3D Reticle Effects for High-NA EUV Lithography

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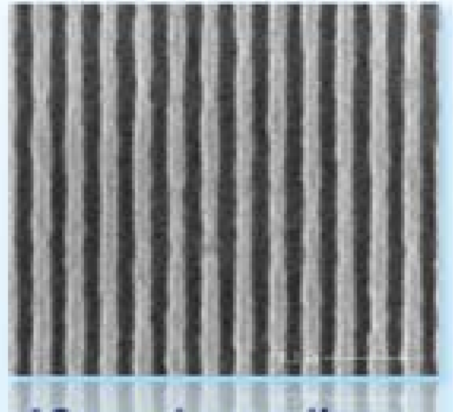
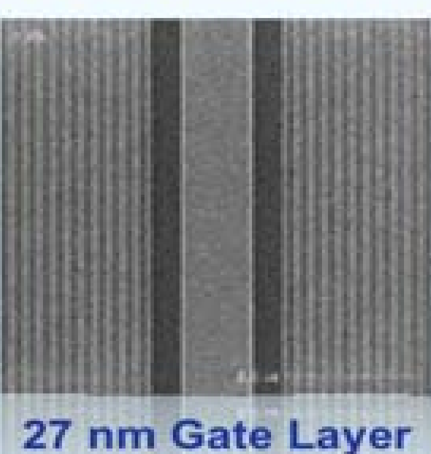
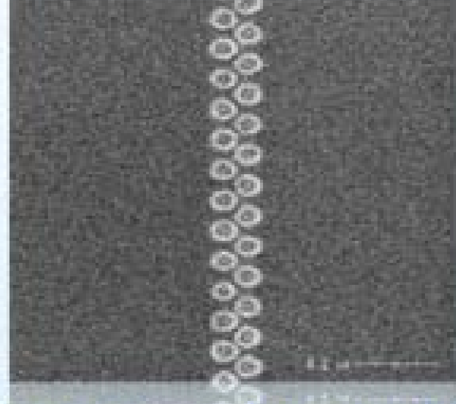
NXE:3100 enables resolution for half-pitches 30nm and below. Future scaling to 10nm and below requires increased NA > 0.33.



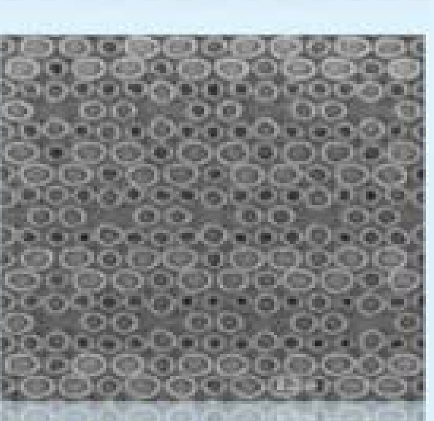
16nm dense lines



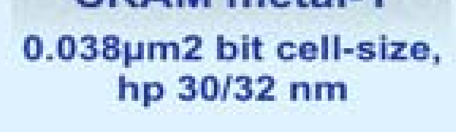
27 nm Gate Layer Flash



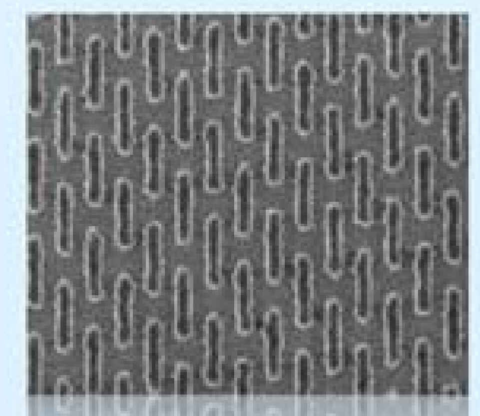
Flash staggered contact layer
Bitline pitch = 44 nm (1:1.2)
CH pitch = 74.4 nm



Sub 16 nm node SRAM Contact Hole
0.038µm2 bit cell-size, hp 30/32 nm



Sub 16 nm node SRAM metal-1
0.038µm2 bit cell-size, hp 30/32 nm



30 nm Brickwall DRAM

Source: ASML, IMEC

source: Bill Arnold, ASML TDC

Sematech Litho Forum 2012

Slide 5

We see design solutions for EUV high NA systems enabling 11 nm resolution and beyond.

NA: 0.25 | 0.33 | 0.45 | 0.6

6 mirrors — *central obscured*

8 mirrors — *unobscured* — *central obscured*

27 nm NXE:3100	16 nm NXE:3300	9 nm	7 nm

schematic designs - for illustration only

(W. Kaiser, Sematech Litho Forum 2012)

Reflective mask requires oblique illumination.

CRAO

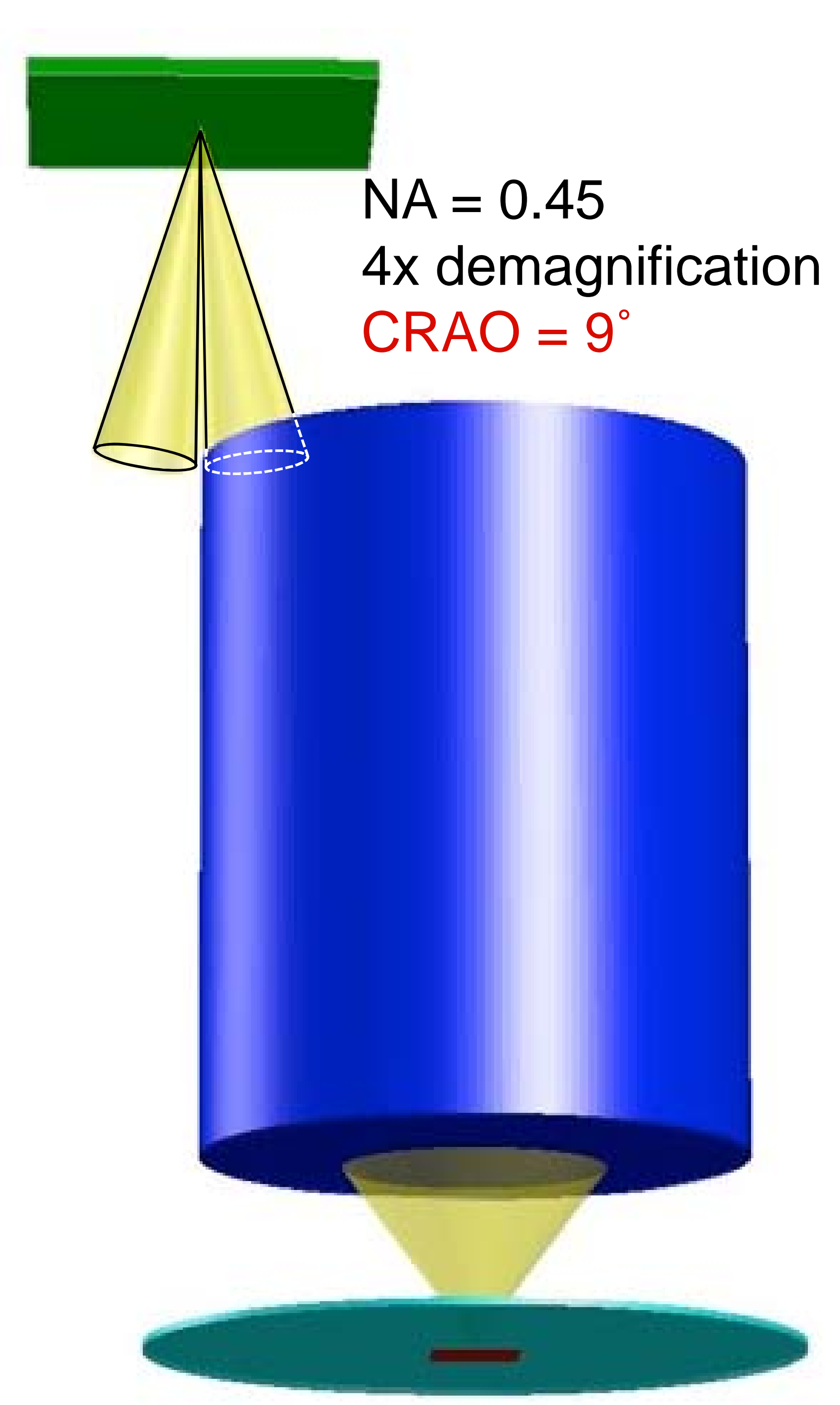
Chief Ray Angle @ Object (mask)

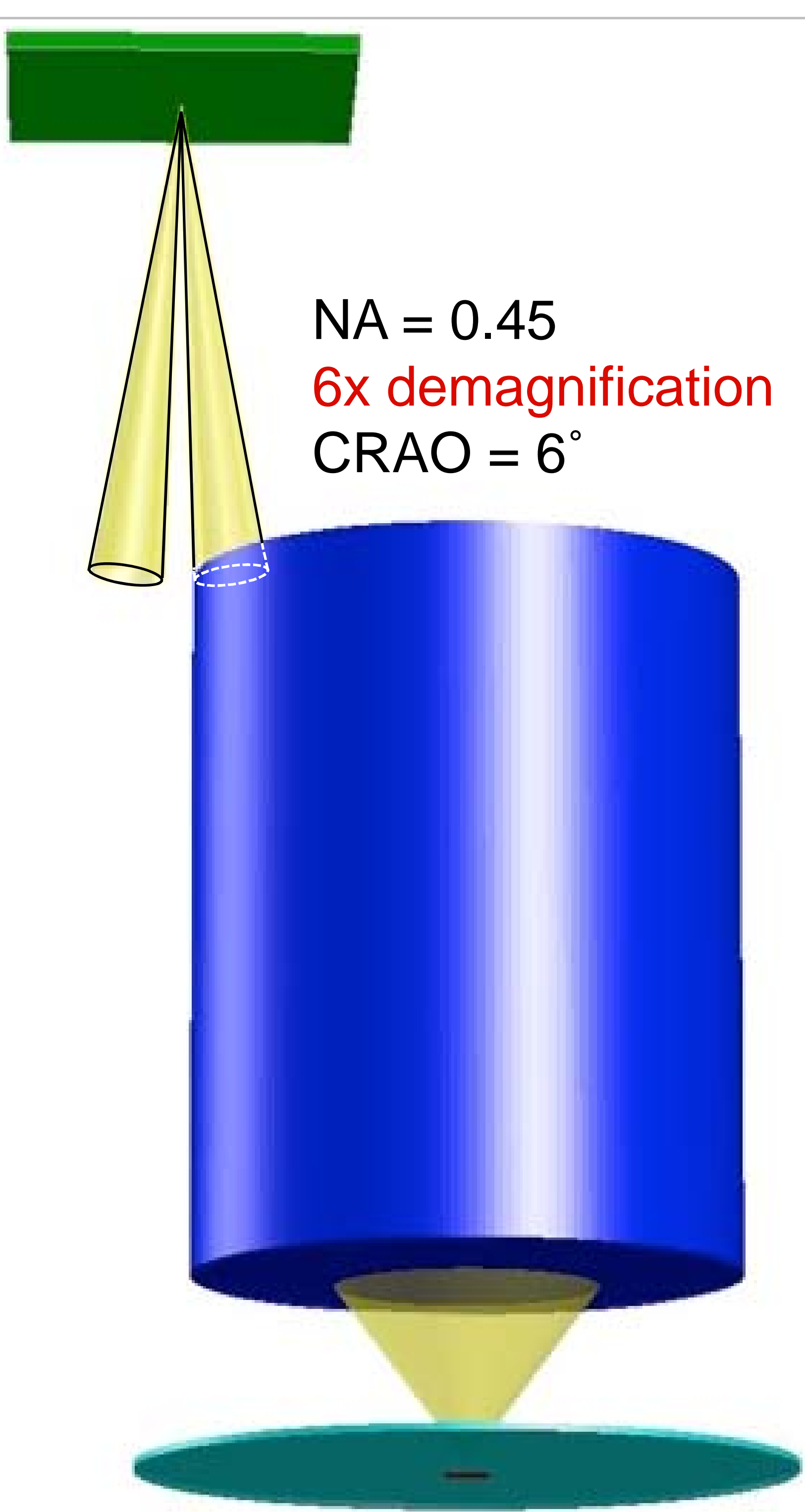
CRAO

Simply increasing the NA would lead to intersecting light cones of illuminator and projection optics.

Increase NA

Two ways out:
Increase CRAO - or increase demagnification.





Absorber shadowing ("effective line width") is angular dependent!

effective line width

w

effective line width

w

Large AoI

Small AoI

Wave optical: ~ $(\tan \varphi)^2$

Key effect: shadowing varies over incoming light cone.

Broadband coating, open frame:
Homogeneous reflection of 0th order.

Patterned absorber:
Combined diffraction & reflection gets asymmetric.

Asymmetry 0th order: Telecentricity error.
➔ V. Philipsen (next talk)

Asymmetry 0th/1st order: contrast loss.

Large AoI

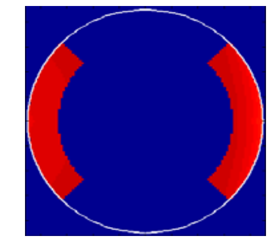
Small AoI

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

11nm L/S at 0.45NA and 9° CRAO

Experimental validation:
- V. Philipsen (IMEC) ➔ next talk.
- R. Chao (LBNL) ➔ SPIE AL 2013.

Tuning of multilayer stack changes the reflectivity behavior.



ML_tuning

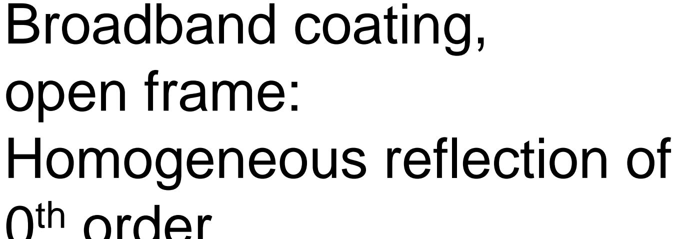
d | d · 1.01 | d · 1.02

mask reflectivity

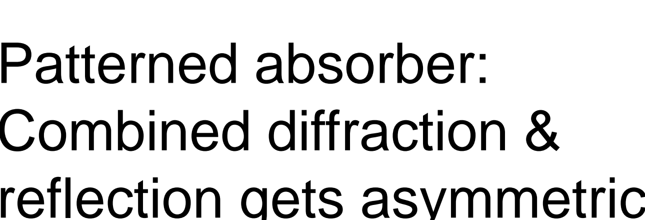
Angle of incidence (deg)

3300 standard

Absorber shadowing can be compensated by ML tuning, but …



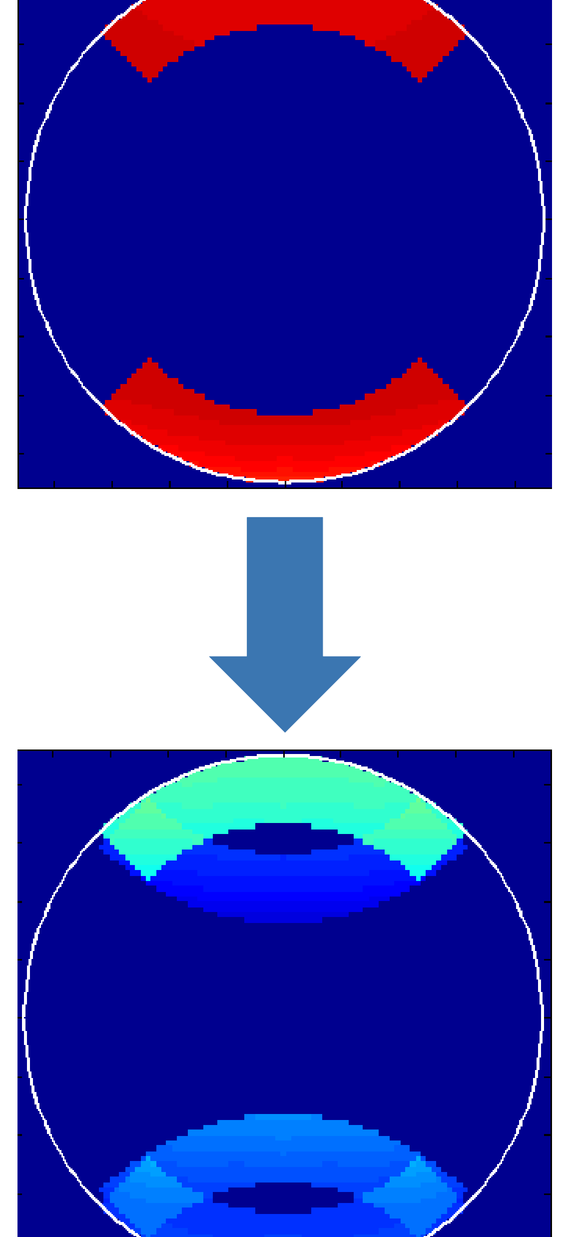
Broadband coating, open frame:
Homogeneous reflection of 0th order.



Patterned absorber:
Combined diffraction & reflection gets asymmetric.

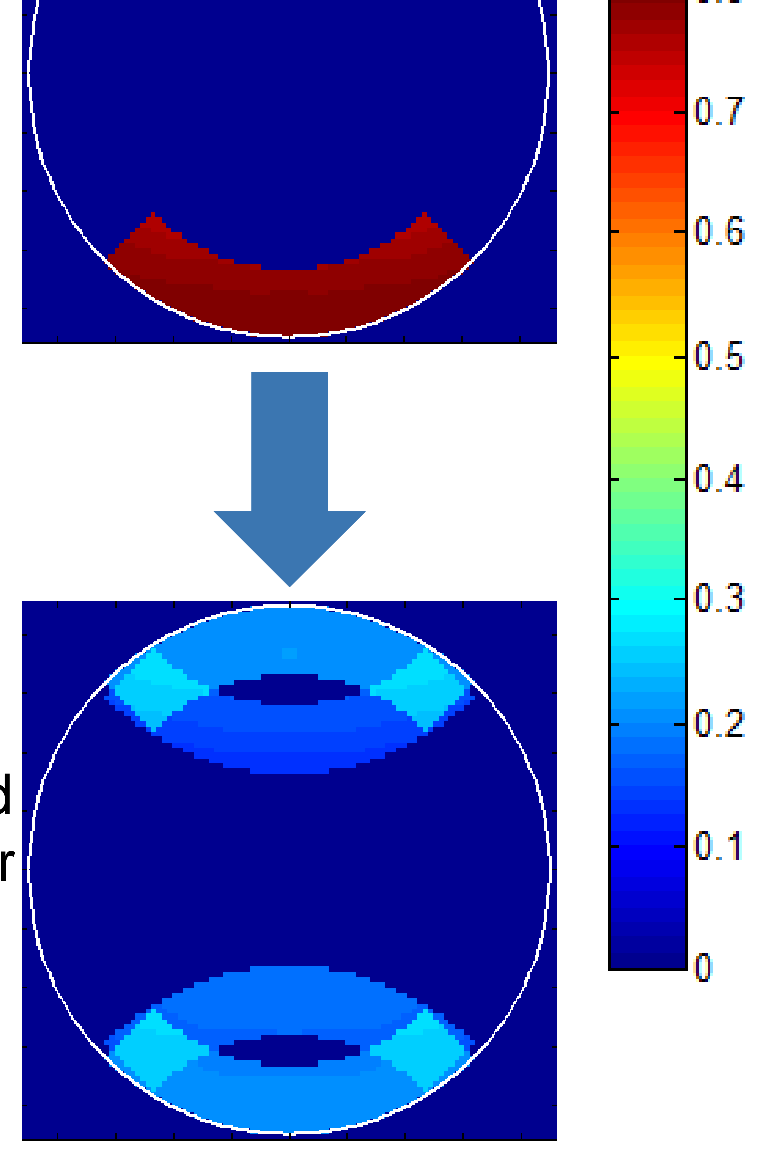
Asymmetry 0th order:
Telecentricity.

Asymmetry $0^{th}/1^{st}$ order:
NILS loss.



Tuned coating:
Attenuation of upper pole (small angles)
➔ inhomogeneous reflection of 0th order (open frame exposure)

Patterned absorber:
Combined diffraction & reflection with increased symmetry, both 0th order and $0^{th}/1^{st}$ order.



11nm L/S at 0.45NA and 9° CRAO

Tradeoff between contrast and efficiency. Contrast and efficiency are recovered for mag 6X (reduced angles @ mask).

NA = 0.45, CRAO 9°

d × ML tuning

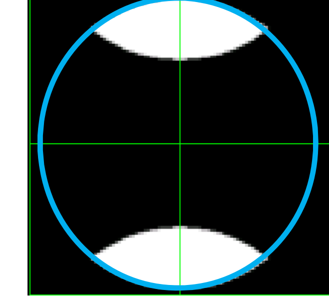
NILS [1]

NA 0.45, mag 6X, CRAO 7°

ML tuning [1]

Patterned mask rel. efficiency [%]

ML tuning [1]

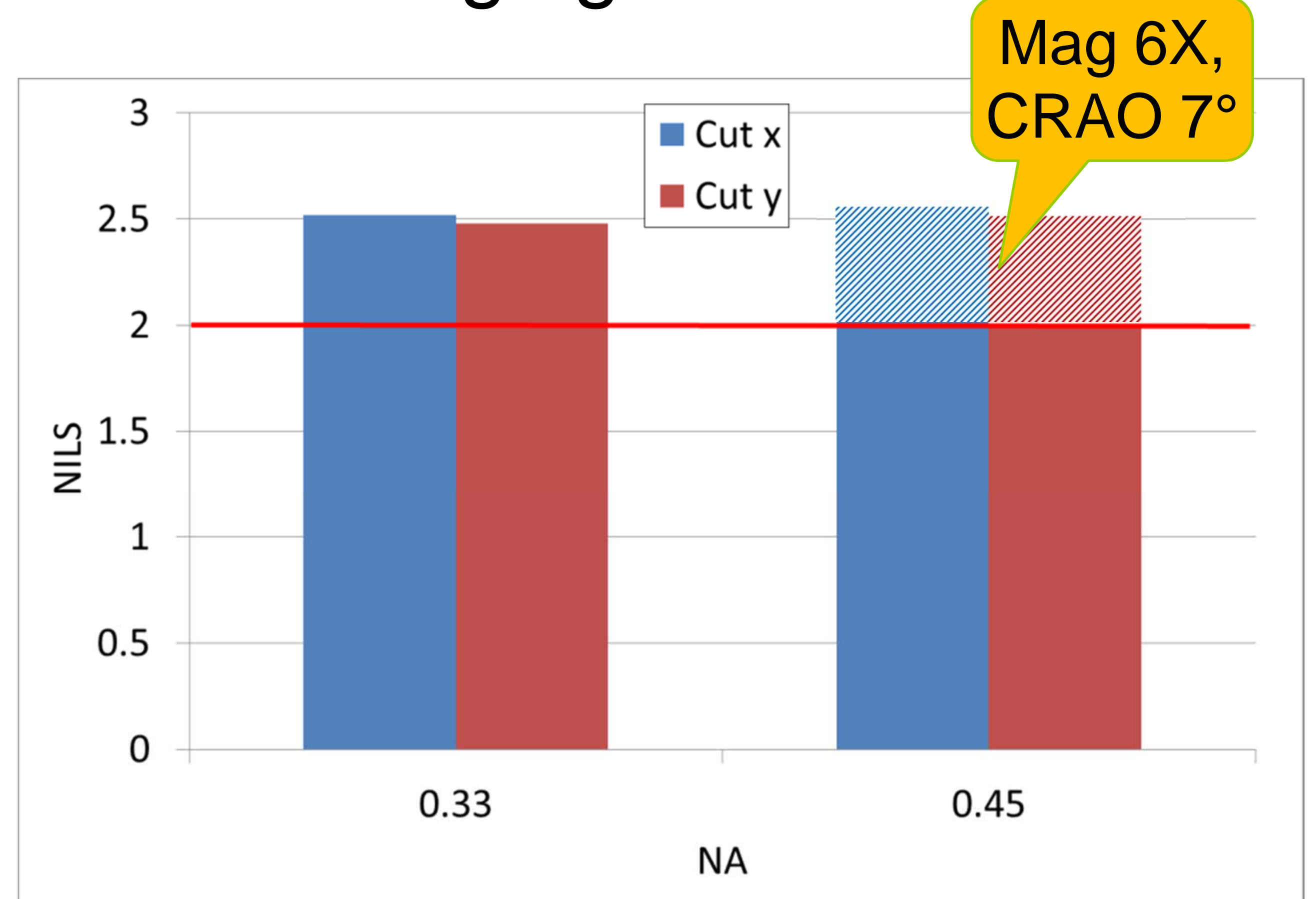


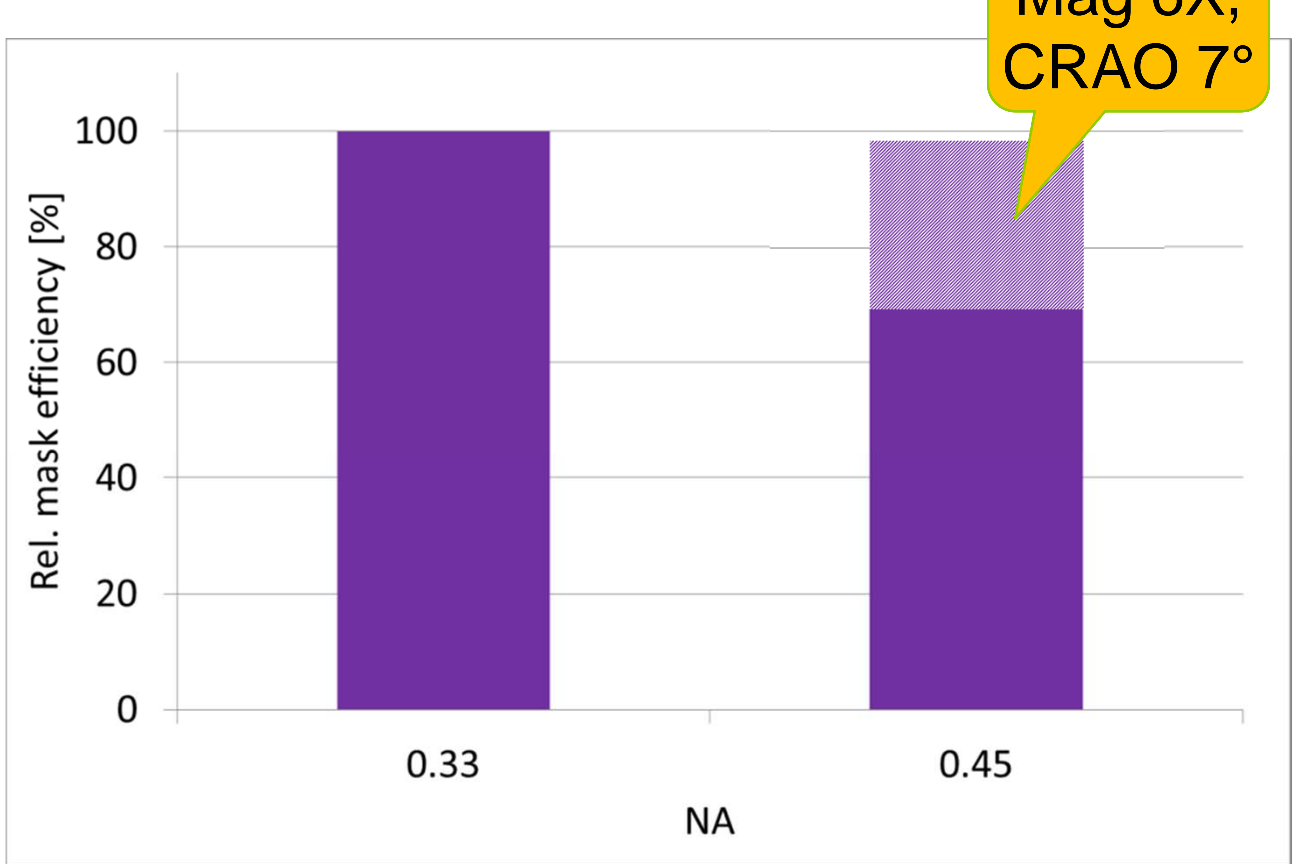
	NA [1]	CRAO [°]	Half pitch [nm]	k1 [1]
●	0.33	6	13	0.32
▶	0.45	9	9.5	0.32

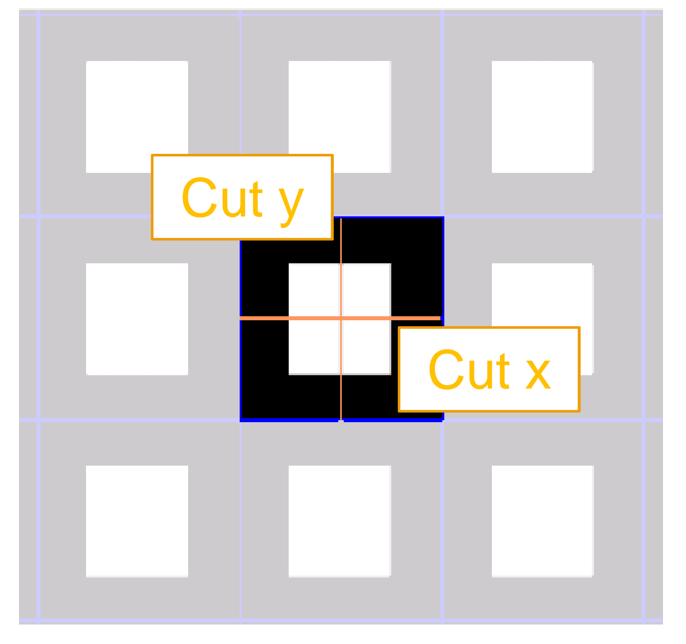
Dense contacts @ NA 0.45, CRAO 9°:

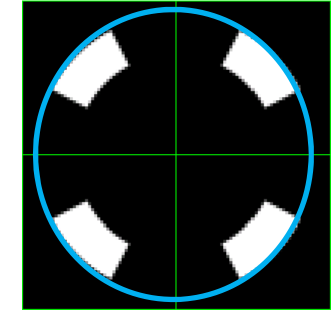
NILS = 2, but reflectivity drops to 70% of reference case.

Good imaging and efficiency for mag 6X (reduced angles).









NA [1]	CRAO [°]	Half pitch [nm]	k1 [1]	ML tuning f [1]
0.33	6	19	0.46	1.00
0.45	9	14	0.46	1.03

High NA EUVL – There is a wide solution space.

Mask size

9“

7“

6“

FF 6x

HF 8x

6M

8M

FF 5x

FF 4x

HF 5x

QF 8x

QF 8x

Considered options

0.45

0.50

0.55

0.60

NA

Example options high NA:
Need to assess the options and make the right choice.

	unit	6M			8M
		Full Field	Half Field	Quarter Field	Quarter Field
System specifications					
NA		0.45	> 0.45	0.50	0.60
magnification		6x	5x	8x	8x
CRAO		6° - 7°	7°	6°	6° - 7°
relative transmission	3300=100%	100%	80%	100%	< 40%
mask size	inch	9	6	6	6
min. pupil fill ratio (etendue limit)		9%	12%	15%	10%
scan field	mm x mm	26 x 33	16.5 x 26	13 x 16.5	13 x 16.5
scan direction					
Resolution (NILS=2 - Aerial Image)					
resolution limit L&S (PFR=16%)	nm	8.9	8.5	8.0	7.2
resolution limit CH (PFR=20%)	nm	11.8	11.2	10.7	9.1

Conclusions

Our judgment: CRAO $\lesssim$ 7°

Higher NA in EUV are feasible (all designs have central obscuration)
~ 0.45 NA for 6 mirrors.
~ 0.6 NA for 8 mirrors.

CRAO limit drives larger demagnification for higher NA.
Due to 3D mask effects and based on current mask technology the min half pitch at mask level will be limited to > 50 nm (~ 13 nm @ wafer level, 4X).

Larger demagnification eases mask specs.
(CDU, registration, defects, surface flatness (quadratic!)).

Larger demagnification reduces scan field size.
Restoring field size would require larger masks (7" or 9") - infrastructure build up would need industry initiative and consensus.
Current baseline for us is 6" mask.

Acknowledgements

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  - Vicky Philipsen
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  - Natalia Davydova
  - Steve Hansen
  - Bill Arnold

We make it visible.