KLA-Tencor

Accelerating Yield

Extending a 193nm Mask Inspector for 22 nm HP

Gregg Inderhees, Tao-Yi Fu, Qiang Zhang, Yalin Xiong

RAPID

Agenda

- Motivation
- 22nm HP investigation
  - Stack optimization
  - Simulations
  - Actual results
- EUV DB modeling challenges
- Blank Mode extensions for 22nm HP and below
- Conclusions
- Future Work & Acknowledgements

KLA Tencor

Motivation

Goal: Extend 193nm inspector as far as possible

Table LITH5CD EUVL Mask Requirements

Year of Production	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
DRAM ½ pitch (nm) (contacted)	45	40	36	32	28	25
Flash ½ pitch (nm) (un-contacted poly)	36	32	28	25	23	20
DRAM/Flash CD control (3 sigma) (nm)	4.7	4.2	3.7	3.3	2.9	2.6
MPU/ASIC Metal 1 (M1) ½ pitch (nm)(contacted)	45	40	36	32	28	25
MPU gate in resist (nm)	35	31	28	25	22	20
MPU physical gate length (nm)	27	24	22	18	17	15
Gate CD control (3 sigma) (nm) [A]	2.8	2.5	2.3	1.9	1.7	1.6
Overlay	9.0	8.0	7.1	6.4	5.7	5.1
Contact after etch (nm)	51	45	40	36	32	28
Generic Mask Requirements						
Mask magnification [B]	4	4	4	4	4	4
Mask nominal image size (nm) [C]	141	126	112	100	89	79
Mask minimum primary feature size [D]	99	88	78	70	62	55
Image placement (nm, multipoint) [E]	5.4	4.8	4.3	3.8	3.4	3.0
CD uniformity (nm, 3 sigma) [F]						
Isolated lines (MPU gates)	4.0	3.7	3.3	2.8	2.5	2.3
Dense lines DRAM (half pitch)	6.5	5.8	5.2	4.6	4.1	3.7
Contact/vias	5.0	4.4	4.0	3.5	3.1	2.8
Linearity (nm) [G]	6.8	6.1	5.4	4.8	4.3	3.8
CD mean to target (nm) [H]	3.6	3.2	2.9	2.5	2.3	2.0
Defect size (nm) [I]	**36**	**32**	**29**	**25**	**23**	**20**
Data volume (GB) [J]	655	825	1040	1310	1651	2080
Mask design grid (nm) [K]	2	2	2	2	2	2
EUVL-specific Mask Requirements						
Substrate defect size (nm) [L]	37	35	34	32	30	29
Mean peak reflectivity	66%	66%	67%	67%	67%	67%
Peak reflectivity uniformity (% 3 sigma absolute)	0.47%	0.42%	0.37%	0.33%	0.29%	0.26%
Reflected centroid wavelength uniformity (nm 3 sigma) [M]	0.06	0.05	0.05	0.05	0.04	0.04
Absorber sidewall angle tolerance (± degrees) [P]	0.75	0.69	0.62	0.5	0.5	0.5
Absorber LER (3 sigma nm) [N]	3.0	2.6	2.4	2.1	1.9	1.7
Mask substrate flatness (nm peak-to-valley) [O]	51	46	41	36	32	29

The scanners are coming, the scanners are coming…

- Industry making progress on remaining EUV HVM issues – source, masks, resist
- Masks: defect review, defect inspection, blank inspection, defectivity

Review - PMJ 2010

Initial simulation data suggests 22nm HP capability

Inspection Performance depends upon Optics & Absorber

Image Contrast (%)

Sensitive

Insensitiv

Goal: Extend i

4 | SPIE Advanced Litho

Example — Comparison of Absorber Stacks

Ta Booster vs 257nm ARC

ARC@257nm (13nm)

TaBN (50nm)

Ta (5nm)

TaBN (50nm)

7 | SPIE Advanced Lithogra

Example — Effects on Illumination and Polarization modes on Defect Contrast for 2D Intrusion in 1D pattern

Defect Contrast (arb)

Gauss

11 | SPIE Advanced Lithography

Example — Image Modulation for 1D pattern with Off-Axis Illumination

EUV 1:1 Line/Space:

Modulation (arb)

10 | SPIE Advanced Lithography 2010

Summary of L/S Pattern Simulation Results

Conventional Illumination

				Bare TaN			Booster			ARC		
				Pol A	Pol B	Pol C	Pol A	Pol B	Pol C	Pol A	Pol B	Pol C
L/S	BP	1:1 L/S >22nm										
	Defect SNR	1D	Ext									
			Int									
		2D	Ext									
			Int									

Base Pattern Contrast

Off-axis illumination

				Bare TaN			Booster			ARC		
				Pol A	Pol B	Pol C	Pol A	Pol B	Pol C	Pol A	Pol B	Pol C
L/S	BP	1:1 L/S >22nm										
	Defect SNR	1D	Ext									
			Int									
		2D	Ext									
			Int									

Multiple options → flexibility

Enhancing Absorber, illumination, polarization provides adequate SNR for 22nm HP

12 | SPIE Advanced Lithography 2010

KLA Tencor

KLA Tencor

Agenda

- Motivation
- 22nm HP investigation
  - Stack optimization
  - Simulations
  - Actual results
- EUV DB modeling challenges
- Blank Mode extensions for 22nm HP and below
- Conclusions
- Future Work & Acknowledgements

KLA Tencor

Increasing Defect Modulation at 22nm HP for EUV Masks

Possibilities:

- ✓ EUV mask stack optimization
- ✓ Off-Axis Illumination (OAI) pupils
- ✓ Polarization in illumination

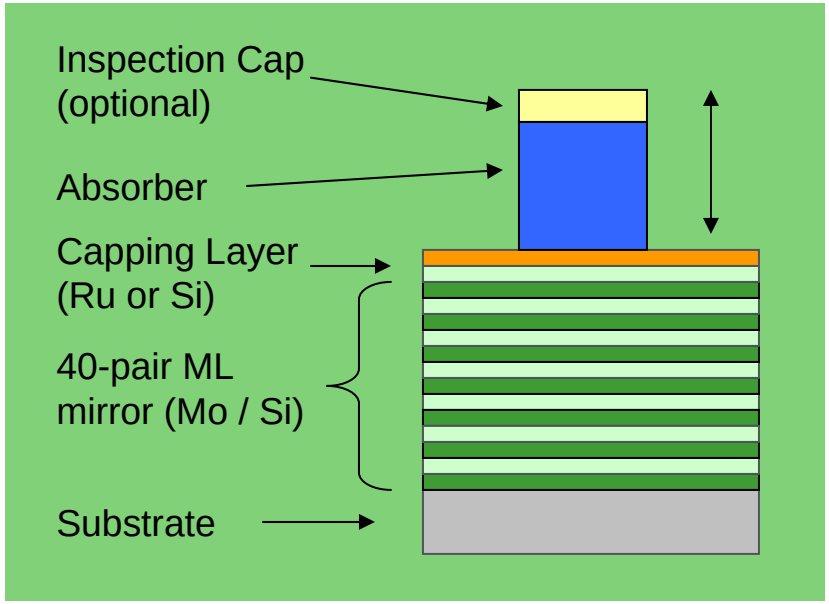
  Higher NA --- Very marginal enhancement

KLA-Tencor Confidential

Stack Optimization Project Summary

Recommendation: Bare TaBN stack for 22nm HP / Teron 630

- Investigated different inspection caps to improve pattern contrast and defect modulation
- Many materials evaluated with a wide range of reflectivity @193nm (1% - 60%)
- Stack height converging to 50 – 60 nm
- Test masks produced and measured to validate simulations

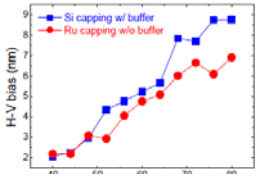


KLA-Tencor Confidential

Mask Absorber Optimization

Balancing often conflicting needs

EUVL process window



- NILS
- EL / DoF
- H-V bias
- MEEF

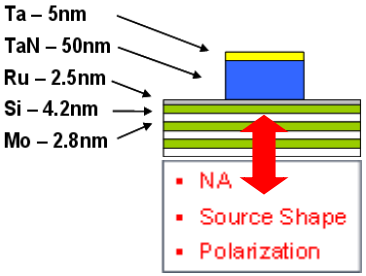
Seo et al. (2009)

Mask & blank fabrication process

	TaN	Cr	Ta	TiN
Index of refraction n	0.925	0.933	0.944	0.936
Absorber coefficient k	0.044	0.0383	0.0403	0.0219
Min. absorber thickness*	440A	500A	480A	880A
Film stress (Mpa)	-744	1150	-566	-530
Oxide stress (Mpa)	30			
Emissivity	0.396	0.122	0.284	0.17

- Stress
- Etch
- LER
- Cleaning

Yan et al. (2000)



Inspection sensitivity & robustness

- Pattern contrast
- Defect SNR
- Focus sensitivity

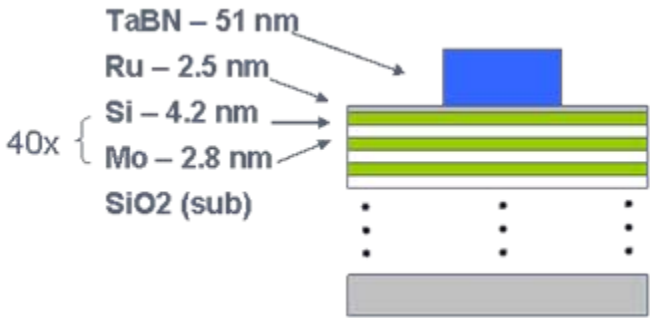
Goal: maximum extension of 193 nm inspection platform

KLA Tencor

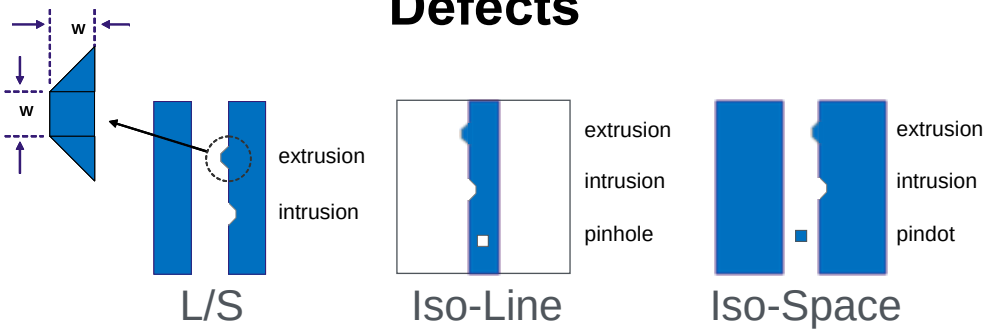
EUV Mask Defect Printability: L/S, Iso-Line (Space)

What defect size must be detected?

Mask Stack



Defects



EUVL Projection System

- λ=13.5nm
- NA = 0.32
- Reduction ratio = 4x
- Illumination sigma = 0.5
- Chief ray angle at the mask = 6°
- Non-polarized
- Illumination along the line to minimize pattern shadowing effect

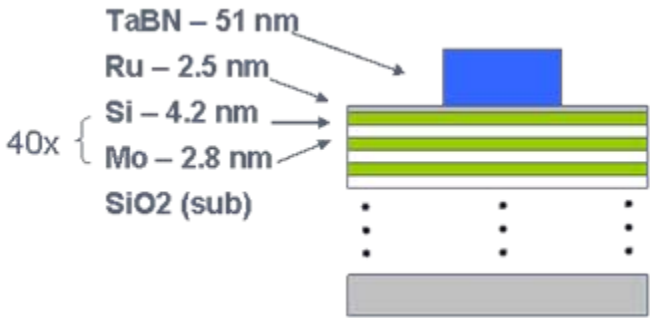
Printable Size (10% ΔCD) 22nm HP

Def Type	Def Width (%CD)
Ext L/S	21.3%
Ext IsoSpace	21.9%
Ext IsoLine	24.2%
Int L/S	25.0%
Int IsoSpace	26.0%
Int IsoLine	25.1%
IsoSpace Pindot	27.2%
IsoLine Pinhole	38.0%

KLA Tencor

EUV Mask Defect Printability: Contact

Mask Stack



Defects

EUVL Projection System

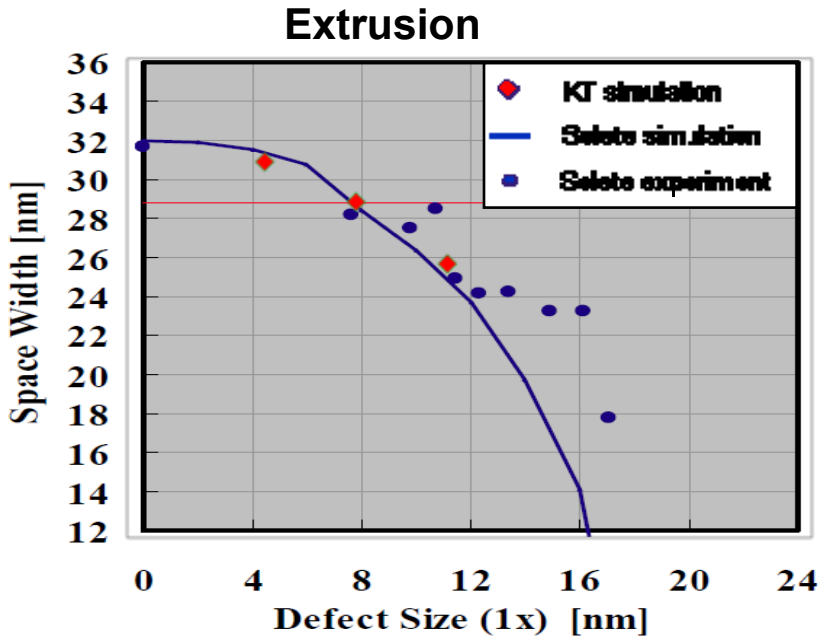
- λ=13.5nm
- NA = 0.32
- Reduction ratio = 4x
- Illumination sigma = 0.5
- Chief ray angle at the mask = 6°
- Non-polarized
- Illumination along the line to minimize pattern shadowing effect

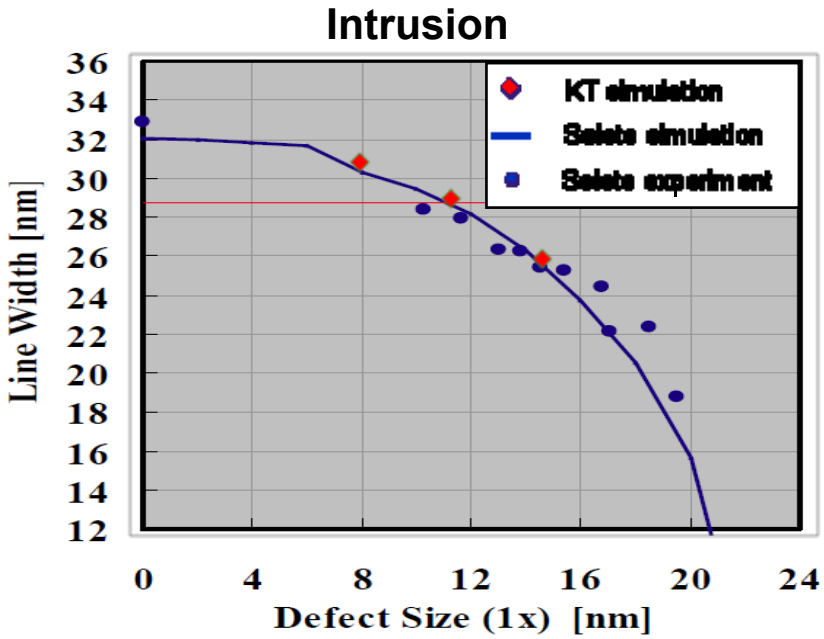
Printable Size (10% ΔCD) 28nm HP

Def Type	Def Width (%CD)
Pindot	28.5%
Corner	28.5%
Extrusion	28.5%
Intrusion	33.0%

EUV Defect Printability Validation

(Line/Space, HP 32nm)





Reference: Kamo et al. (Selete) Proc. of SPIE 7636, 2010

EUVL Configuration (SFET)

- λ=13.5nm
- NA = 0.3 (30% central obscuration)
- Reduction ratio = 5x
- Illumination sigma = 0.3-0.7
- Chief ray angle at the mask = 6°
- Non-polarized
- Illumination along the line to minimize pattern shadowing effect

KLA Tencor

EUV Mask: Any Hope of Defect Modulation on Line/Space Layer?

EUV 1:1 L/S,
≥HP 22nm

Conventional Illumination

						Bare TaN			Booster			ARC		
						Pol A	Pol B	Pol C	Pol A	Pol B	Pol C	Pol A	Pol B	Pol C
L/S	BP	1:1												
	Defect	1D	Full Height	Ext	10%									
				Int	10%									
		2D	Full Height	Ext	21.3%									
				Int	25.0%									

OAI Illumination

						Bare TaN			Booster			ARC		
						Pol A	Pol B	Pol C	Pol A	Pol B	Pol C	Pol A	Pol B	Pol C
L/S	BP	1:1 L/S												
	Defect	1D	Full Height	Ext	10%									
				Int	10%									
		2D	Full Height	Ext	21.3%									
				Int	25.0%									

Multiple options → flexibility

Enhancing absorber, illumination, polarization provides adequate SNR for 22nm HP!

KLA Tencor

EUV Mask: Any Hope of Defect Modulation on Contact Layer?

EUV 1:1
Contact 28nm

Conventional Illumination

				Bare TaN			Booster			ARC		
				Pol A	Pol B	Pol C	Pol A	Pol B	Pol C	Pol A	Pol B	Pol C
BP Contrast	1:1 CT											
Def Modulation	2D	Undersized	10%									
		Oversized	10%									
		Center	28.5%									
		Corner	28.5%									
		Extrusion	28.5%									
		Intrusion	33.0%									

OAI Illumination I

				Bare TaN			Booster			ARC		
				Pol A	Pol B	Pol C	Pol A	Pol B	Pol C	Pol A	Pol B	Pol C
BP Contrast	1:1 CT											
Def Modulation	2D	Undersized	10%									
		Oversized	10%									
		Center	28.5%									
		Corner	28.5%									
		Extrusion	28.5%									
		Intrusion	33.0%									

OAI Illumination II

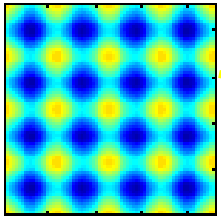
				Bare TaN			Booster			ARC		
				Pol A	Pol B	Pol C	Pol A	Pol B	Pol C	Pol A	Pol B	Pol C
BP Contrast	1:1 CT											
Def Modulation	2D	Undersized	10%									
		Oversized	10%									
		Center	28.5%									
		Corner	28.5%									
		Extrusion	28.5%									
		Intrusion	33.0%									

KLA Tencor

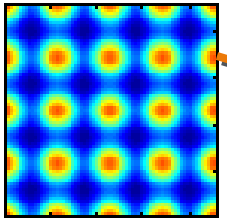
Simulation vs. Real Measurement:

Contact pattern contrast > 30%

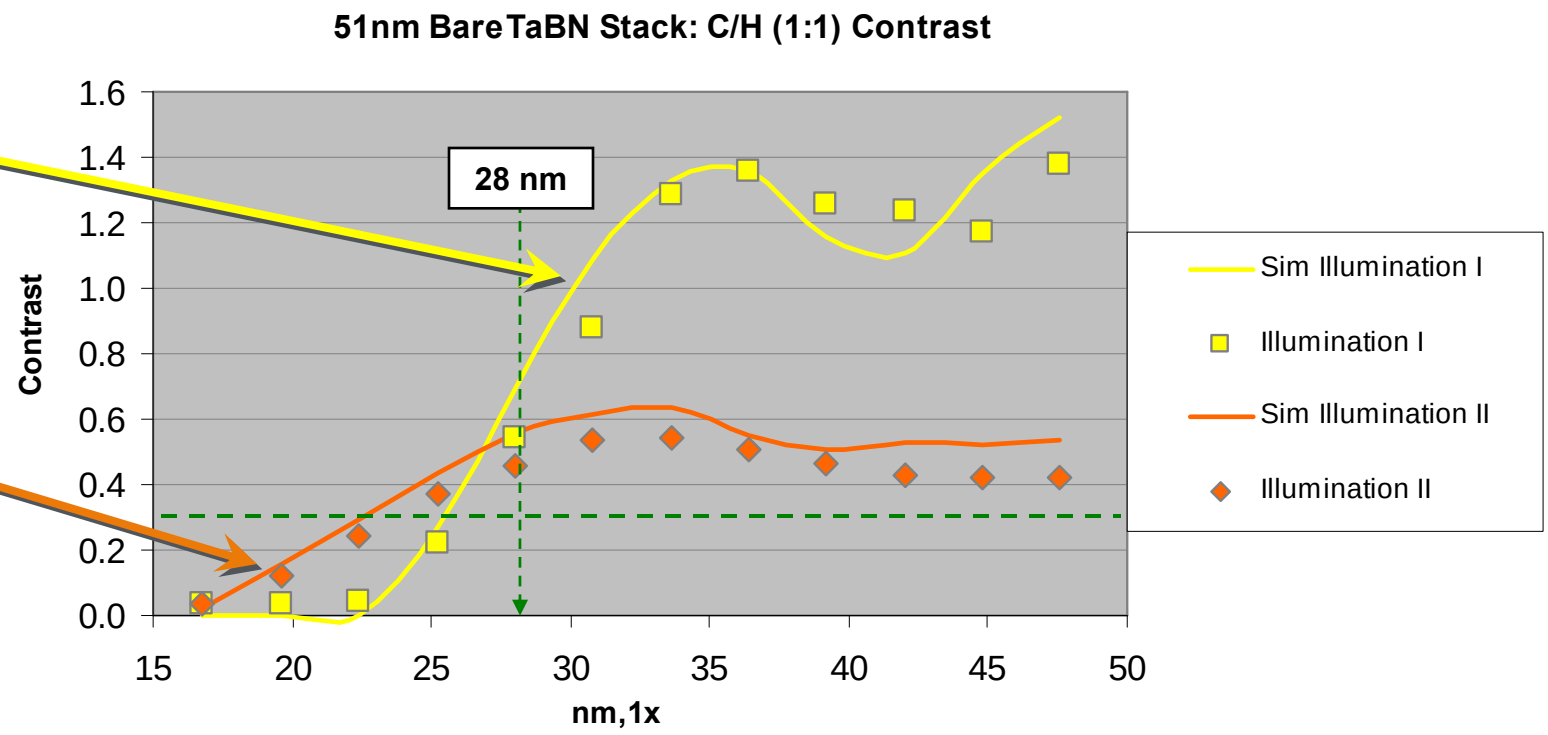
Contact Hole
1:1



Illumination I



Illumination 2



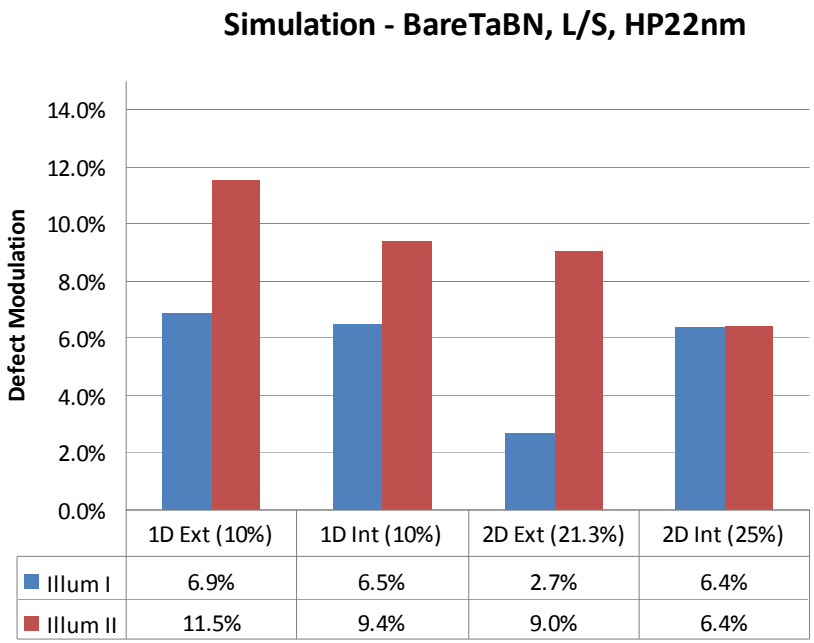
Experiments validate simulations.

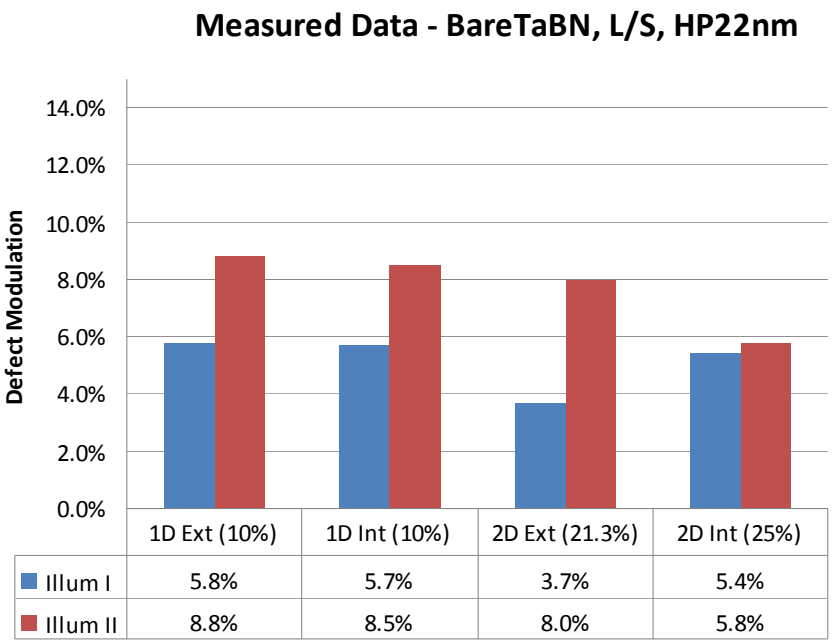
Results meet 22 nm HP requirements.

KLA-Tencor Confidential

KLA-Tencor

Simulation vs. Real Measurement:
22 nm L/S defect modulation

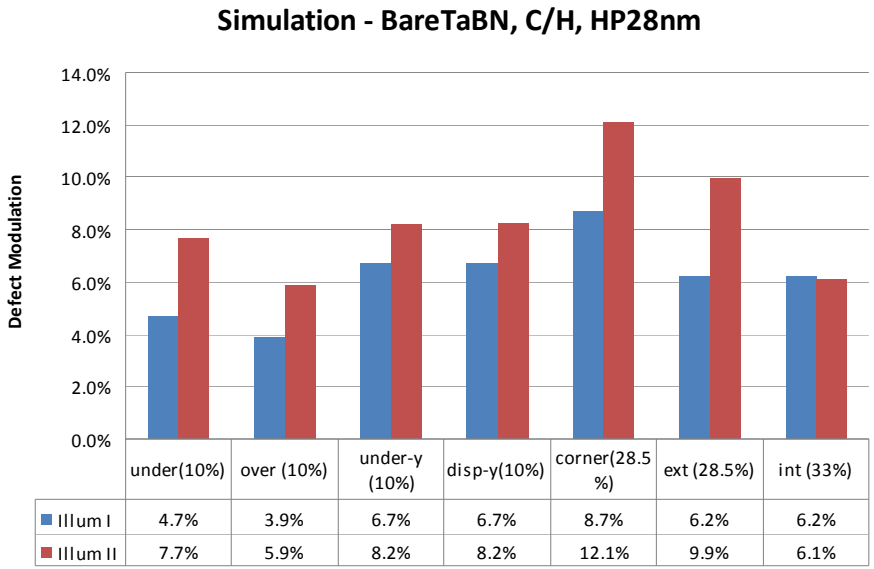




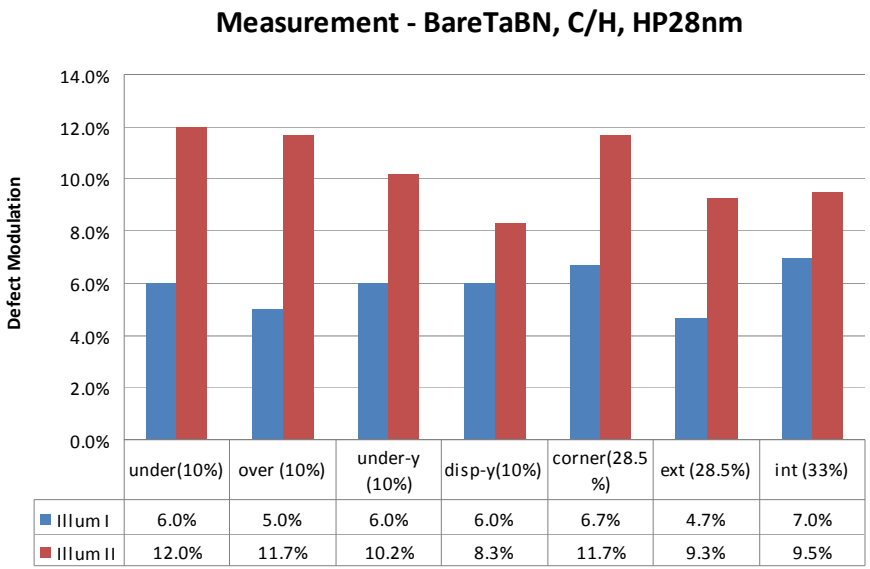
Simulations and data in excellent agreement

KLA Tencor

Simulation vs. Real Measurement:
28 nm contact defect modulation



	under(10%)	over (10%)	under-y (10%)	disp-y(10%)	corner(28.5 %)	ext (28.5%)	int (33%)
Illum I	4.7%	3.9%	6.7%	6.7%	8.7%	6.2%	6.2%
Illum II	7.7%	5.9%	8.2%	8.2%	12.1%	9.9%	6.1%

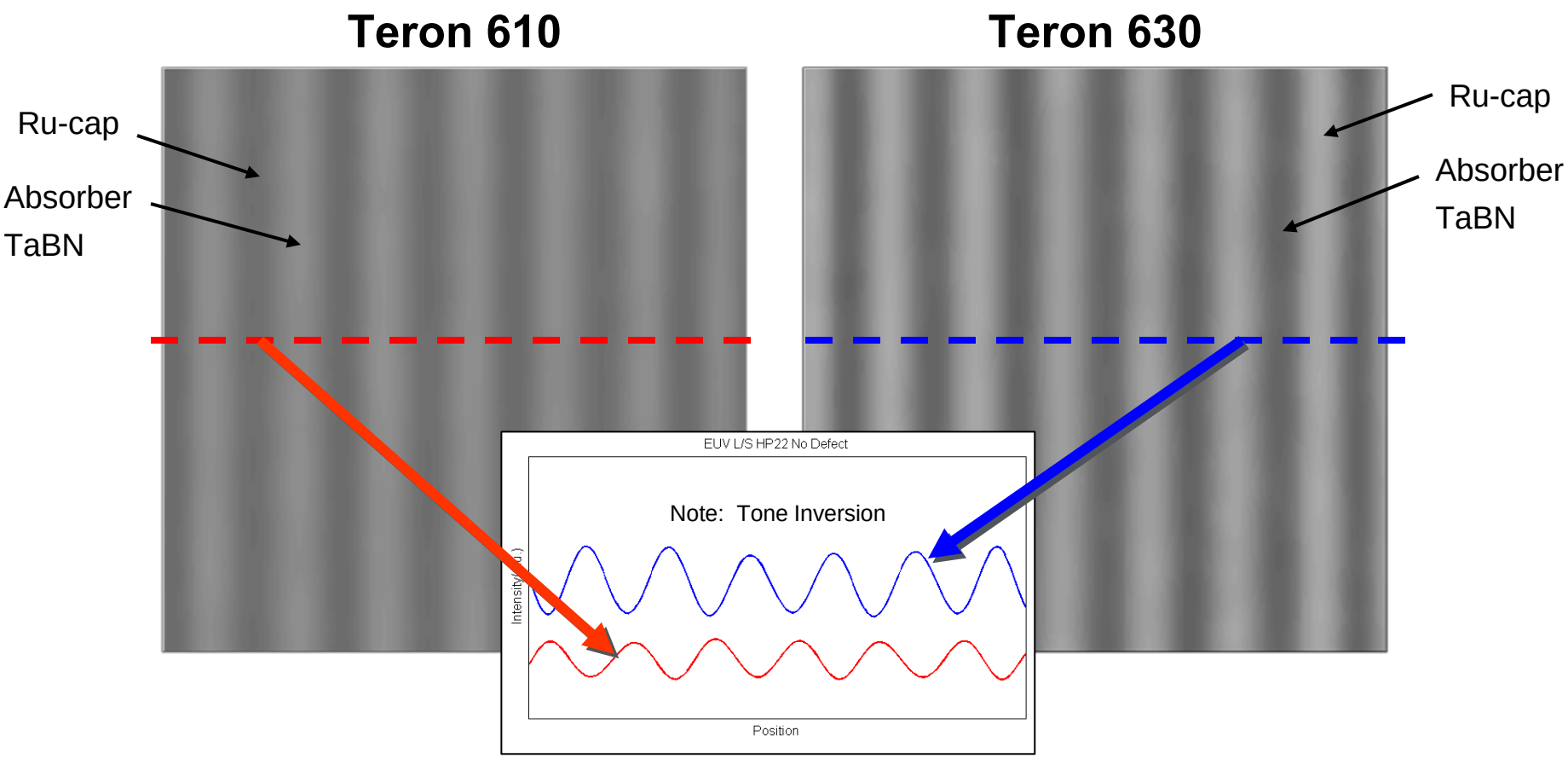


	under(10%)	over (10%)	under-y (10%)	disp-y(10%)	corner(28.5 %)	ext (28.5%)	int (33%)
Illum I	6.0%	5.0%	6.0%	6.0%	6.7%	4.7%	7.0%
Illum II	12.0%	11.7%	10.2%	8.3%	11.7%	9.3%	9.5%

Simulations and data in excellent agreement

KLA Tencor

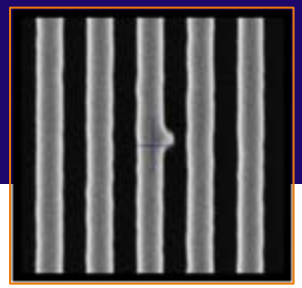
L/S(1:1) Pattern, HP 22nm



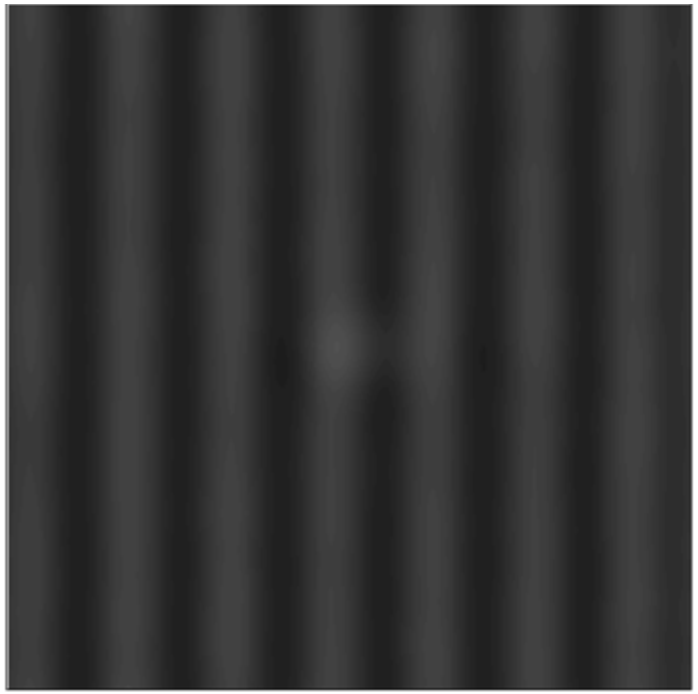
Teron 630 provides 2x improvement in base pattern modulation

KLA-Tencor Confidential

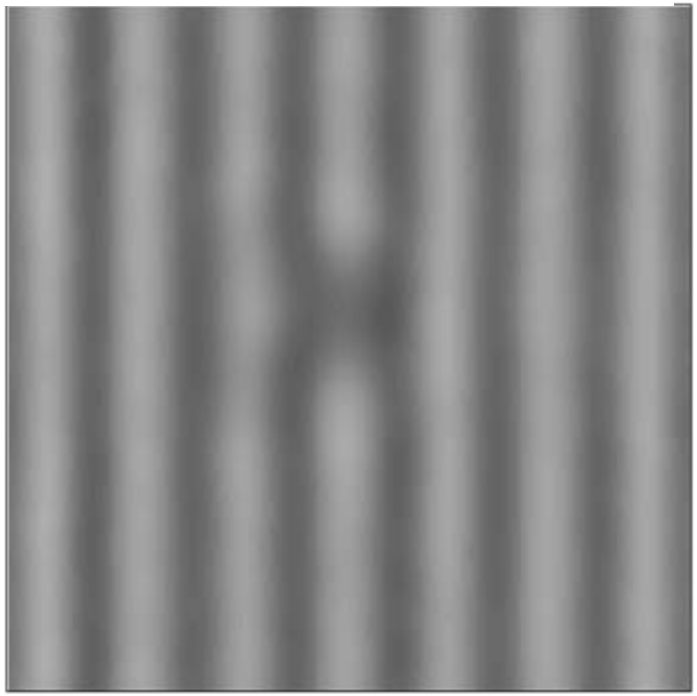
Extrusion, HP 22nm



Teron 610



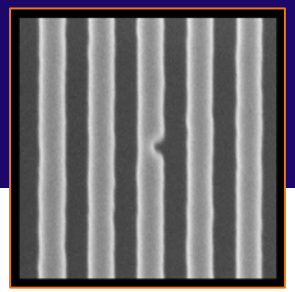
Teron 630



Clearly see improvement provided by Teron 630

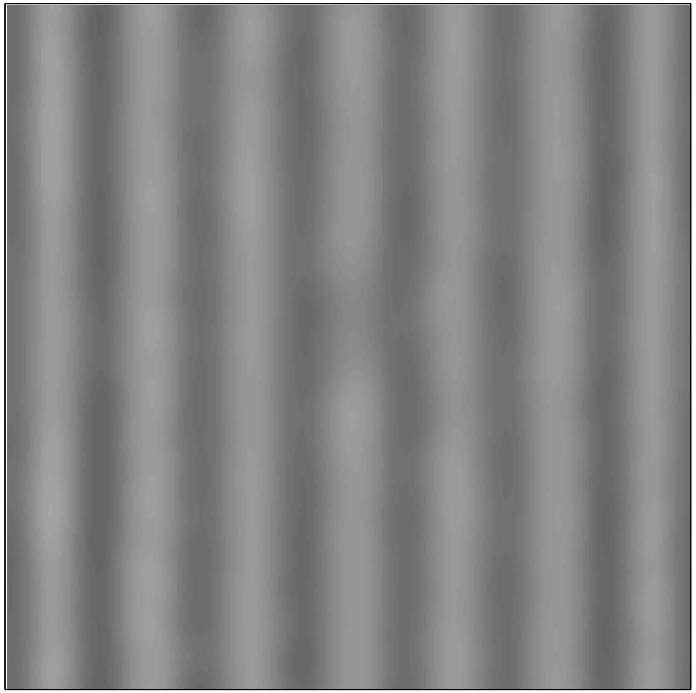
KLA Tencor

Intrusion, HP 22nm



Teron 610

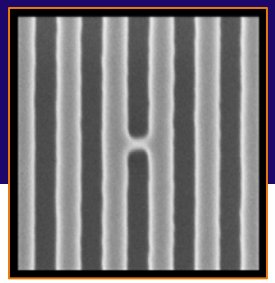
Teron 630



Teron 630 benefits less pronounced

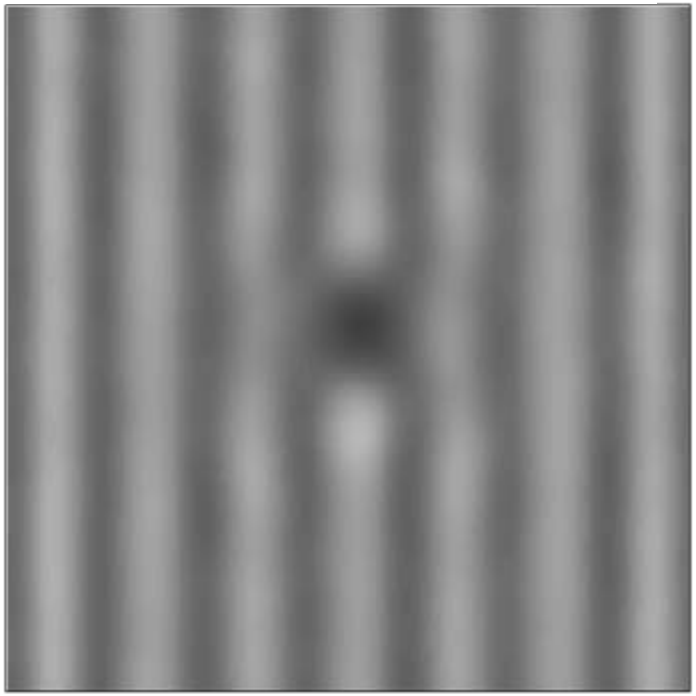
KLA Tencor

Bridge



Teron 610

Teron 630



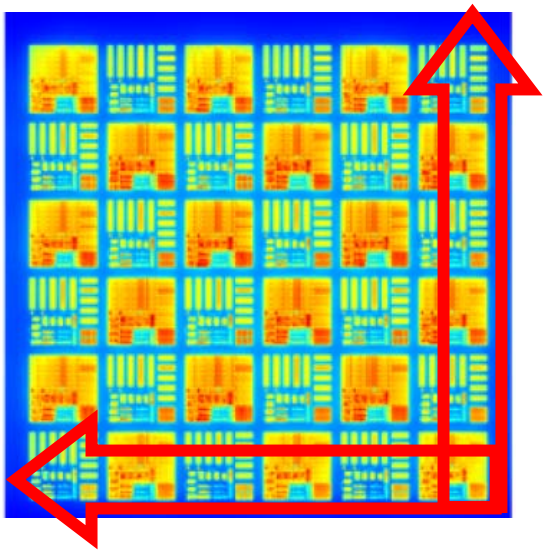
Teron 630 provides significant benefit for this defect type

KLA Tencor

Agenda

- Motivation
- 22 nm HP investigation
  - Stack optimization
  - Simulations
  - Actual results
- EUV DB modeling challenges
- Blank Mode extensions for 22 nm HP and below
- Conclusions
- Future Work & Acknowledgements

EUV Flare Correction May Inhibit D:D Inspection



Flare correction across EUV mask*

	22nm HP	16nm HP
Mask half pitch	88 nm	64nm
Mask defect: 10% CD	8.8 nm	6.4nm
Detection allowance: 20%	1.8nm	1.3nm
Max flare correction	**1.8nm**	**1.3nm**

Key Questions

- Magnitude of flare correction
- Spatial distribution of correction

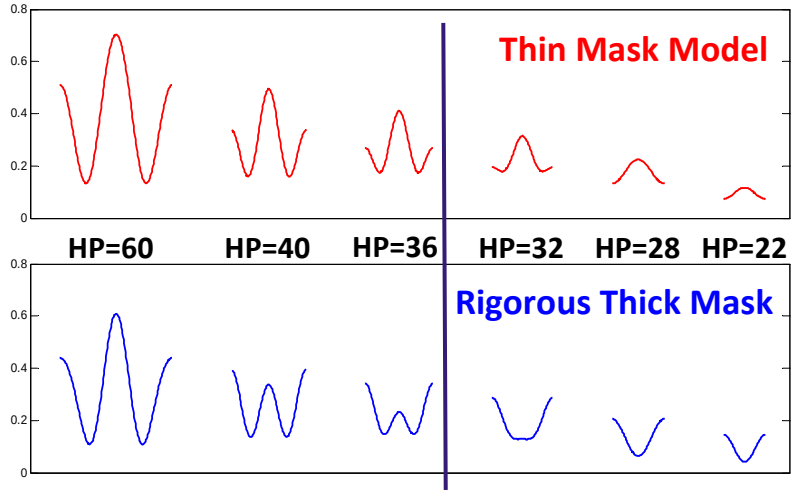
*Source: "Full chip correction of EUV design", Lorusso, et al., IMEC / Mentor Graphics / Micron. SPIE 2010

EUV masks may require D:DB inspection

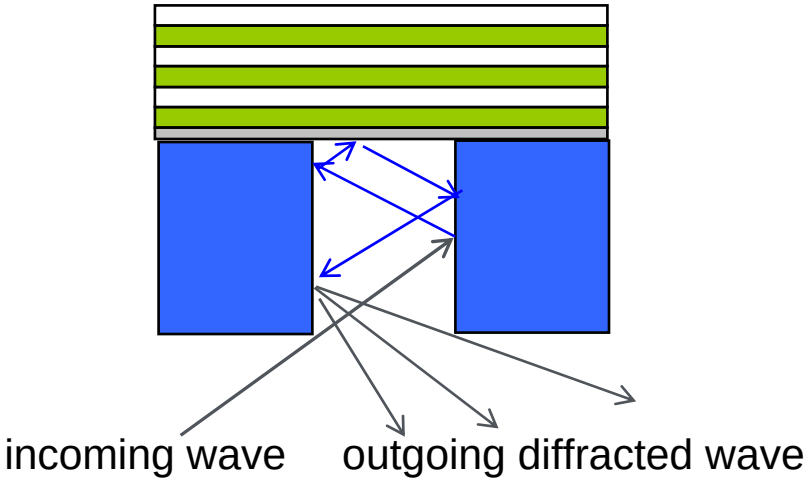
KLA-Tencor Confidential

EUV DB Modeling Challenge: Mask 3D Effect

Tone inversion at small pitches



Multiple scattering must be considered

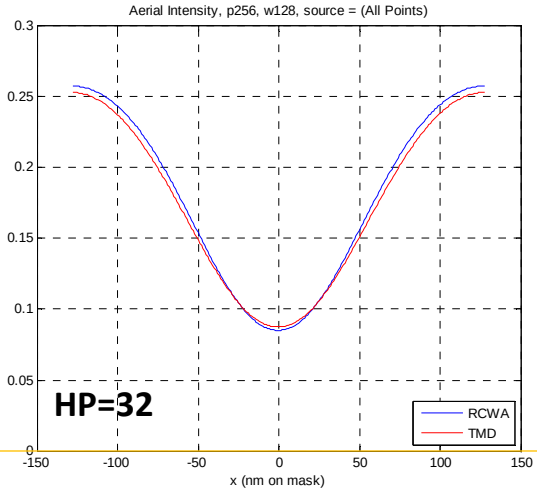


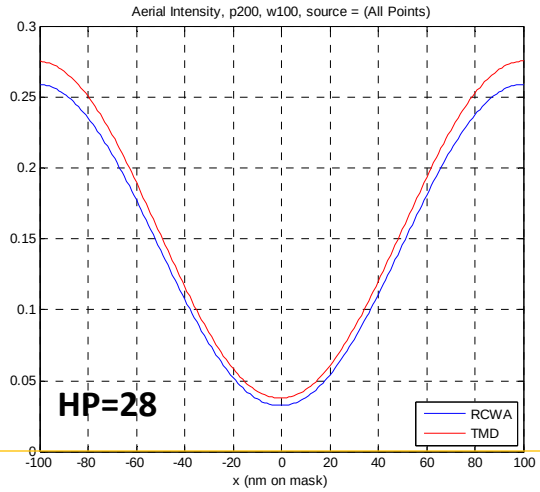
- **Key requirements of new Thick Mask Diffraction (TMD) model**
  - ***Edge-to-edge* interaction due to multiple scattering**
  - ***Long-range* and *resonant* nature of multiple scattering**

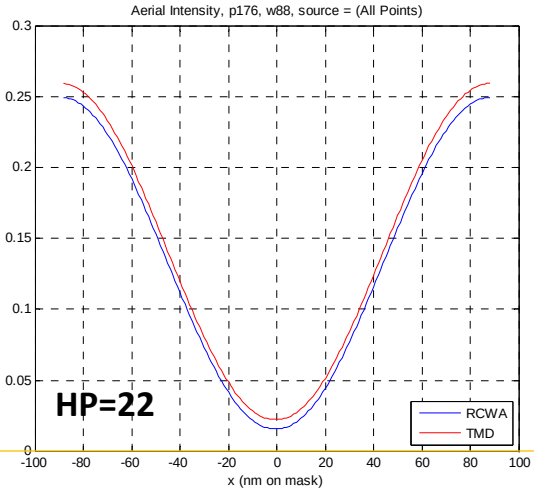
KLA Tencor

Teron 630 DB Rendering of Small L/S

- **Early results show excellent match between rendered image (TMD) and rigorous simulation (RCWA)**
- **Tone inversion can be predicted by good thick mask diffraction model**
- **Development of new thick mask diffraction model underway to further improve rendering accuracy**







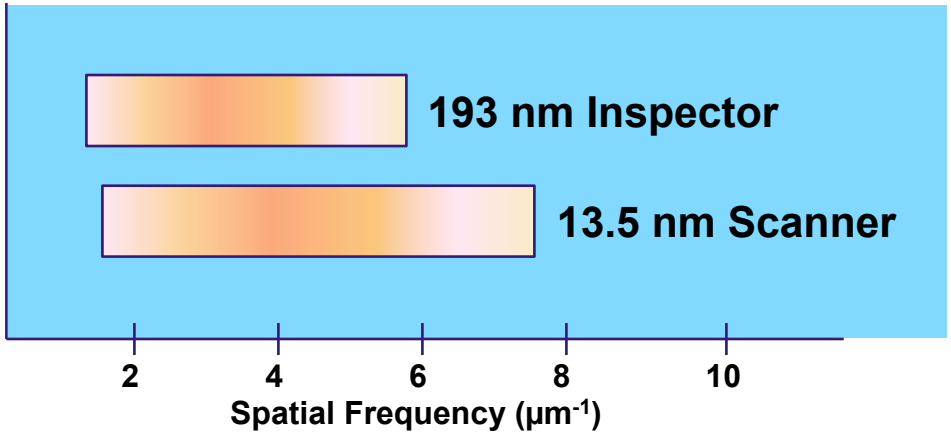
Agenda

- Motivation
- 22 nm HP Investigation
  - Stack Optimization
  - Simulations
  - Actual Results
- EUV DB modeling challenges
- Blank Mode extensions for 22 nm HP and below
- Conclusions
- Future Work & Acknowledgements

EUV Multi-layer Roughness Limits Inspection Sensitivity

"… achieving an RSR [replicated surface roughness] of approximately 50 pm will be required in order to push down the mask roughness induced LER contribution to below 1 nm." --McClinton and Naulleau, Proc. SPIE Vol. 7636 (2010)

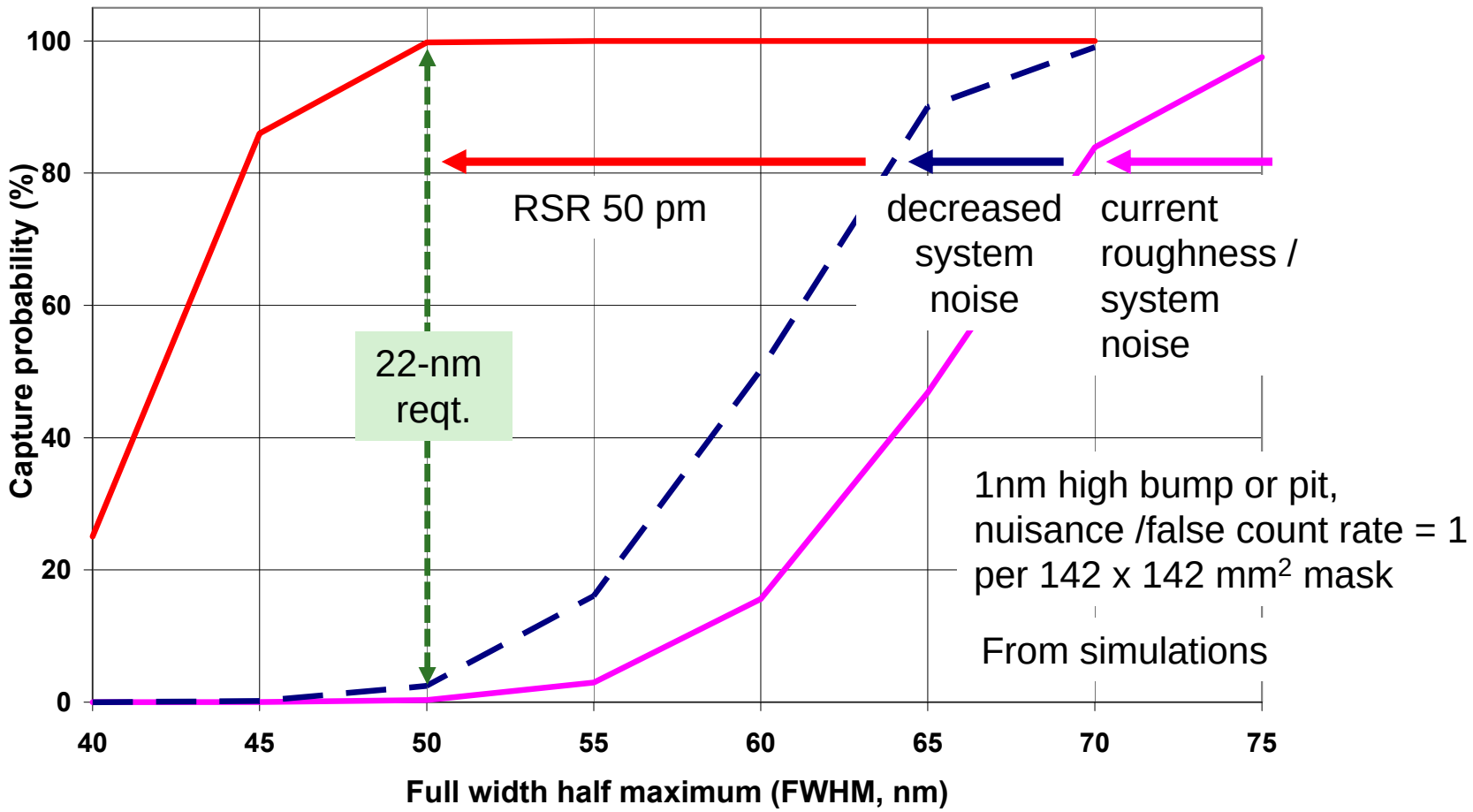
(Above statement for litho NA=0.32)



- **EUV multi-layer roughness defects cause LER in litho and limit inspection sensitivity**
- **Surface roughness affects similar spatial bands in both litho and 6xx inspection**

KLA Tencor

Teron 600 Series Can Meet 22nm HP Phase Bump/Pit Requirements



Improvements in surface roughness for both EUV Lithography and 22 nm HP blank inspection required

KLA Tencor

Agenda

- Motivation
- 22 nm HP investigation
  - Stack optimization
  - Simulations
  - Actual results
- EUV DB modeling challenges
- Blank Mode extensions for 22 nm HP and below
- Conclusions
- Future Work & Acknowledgements

Conclusions

1. 193nm mask inspector can be extended to meet EUV 22 nm HP production requirements for L/S and Contact layers
2. Significant technical innovation and development are needed, including OAI, polarized illumination and stack optimization
3. Die-Database inspection for single-die and flare-corrected multiple-die 22nm HP EUV reticles can be modeled on 193nm inspector
4. 193nm inspector can inspect 22nm HP EUV mask blanks for bump/pit phase defects with improvement in blank surface roughness

KLA Tencor

Future Work & Acknowledgements

- Finalize the optimum number of inspection passes
- Investigate further extensions of the193 nm inspection platform to meet requirements for smaller nodes, including pattern and blank phase defect inspection

- My co-authors for their contributions to this work.
- Tsutomu Shoki from Hoya Blank for providing test masks and consultations.
- Ted Liang from Intel Mask Operations for providing test masks and consultations.
- SongSue Kim and HwanSeok Seo from the Samsung Mask Shop for providing test masks and consultations.