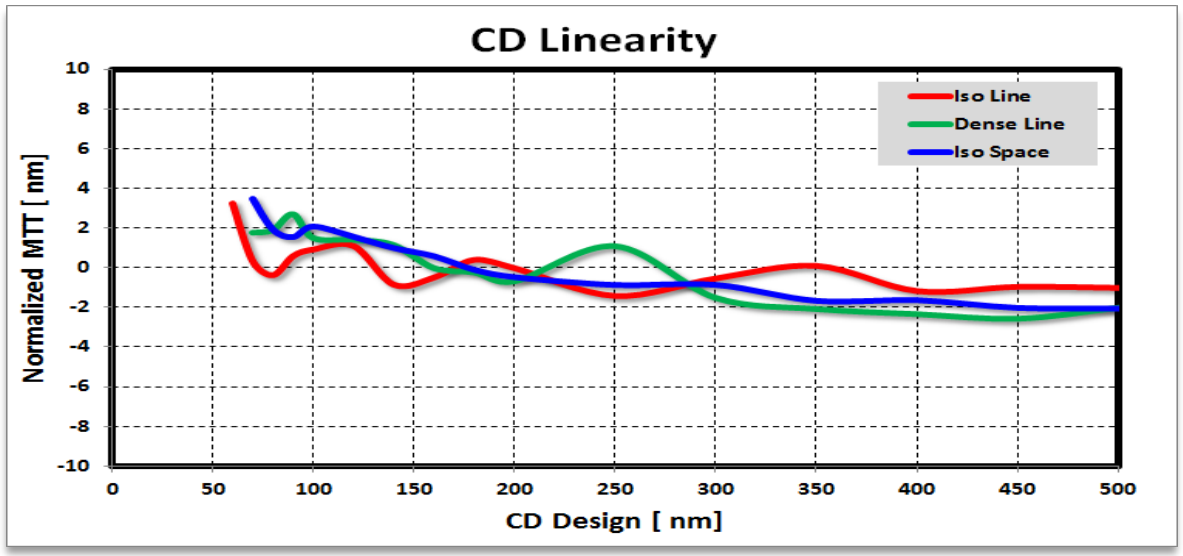
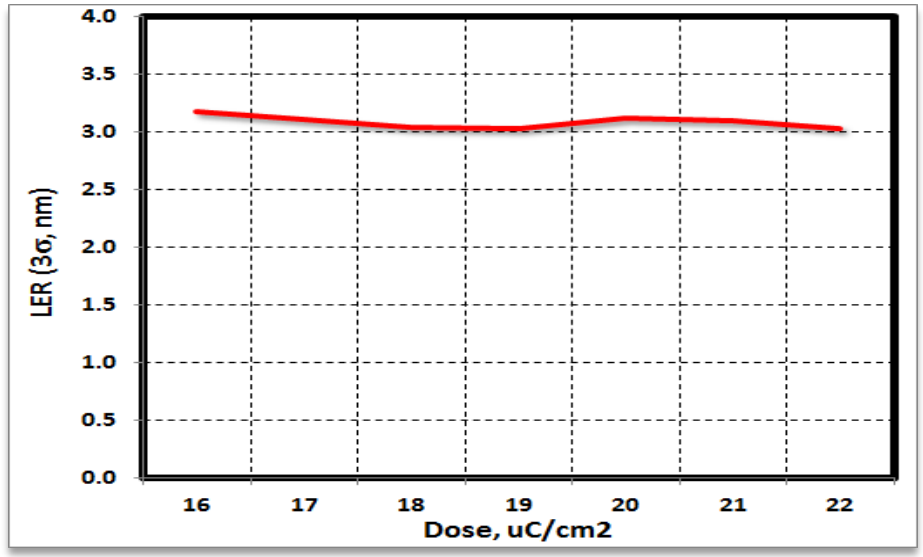
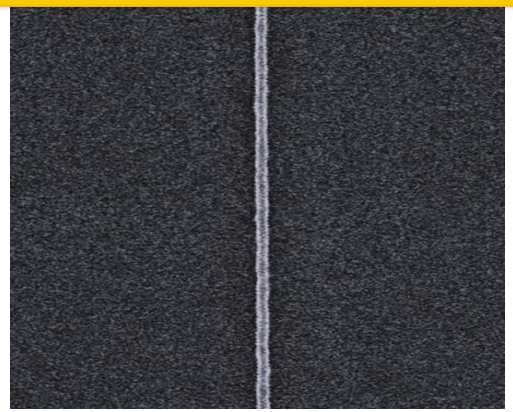
RESOLUTION, LINEARITY AND LER – PCAR

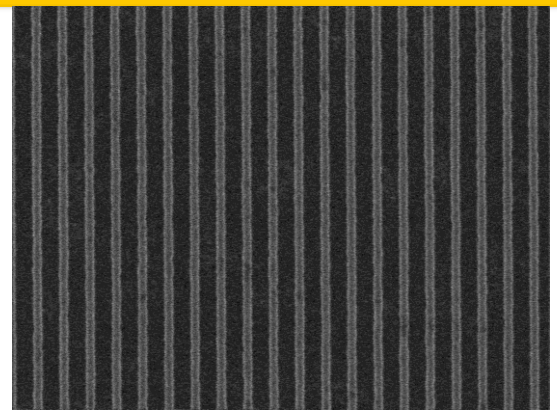




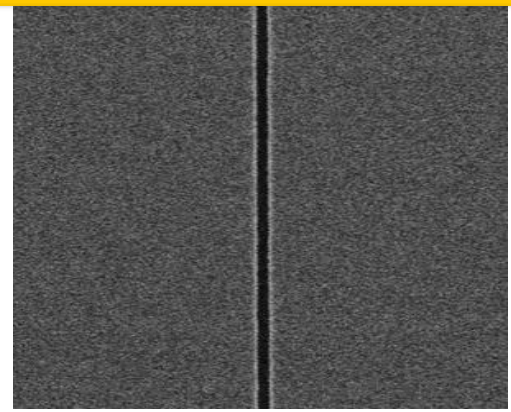
60nm Isolated Line



60nm Dense Line



46nm Isolated Space

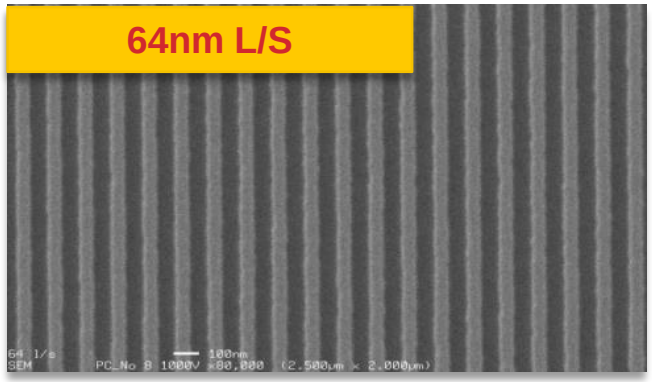


RESOLUTION, LINEARITY AND LER – PCAR

L/S	60nm	56nm	52nm	48nm
CD Mean (nm)	56.5	51.8	47.4	42.3
CD MTT (nm)	-3.53	-4.16	-4.64	-5.69

	64nm Line H	64nm Space V
CD Mean (nm)	66.9	61.9
CD MTT (nm)	2.88	-2.20
CDU (nm, 3σ)	2.85	2.92

64nm L/S

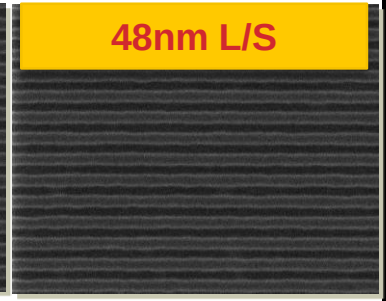


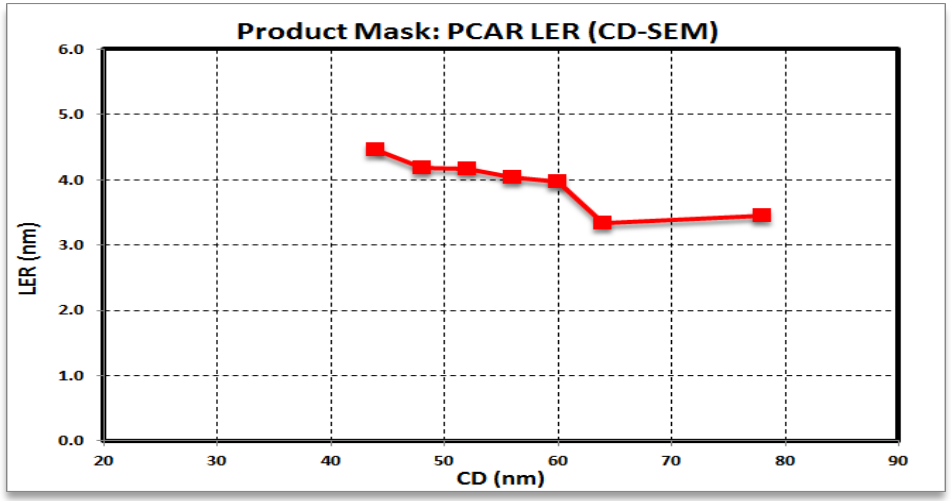
60nm L/S

56nm L/S

52nm L/S

48nm L/S





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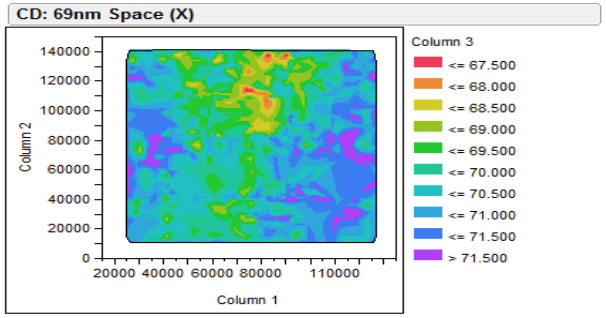
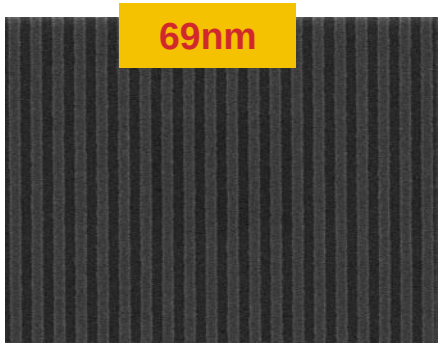
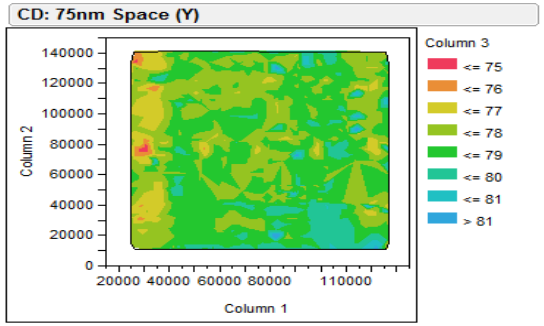
N7 LOGIC DESIGN - PCAR

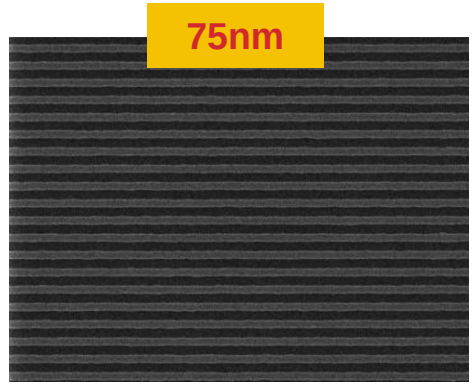
CD–Space (nm)	69
Count	861
Axis	X
Mean	70.25
MTT	1.25
CDU (3σ)	3.01
Mean 3σ LER	3.31
LER Variation (3σ)	1.74



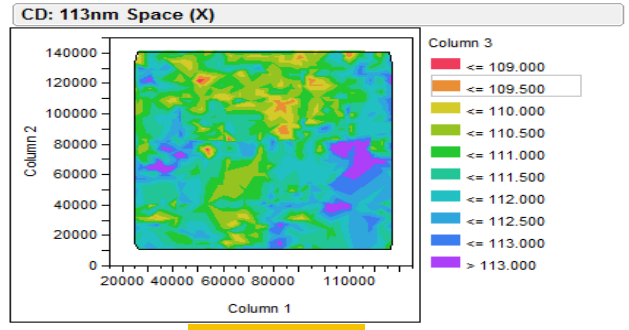


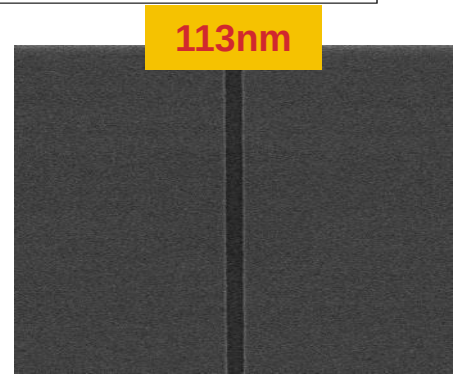
CD–Space (nm)	75
Count	861
Axis	Y
Mean	78.14
MTT	3.14
CDU (3σ)	2.95





CD–Space (nm)	113
Count	861
Axis	X
Mean	111.29
MTT	-1.71
CDU (3σ)	2.91
Mean 3σ LER	2.99
LER Variation (3σ)	1.61





EUV MASK PATTERNING: NCAR PROCESS RESULTS

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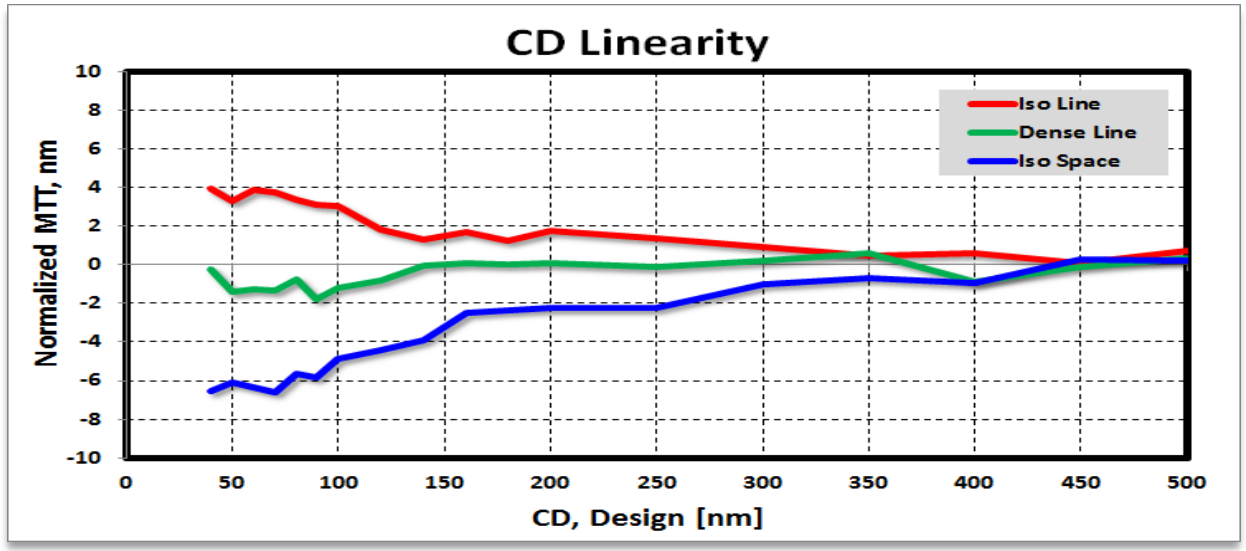
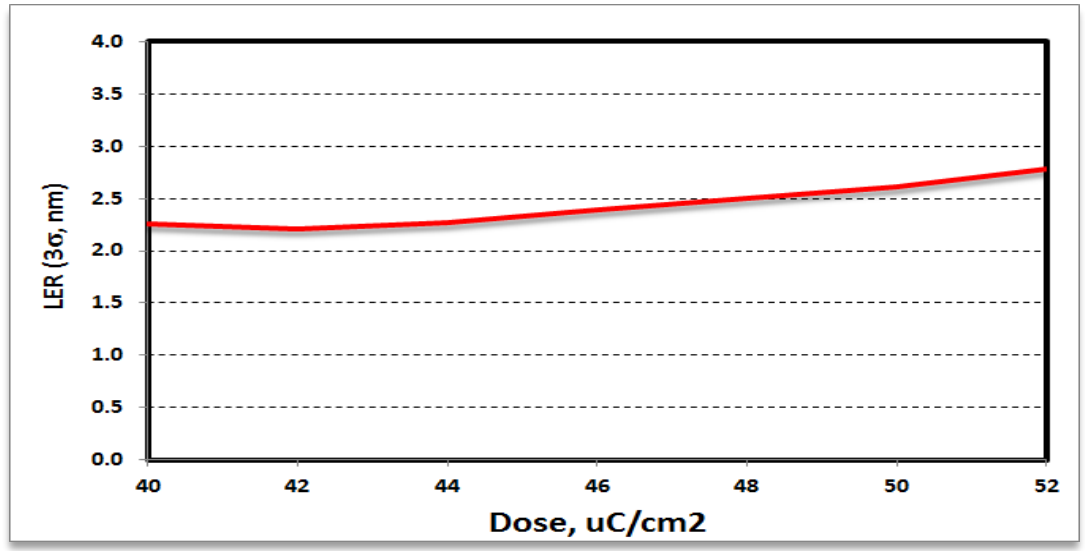
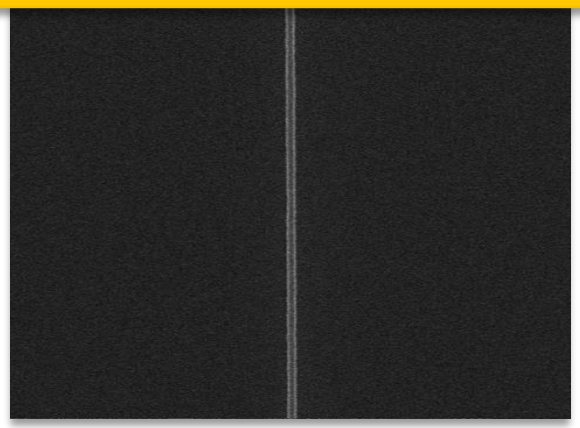
RESOLUTION, LINEARITY AND LER – NCAR

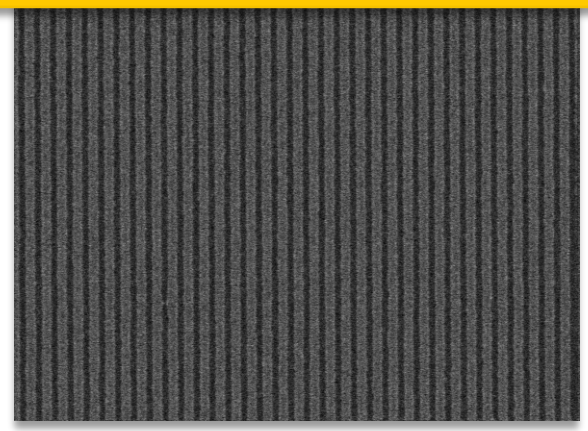




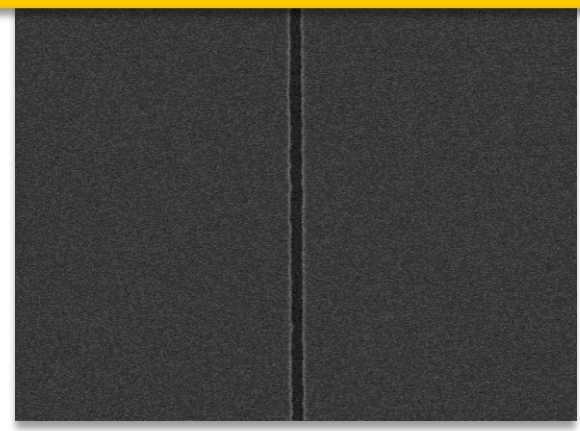
46nm Isolated Line



46nm Dense Line



58nm Isolated Space



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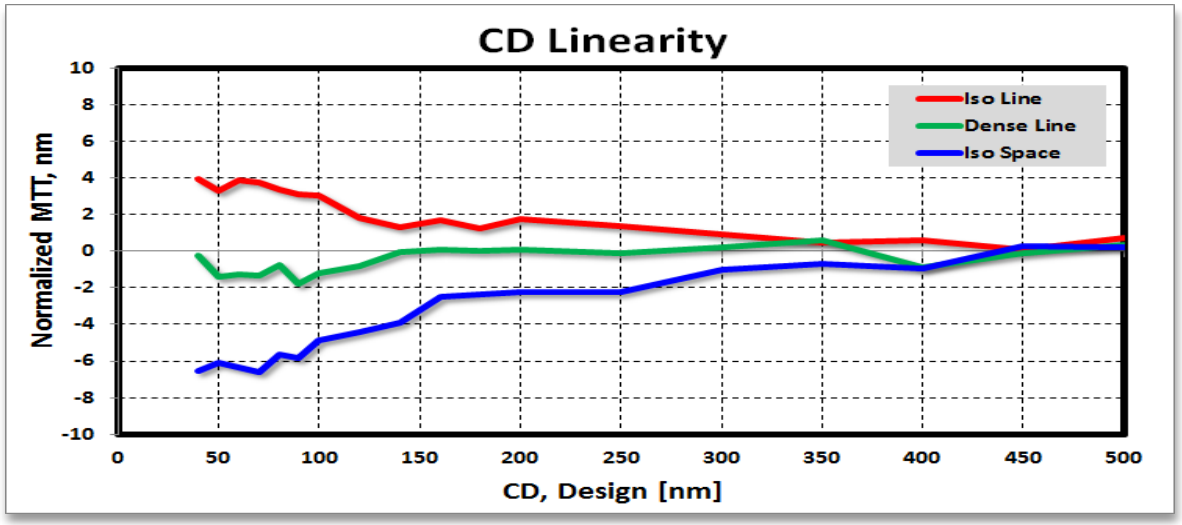
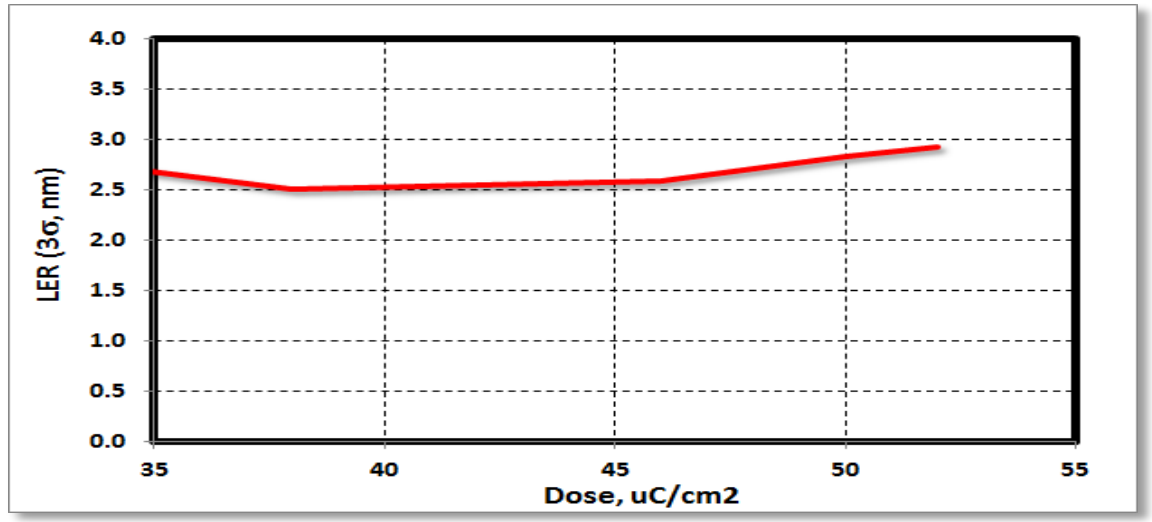
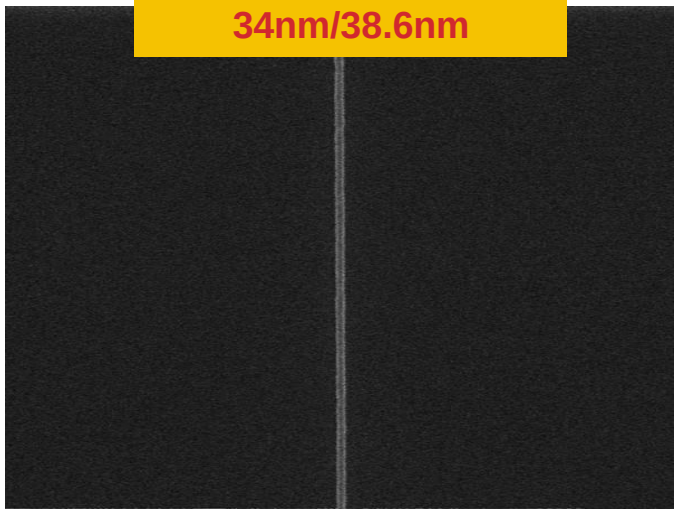
RESOLUTION, LINEARITY AND LER - NCAR

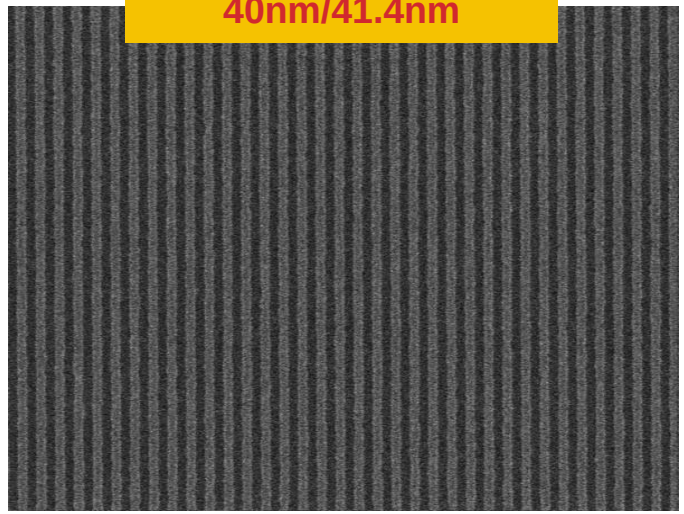




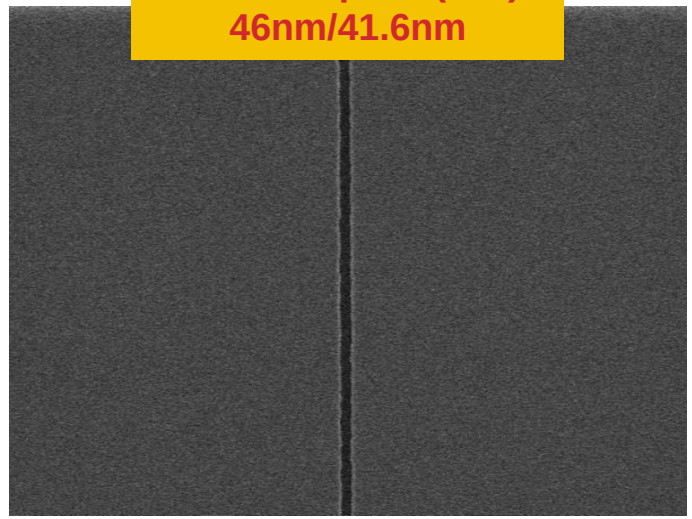
Isolated Line(D/A): 34nm/38.6nm



Dense Line(D/A): 40nm/41.4nm



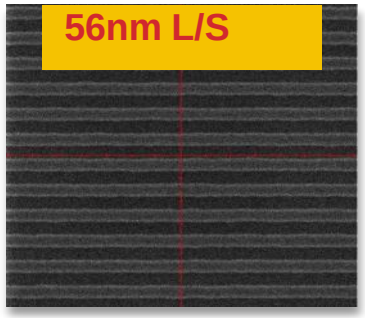
Isolated Space (D/A): 46nm/41.6nm

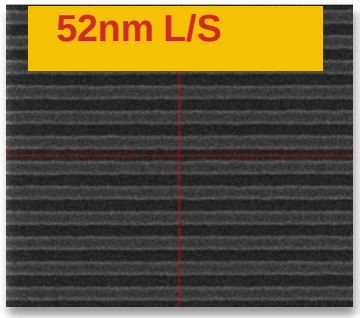


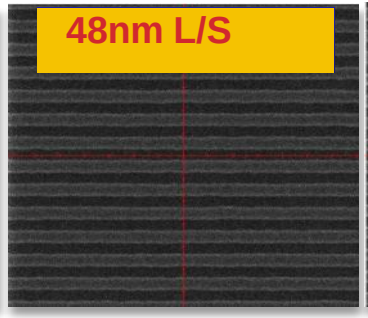
ADVANCED TEST MASK - NCAR

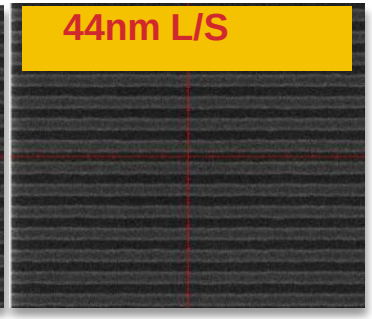
Feature	60nm	56nm	52nm	48nm	44nm
CD Mean (nm)	60.07	55.81	52.07	48.33	43.60
CD MTT (nm)	0.07	-0.19	0.07	0.33	-0.40
CDU (nm, 3σ)	3.12	3.54	4.03	4.75	5.19
LER (3σ, nm CD-SEM)	2.58	2.57	2.61	2.75	3.05

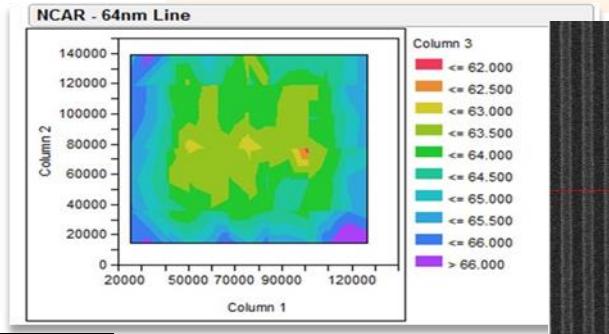
Feature	64nm
CD Mean (nm)	64.39
CD MTT (nm)	0.39
CDU (nm, 3σ)	2.93
LER (3σ, nm CD-SEM)	2.52

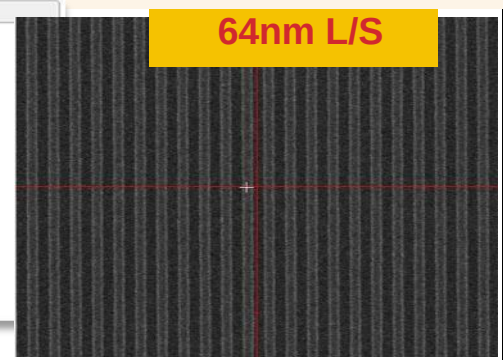


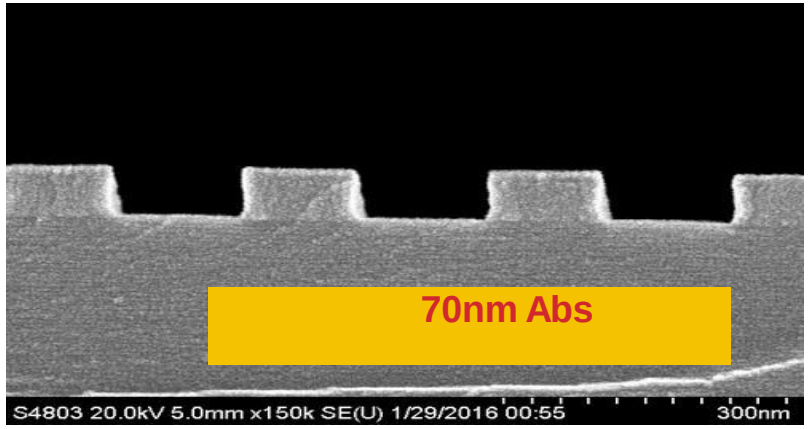


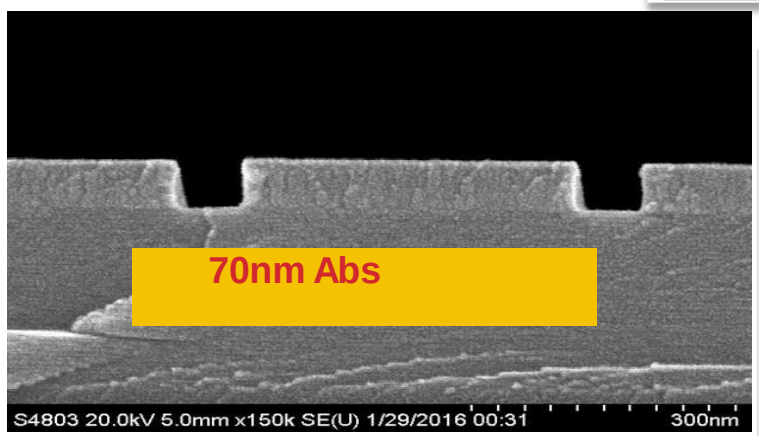


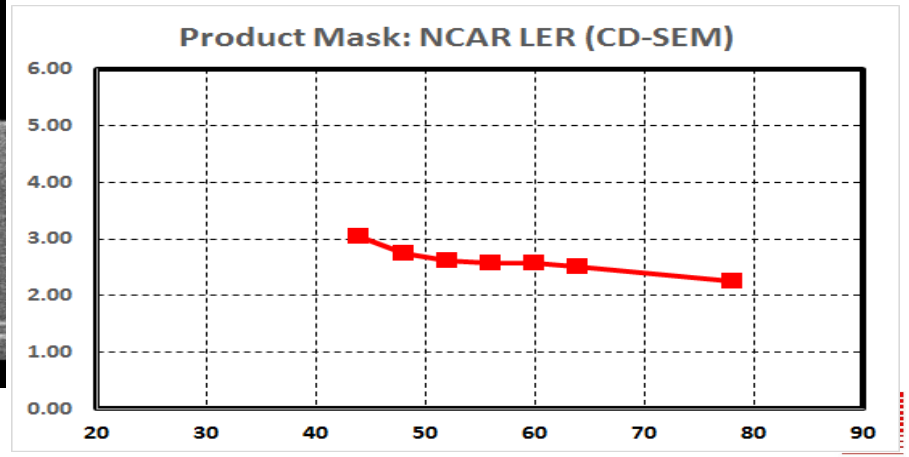












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IMAGING CONSIDERATIONS: EUV REFLECTIVITY

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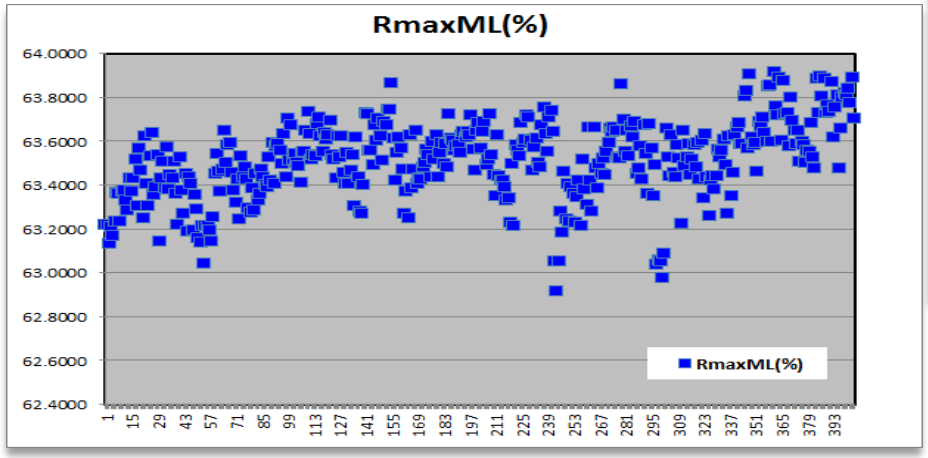
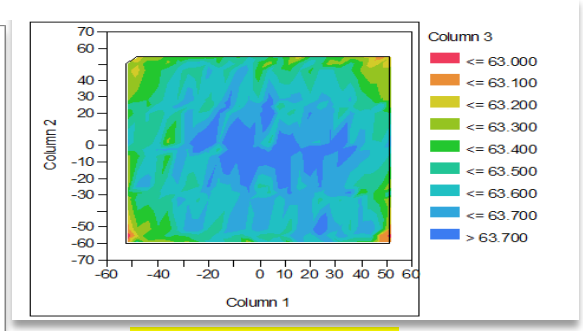
EUV REFLECTIVITY



Single mask, 400 locations

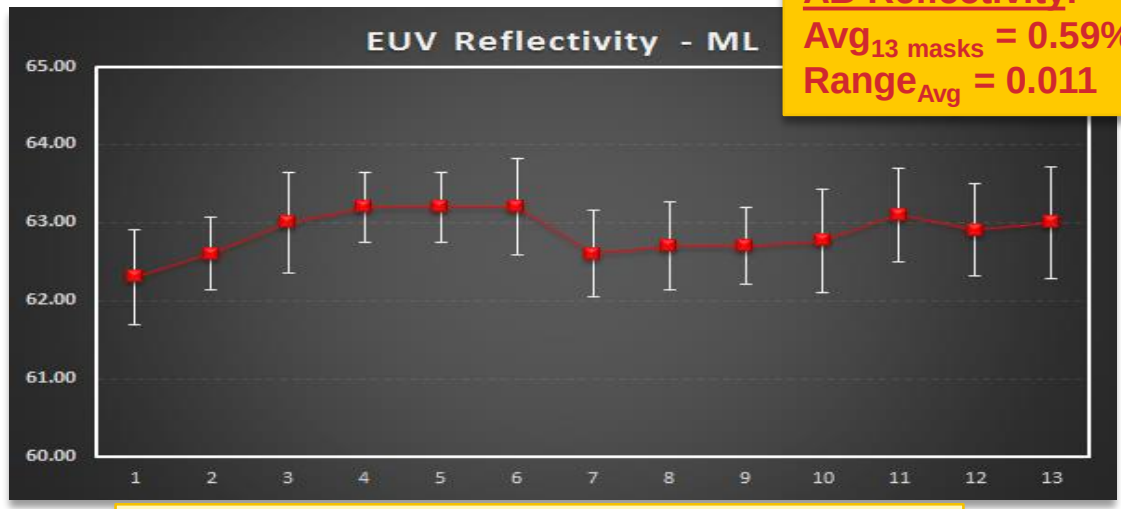


Mean = 63.5%
3σ = 0.53

13 Product Masks

ML Reflectivity:
$Avg_{13\ masks}$ = 62.85%
$Range_{Avg}$ = 0.55

AB Reflectivity:
$Avg_{13\ masks}$ = 0.59%
$Range_{Avg}$ = 0.011



Multi-Layer Property	Specifications	Product Mask
CTW50 (nm)	13.53	13.534
Mean center wavelength shift [%]	< ± 0.05	0.027
Mean FWHM of reflectivity vs wavelength [nm]	> 0.5	0.55
Max. range of bandwidth @FWHM [nm]	0.01	0.009
Max. range of centroid wavelength [nm]	0.06	0.027
Mean peak reflectivity [%]	≥ 62	63.5
Max. range of peak reflectivity [%]	< 1.4	1.0

Absorber Property	Specifications	Product Mask
Reflectivity averaged over wavelength range (13.395 - 13.665 nm)	< 0.5	0.5

ML Reflectivity Specifications:
Mean peak reflectivity: ≥ 62%
Max. range of peak reflectivity: < 1.4%

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IMAGING CONSIDERATIONS: BLACK-BORDER PROCESS

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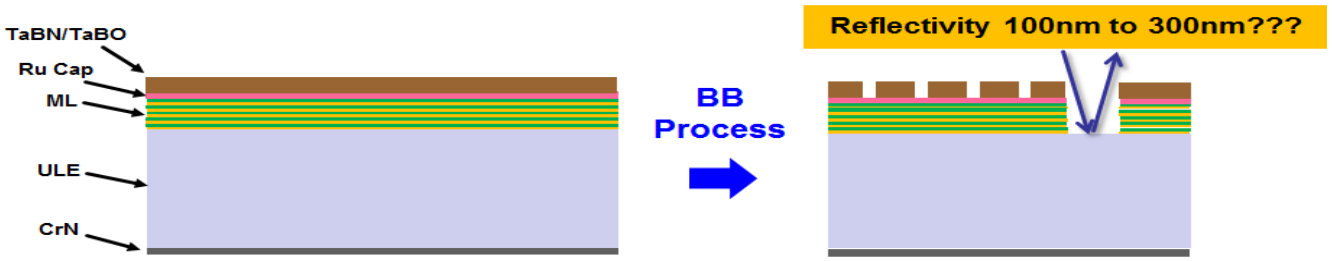
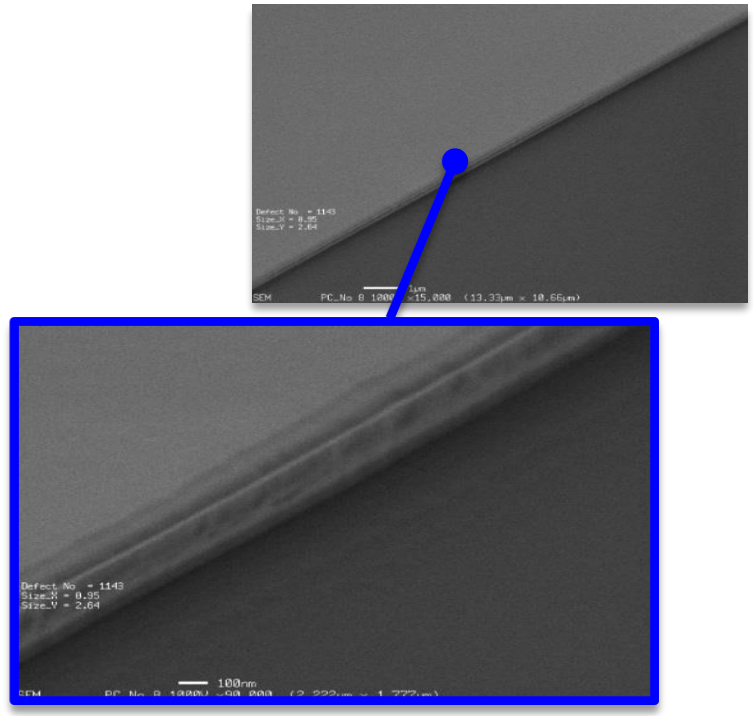
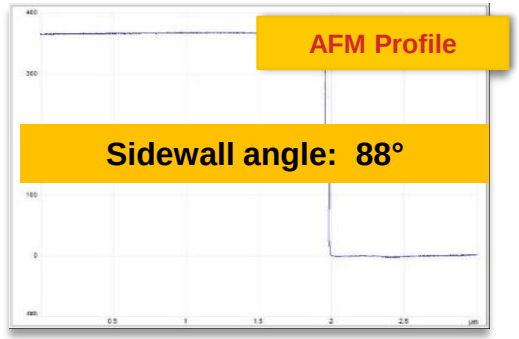
BLACK BORDER AND EUV DUV OOB REQUIREMENTS

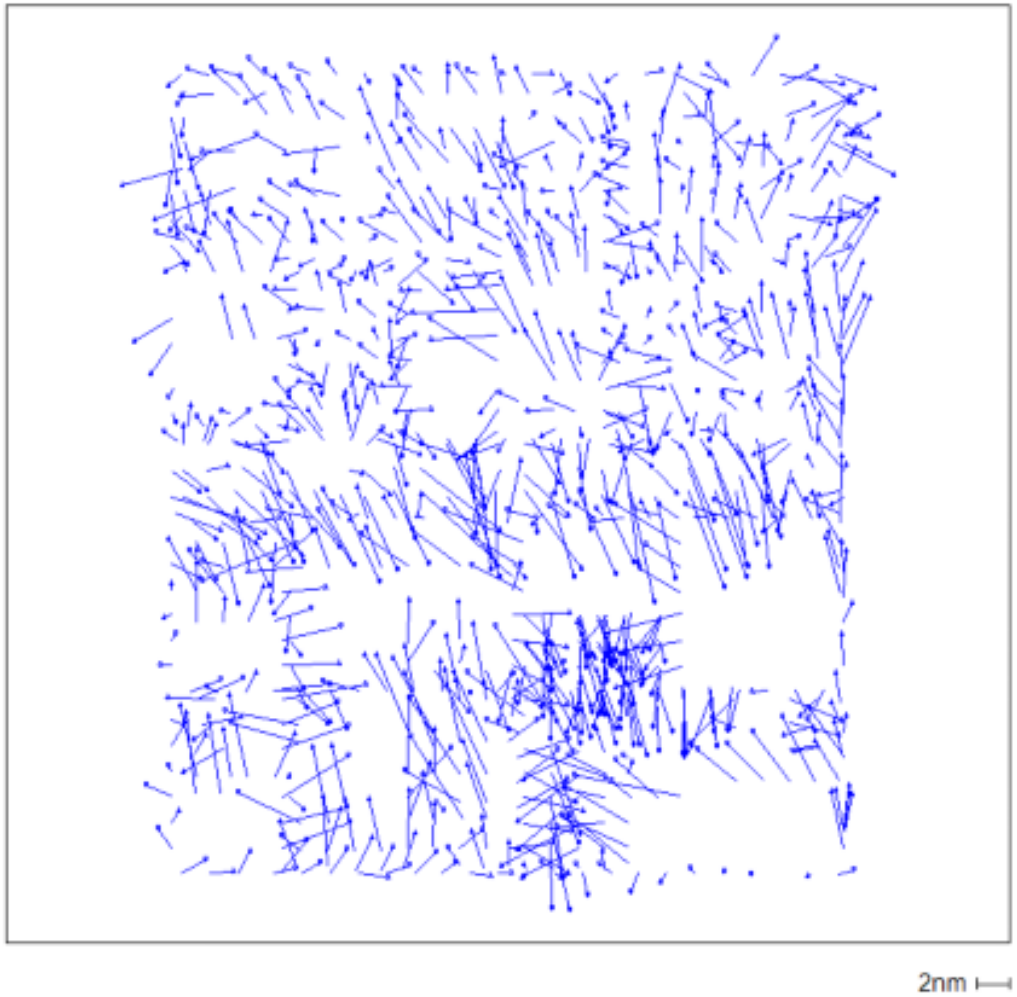
Attribute	Specification
Placement tolerance	± 100 nm
Width Uniformity (3σ)	200 nm
Side wall angle (SWA)	90° ± 5°
Out of Band Reflectivity (OOB R) Avg. ʎ 100 - 280nm (steps of 5 nm)	≤ 2.0%
Out of Band Reflectivity (OOB R) Max. ʎ 100-280nm (steps of 5 nm)	≤ 10.0%
Out of Band Reflectivity (OOB R) avg. ʎ 100-200nm (steps of 5 nm)	≤ 3.0%
EUV Reflectivity ʎ12.8-14.2nm (EUV R) max.	≤ 0.05%







REGISTRATION – PRE – BB



Summary	X [um]	Y [um]
Mean	0.00000	0.00000
Max 3 S.D.	0.00481	0.00690
Min	-0.00642	-0.00711
Max	0.00501	0.00683

Scale: -0.18139 / -0.24419 [ppm]
Ortho: 0.00898 [10^-6 rad]

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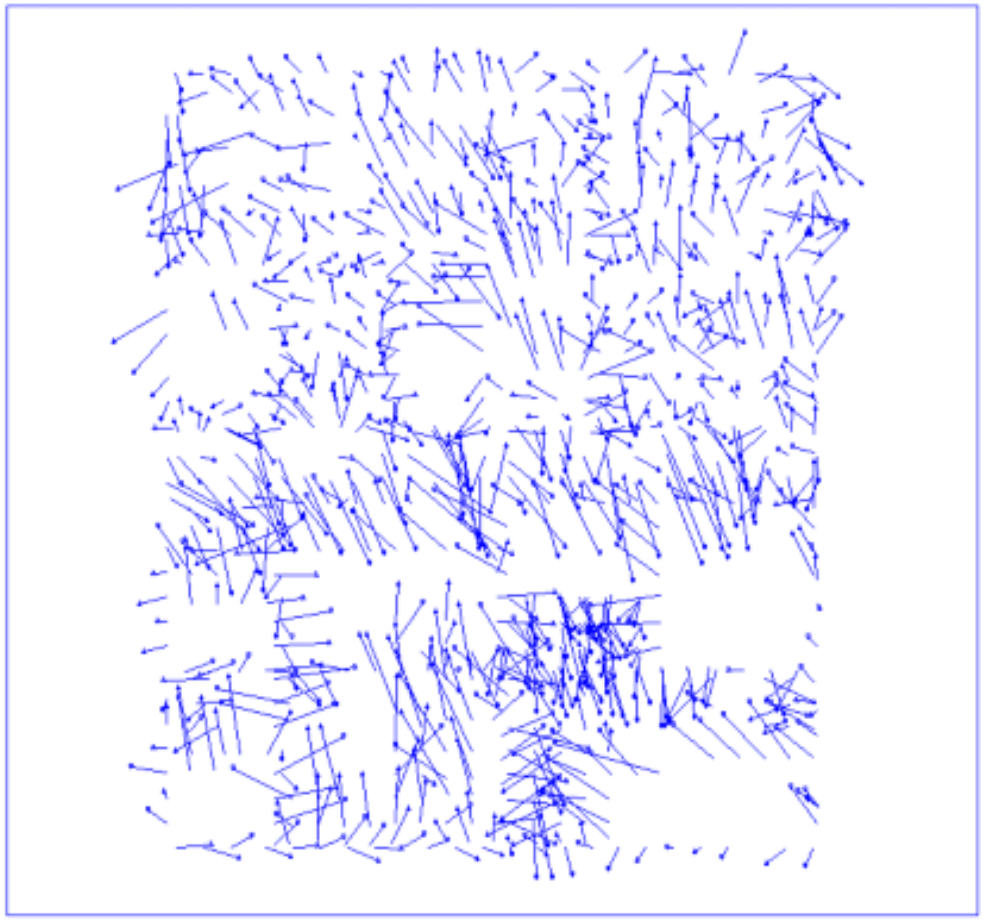
REGISTRATION – POST – BB



Summary	X [um]	Y [um]
Mean	0.00000	0.00000
Max 3 S.D.	0.00485	0.00670
Min	-0.00649	-0.00679
Max	0.00511	0.00661

Scale: -0.17014 / -0.24111 [ppm]
Ortho: 0.00006 [10^-6 rad]

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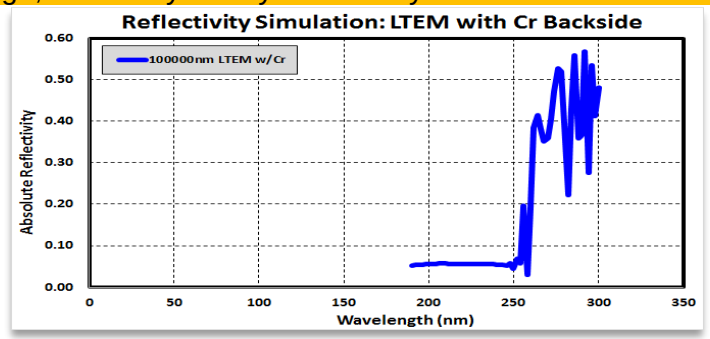
EUV PROCESS CAPABILITY – BB BORDER

VUV/DUV OoB Reflectivity Suppression Methodology

- Developed a new BB process
  - Simulation shows methodology works and would meet requirements

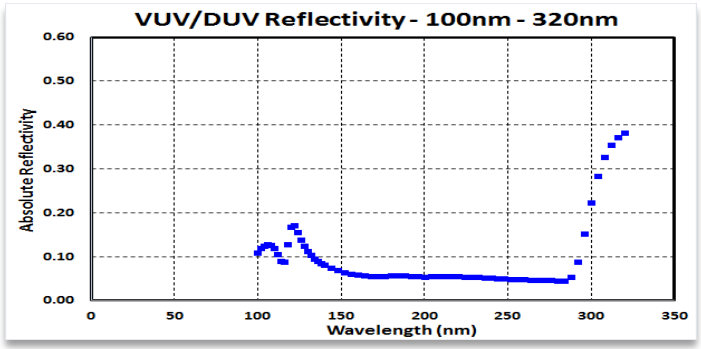
Optical Reflectivity LTEM - Simulation

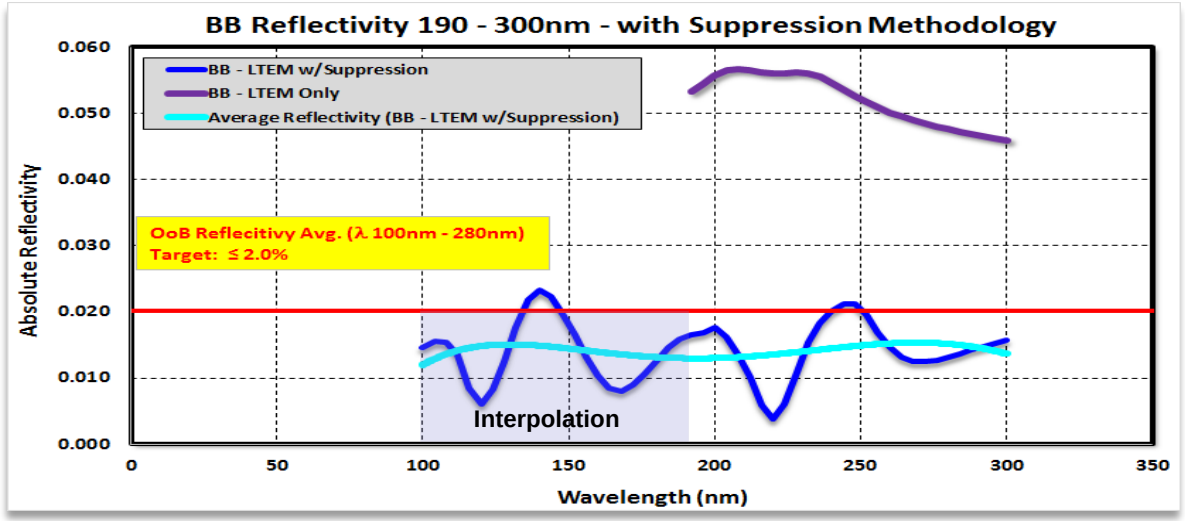
- Optical reflectivity from LTEM only; There is no impact to reflectivity in 190-280nm range with/without backside CrN
- In 280-300nm range, reflectivity mostly affected by CrN film



Optical Reflectivity LTEM - Actual

- Measurement results with VUV/DUV Reflectometer, with backside CrN
- BB process without any reflectivity suppression



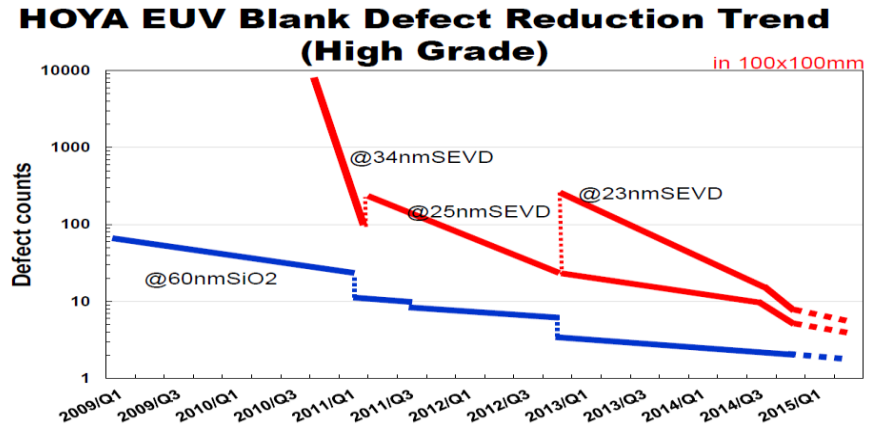


BLANKS: EVOLUTION AND COST

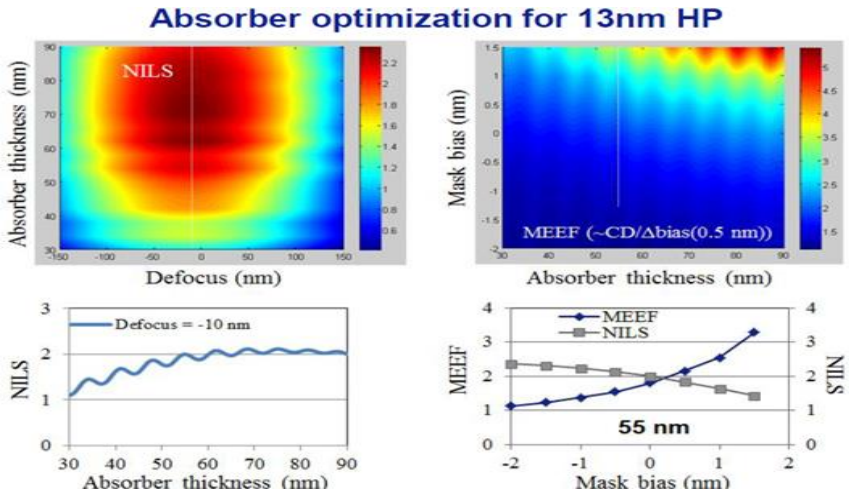
PHOTRONICS

EUV BLANK COMPOSITION – CURRENT MATERIALS

AR layer: Ta-based (2nm - 14nm)
Main layer: Ta-based (51nm - 76nm)
Ru Capping layer
ML: Mo/Si
Substrate: LTEM
Conductive Layer: CrN (20nm or 360nm)



Source: T. Onoue (2015 BACUS)



Source: T. Last (ASML)

Thinner Absorber stack driven by:

- Resolution requirements on mask
- Mitigation of Mask 3D effects

Besides defectivity (ML, Abs, etc.) other blank properties are tightened which impact overall blank costs…

- Substrate flatness and Bow
- Absorber thickness control and uniformity
- Centroid wavelength control and uniformity
- Backside defectivity

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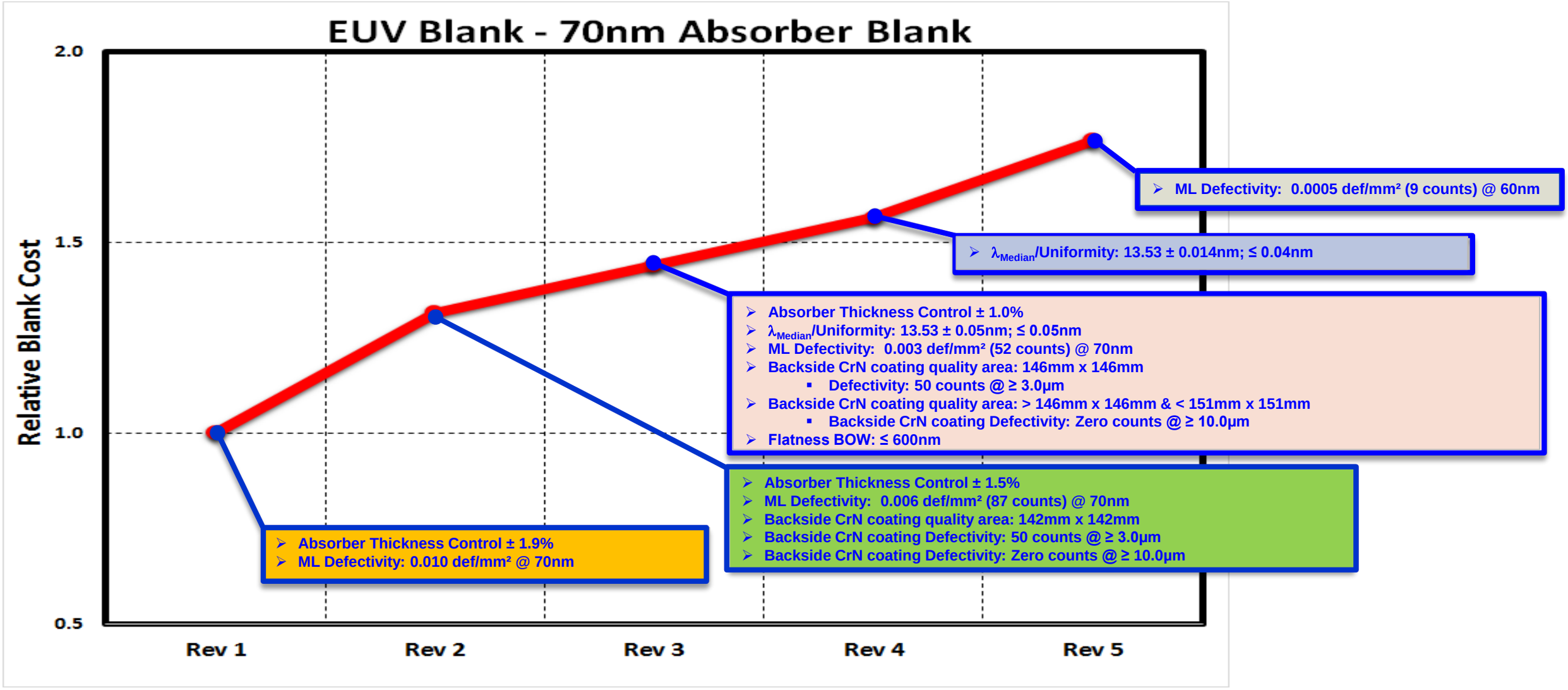
EUV BLANK COMPOSITION – CURRENT MATERIALS



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SUMMARY

EUV Mask Requirements

- Mask Pattern specifications are getting more challenging, but perhaps achievable with current infrastructure
    - SRAF's are driving resolution

Mask Patterning Requirements

- Dual resist strategy to manage multiple mask layer types
    - NCAR process performance has improved resolution and LER performance, but at the expense of write time
- EUV reflectivity requires monitoring and process stability
- Novel BB suppression process being demonstrated to help reduce VUV/DUV OoB reflectivity

EUV Blanks

- Defectivity is priority one, but….
- Cost is directly to evolution of material properties and specification targets.
    - Harmonization would help

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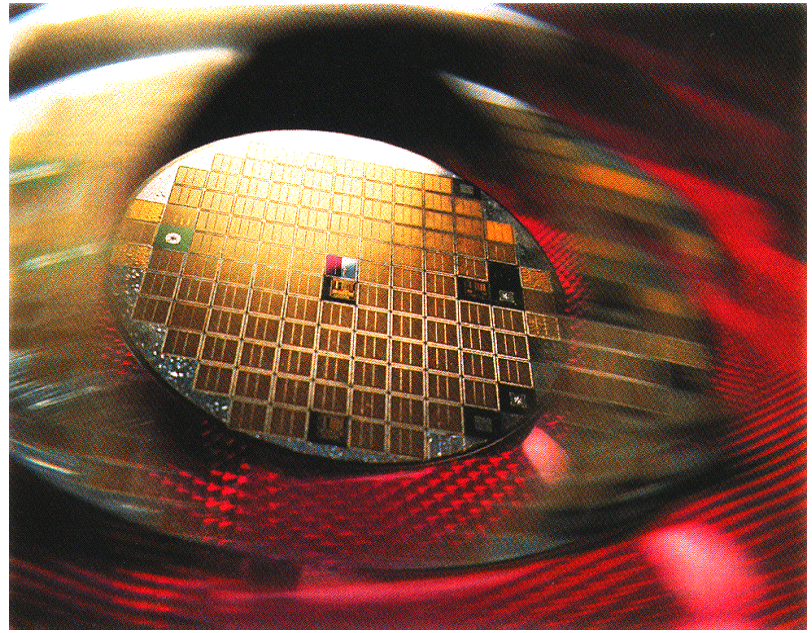
THANK YOU FOR YOUR ATTENTION!



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