Lithography for 32nm Half Pitch

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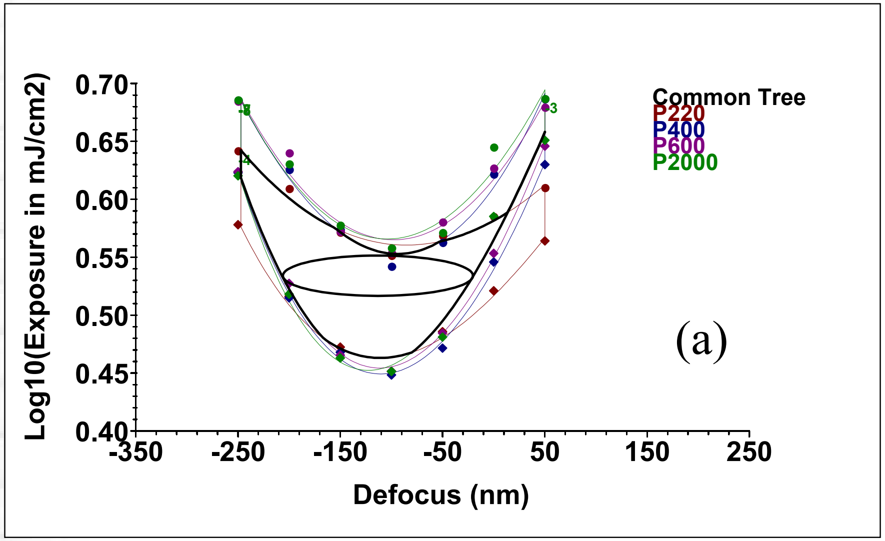
Introduction

- Water immersion at 1.35 NA can barely support 32nm node at 45nm half pitch.
- Litho technology for 22nm node at 32nm half pitch is not settled.
- We will discuss 4 possibilities here
  - *Water immersion and pitch splitting*
  - *High-index fluid immersion*
  - *Extreme ultra violet lithography*
  - *Multi-e-beam direct write*

Status of 193nm Immersion Lithography

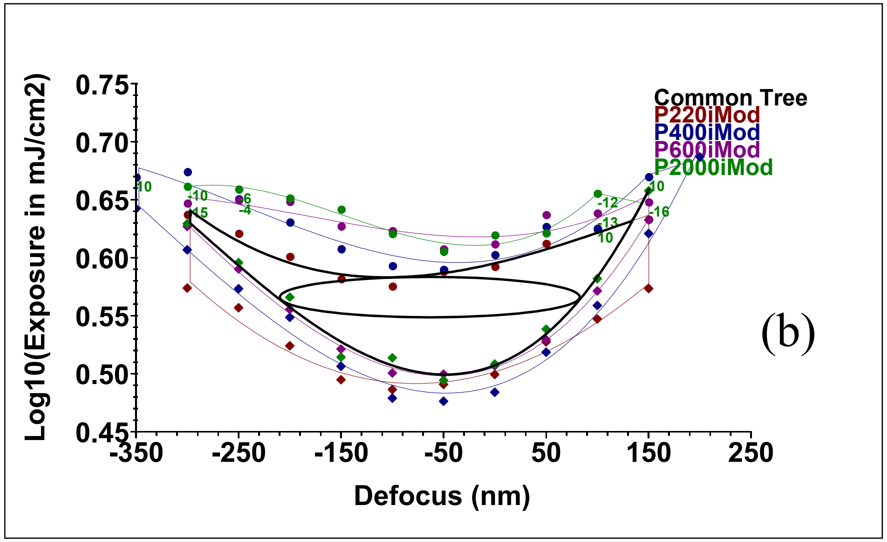
DOF of Contact Holes



0.85NA 0.8σ, OPC
110nm CD ± 11nm
Pitches: 220, 400, 600, 2000 nm

193nm dry
DOF 186 nm, Elat 8%

193nm immersion
DOF 293 nm, Elat 8%



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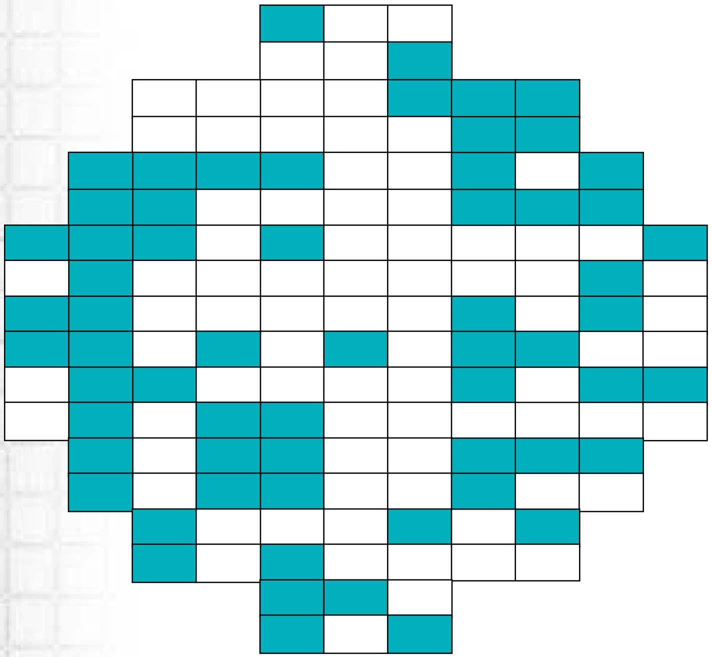
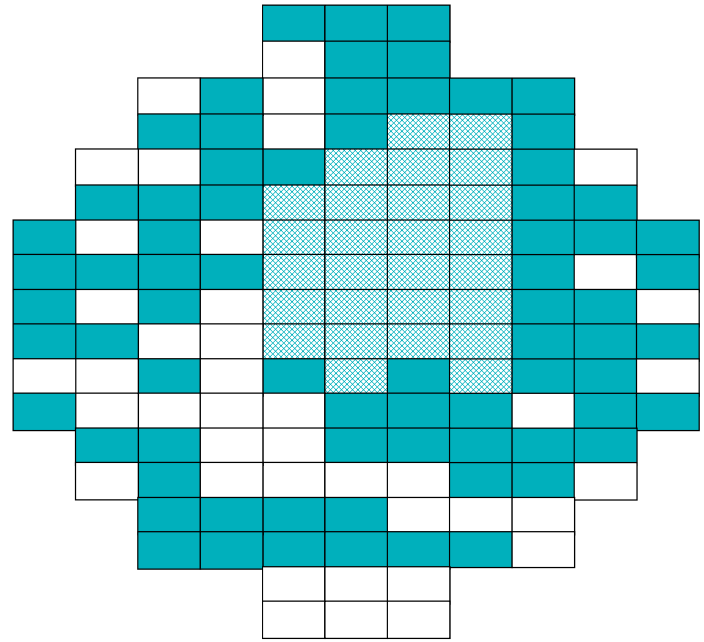
65-nm SRAM Immersion Yield from R&D Lot

Better than dry despite higher inter-metal defect level



Good die: 62
Bad die: 80

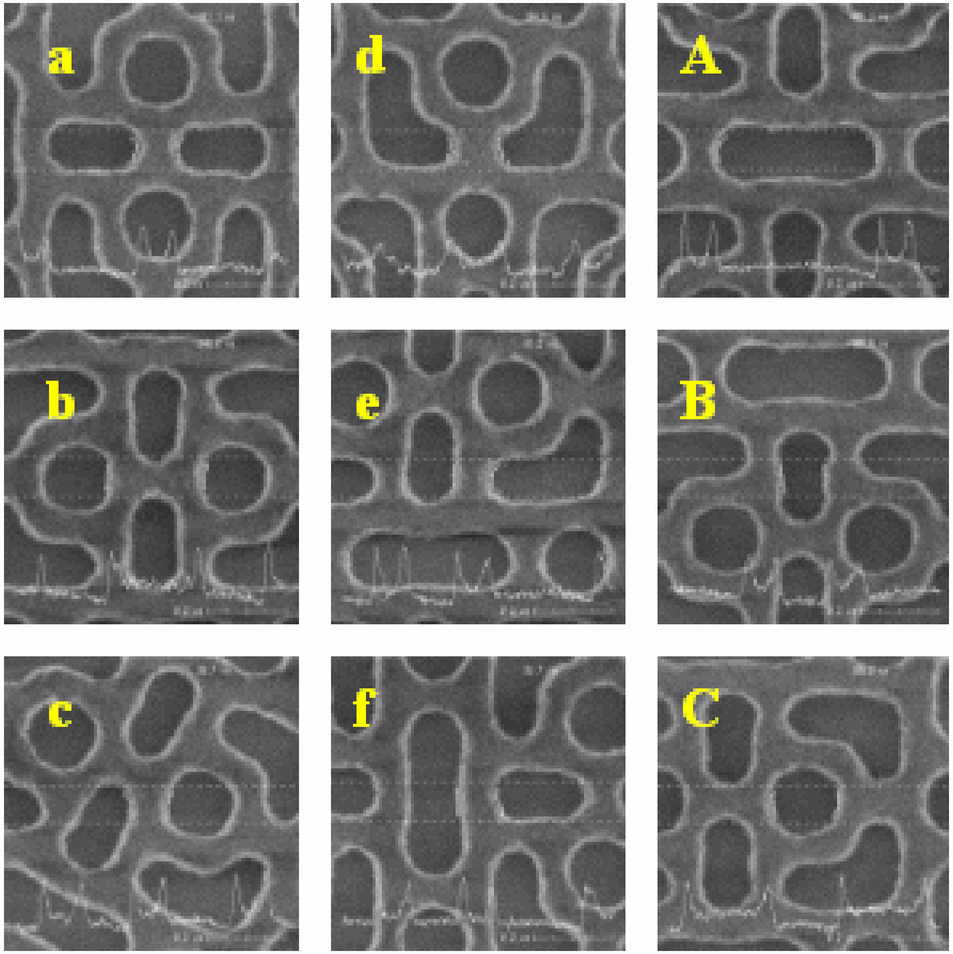


Good die: 72
NPD die: 27
Bad die: 43

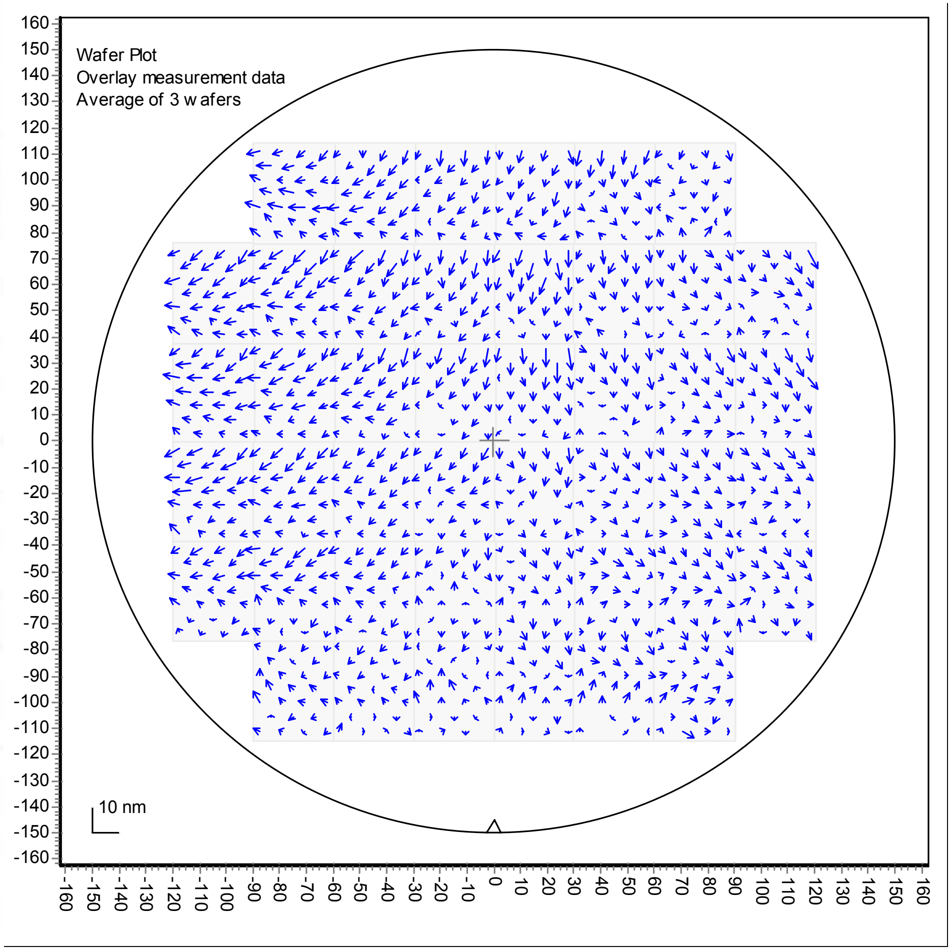
NPD: Non-Photo Damaged

$0.4\mu m^2$ 55-nm SRAM Metal Layer

- Delineated with a 0.85NA Immersion Scanner



Overlay Accuracy on I250i

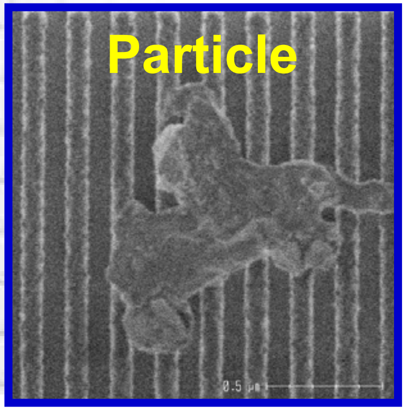


Single machine overlay
Raw: x 8.2, y 9.7

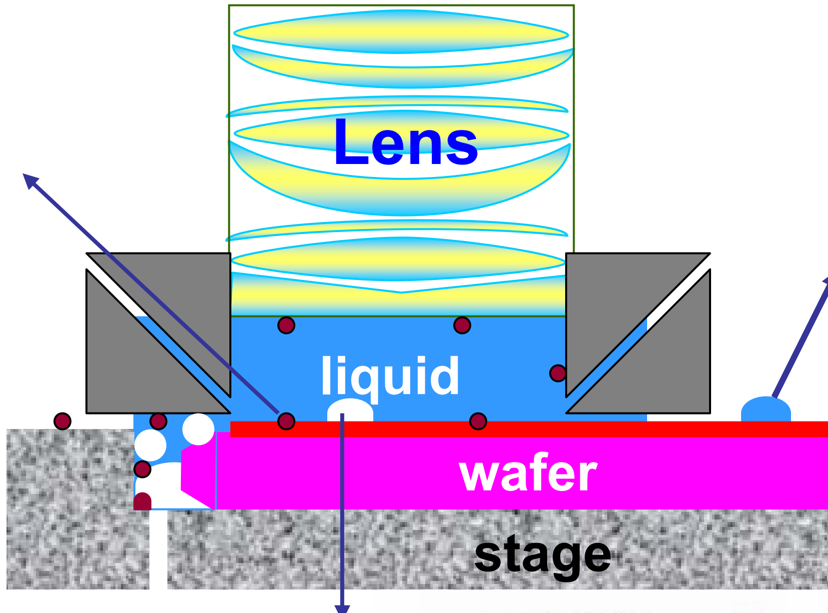
Sept. 2005

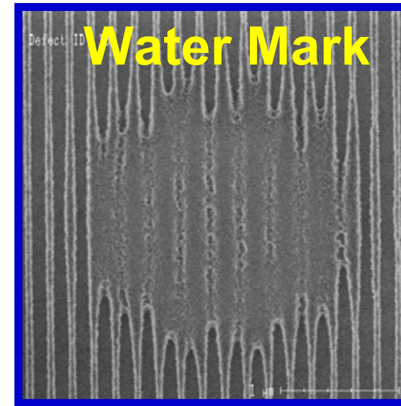
Immersion Defect Reduction

Cause and Solution of Immersion Defects

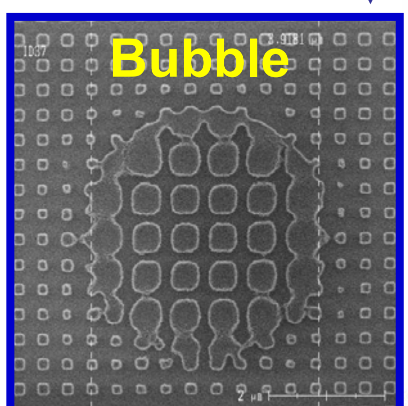


- cross contamination (tool/material)
- seal ring solution
- tsmc surfactant
- stage/lens clean

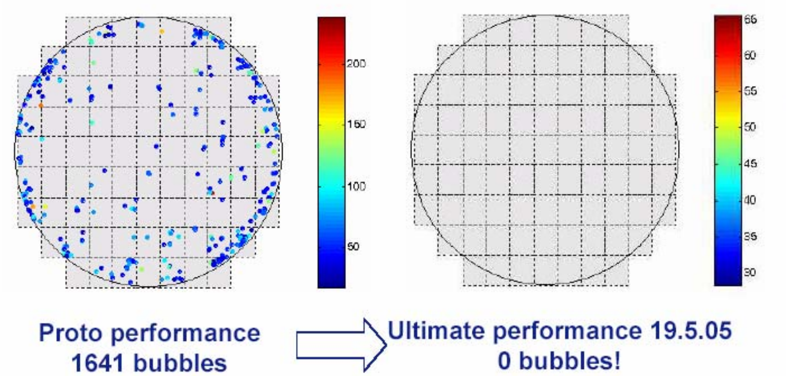




- new IH design
- new process
- new material

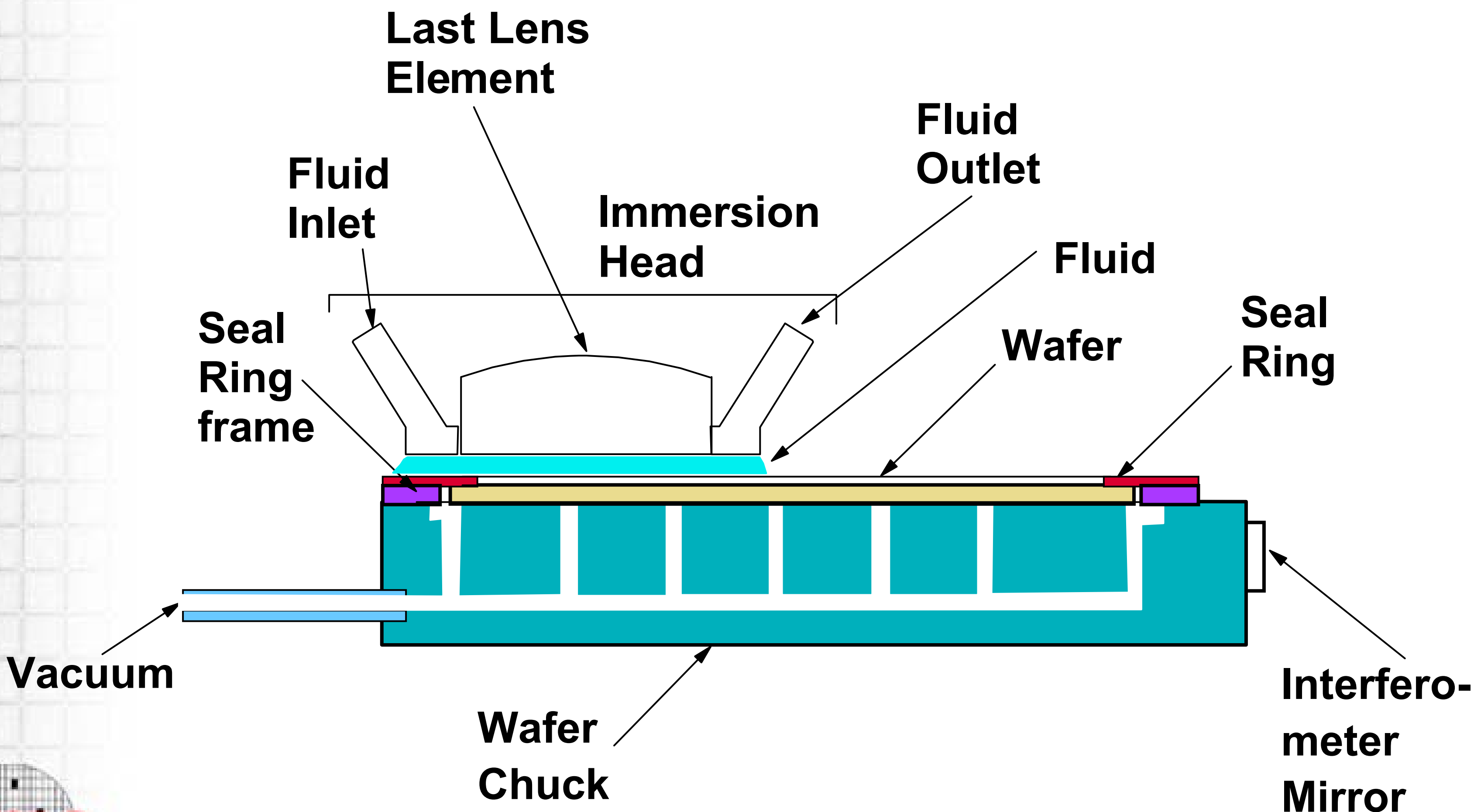


- stage gap induced
- seal ring solution

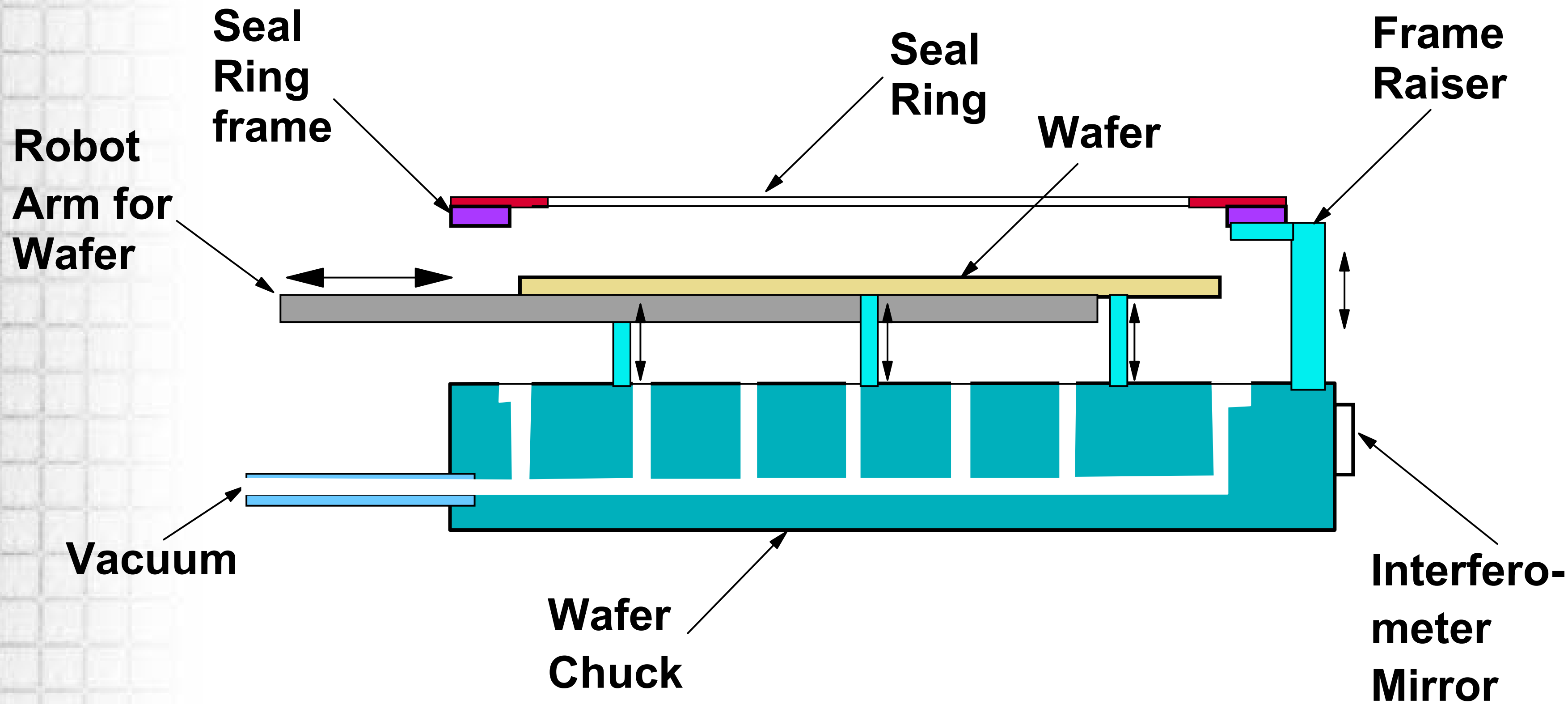


•KLA inspection of i2 demo wafers @ TSMC shows NO bubbles

Wafer Edge Seal Ring



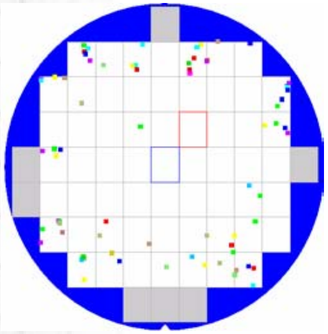
Wafer-Edge Seal Ring and Support during Wafer Load/Unload



Immersion Defect Study By Multiple Exposures

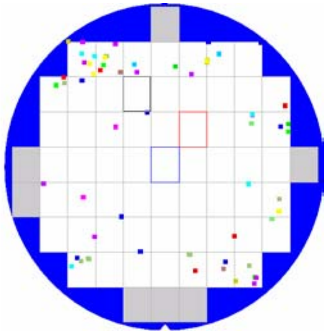
39 mJ/cm^2

Defect count: 85



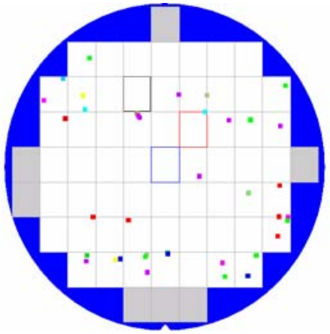
31.2+7.8 mJ/cm^2

Defect count: 72



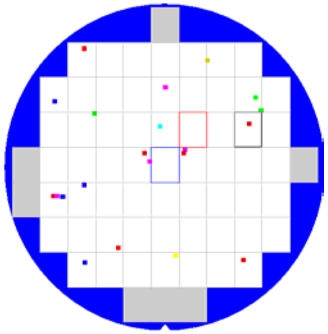
23.4+7.8*2 mJ/cm^2

Defect count: 46



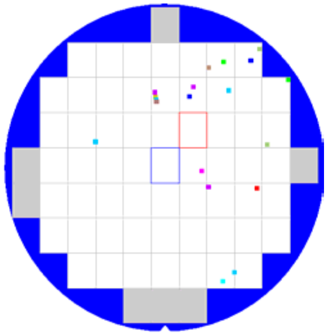
15.6+7.8*3 mJ/cm^2

Defect count: 23

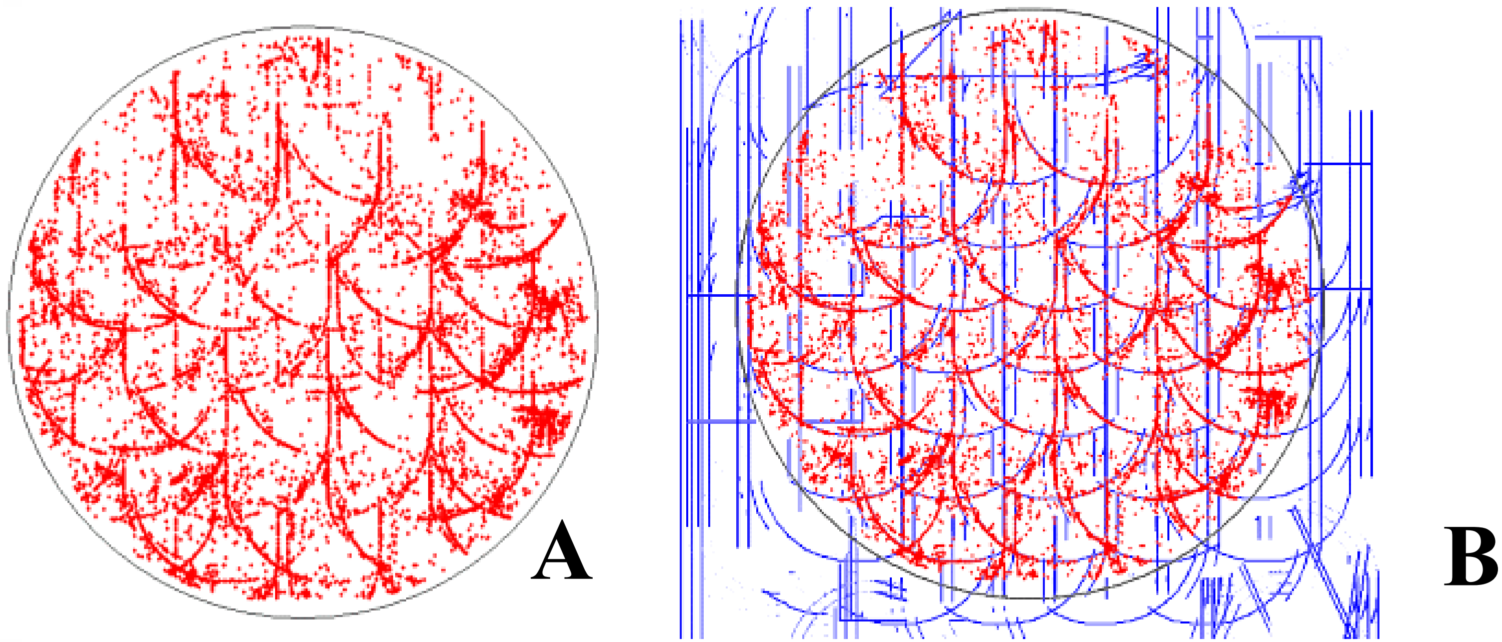


7.8*5 mJ/cm^2

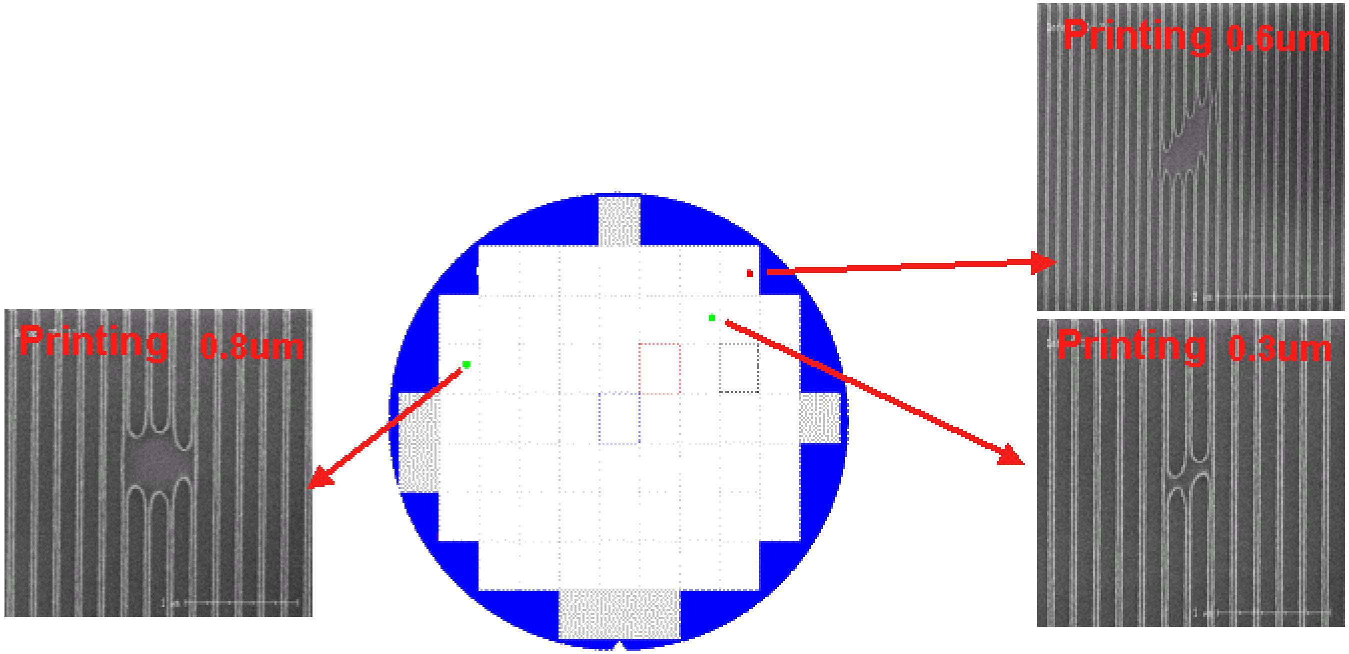
Defect count: 20



Accumulated Defect Distribution from 20 Bare-Si Test Wafers



Immersion wafer defect map



- Champion data shows 3 defects/wafer, defect density 0.006/cm^2
- Result is repeatable and consistent

Defect Distribution in a Wafer Lot

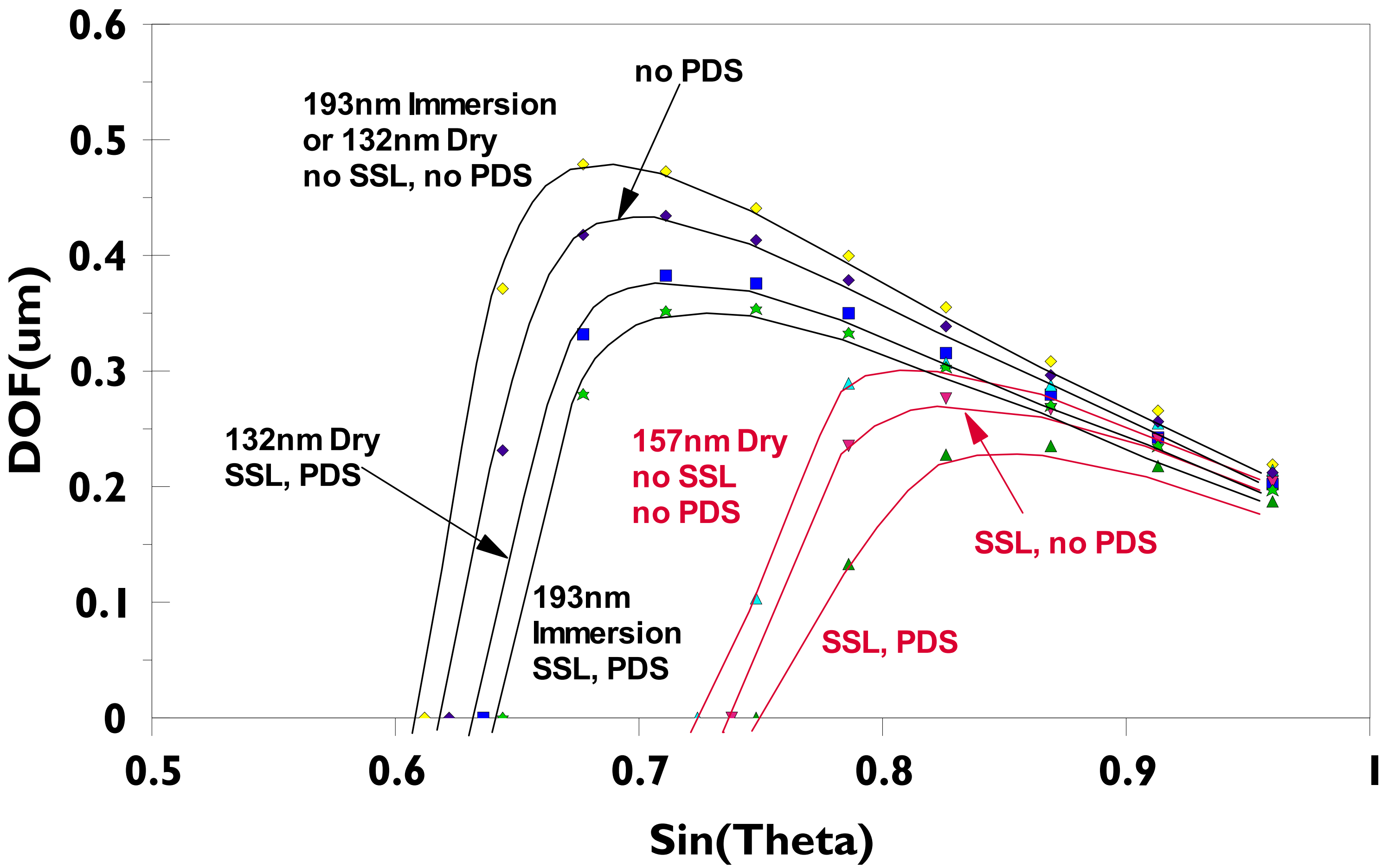
Wafer no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Printing	7	4	3	7	5	10	6	2	1	5	5	5	1	5	1	3	5	5	7	1	1	3	7		4
Bubble		1										1						1		1			1		
Fall on			1	1	1								1				1	1				1	4		
Water Mark								1																	
Pattern Failed																								1	
Immersion Defects	**7**	**5**	**4**	**8**	**6**	**10**	**6**	**3**	**1**	**5**	**5**	**6**	**2**	**5**	**1**	**3**	**6**	**7**	**7**	**2**	**1**	**4**	**12**	**1**	**4**

Mean	**4.8**

3σ	**8.5**

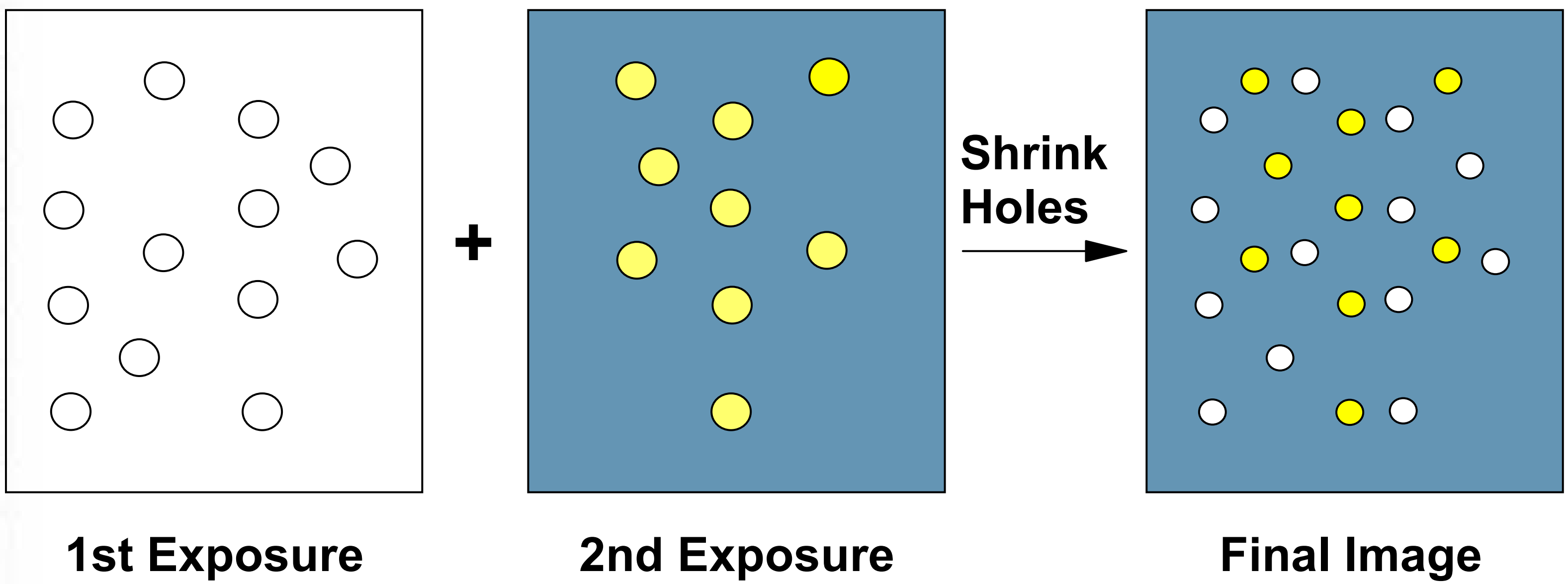
Extending 193nm Lithography

Polarization-Dependent and System Stray Lights

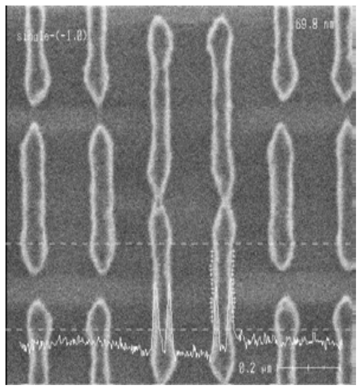
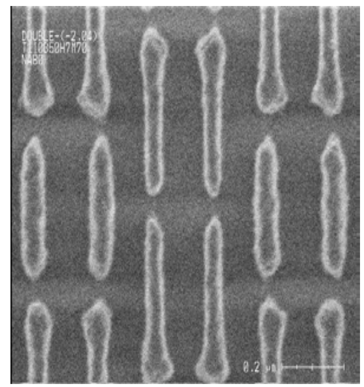
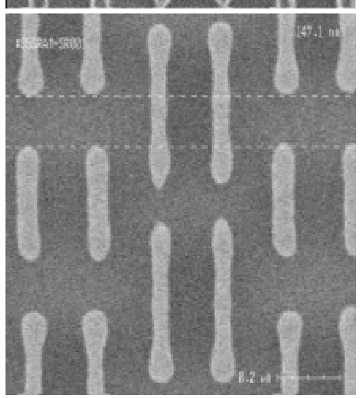
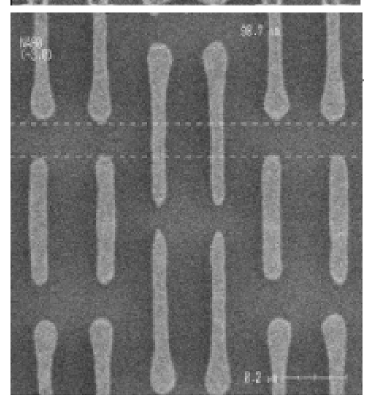
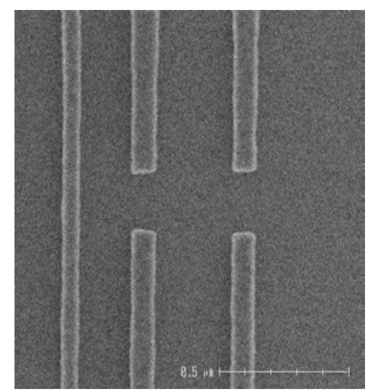


PDS from 157nm, and 132nm dry, as well as 193 immersion, 65nm lines, 65nm openings, σ=0.82, 8% exposure latitude, n_{water}=1.46, n_{resist}=1.75, CD tolerance = ¡ Ó0%, SSL=10%.

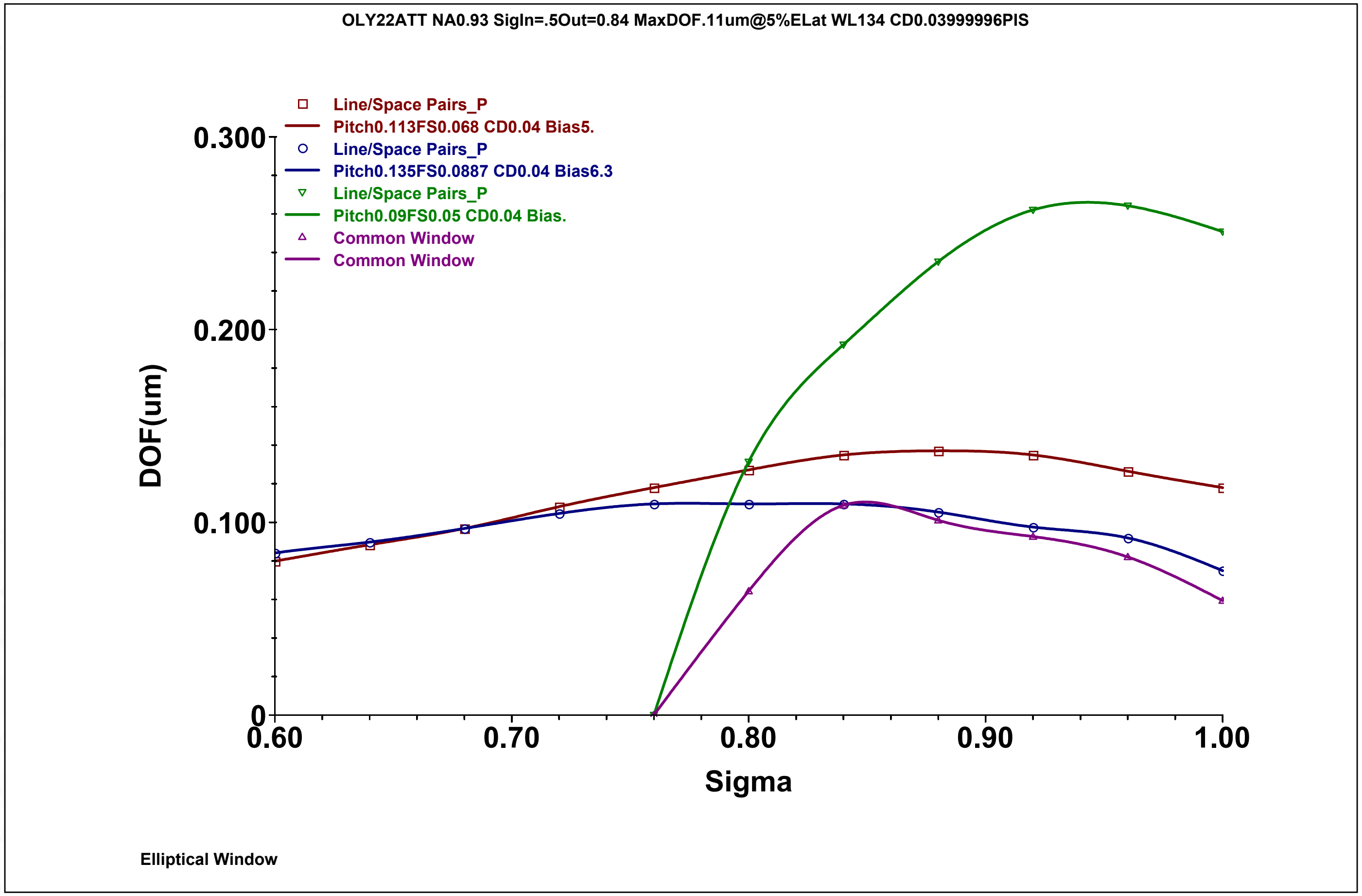
Pitch Splitting



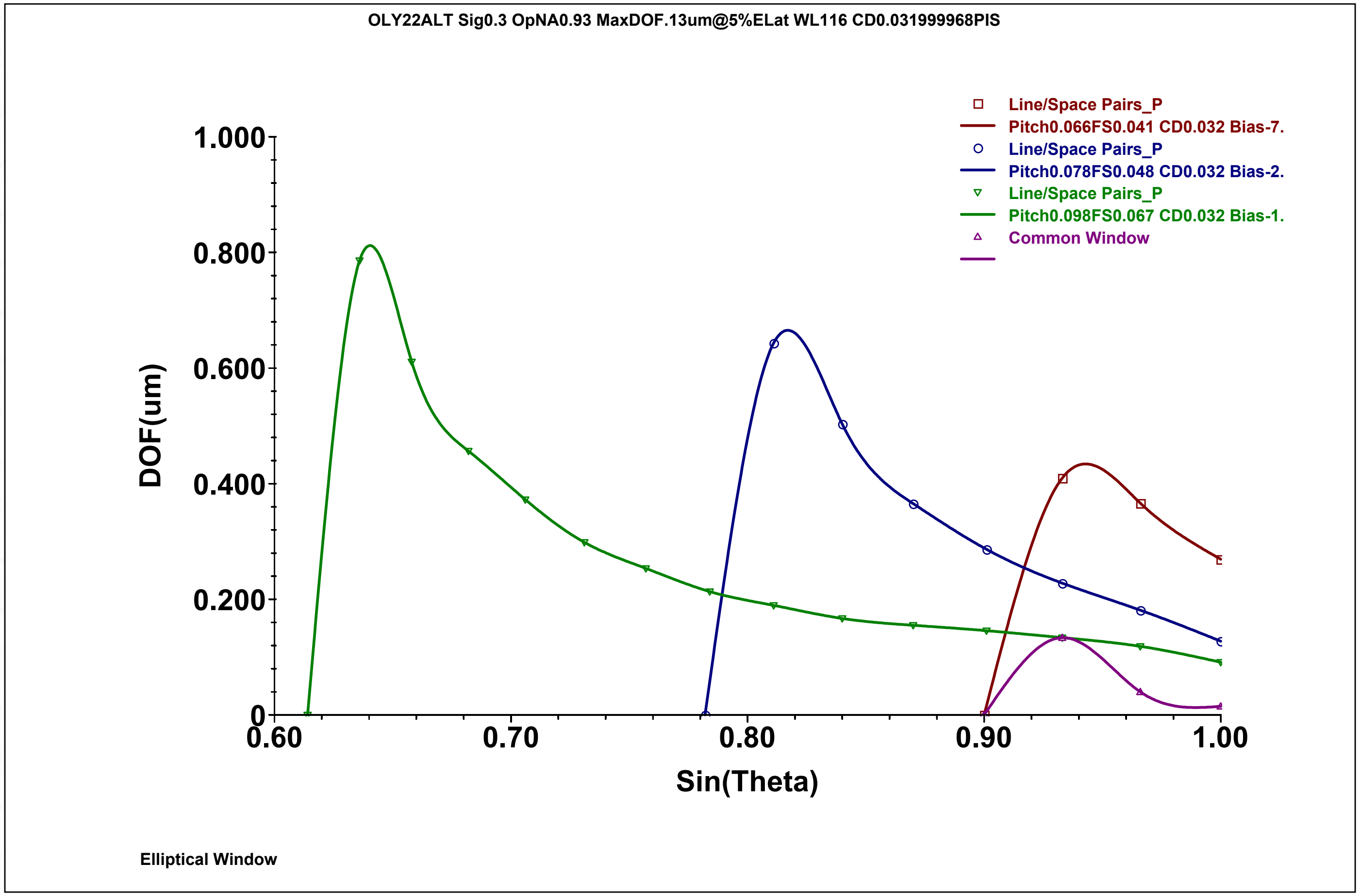
Better End Caps With Double Exposures

	Single exposure	Double exposures in resist	Double exposures through etch.
ADI			2 coatings 2 exposures 2 developments 2 etches
AEI			

DOF of AttPSM Using Water Immersion and Double Patterning



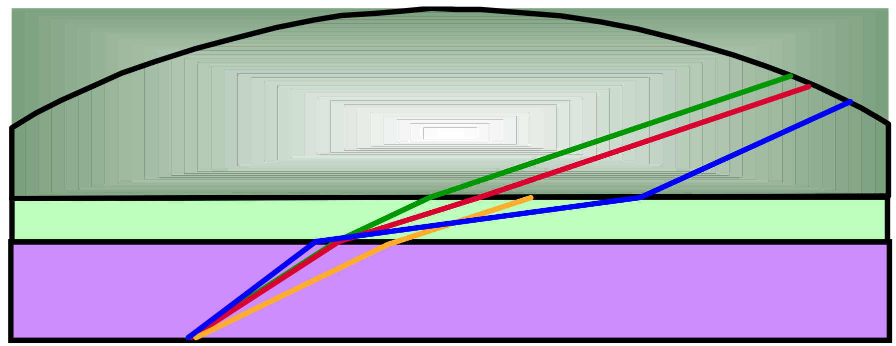
DOF of AltPSM Using High Index Fluid and Single Exposure



High-Index Materials

Impact of Fluid Index

n_{quartz}= 1.56
n_{resist} = 1.75



n_{fluid}= 1.44, sinθ_{fluid}= 0.99, NA = 1.425 (blue line)

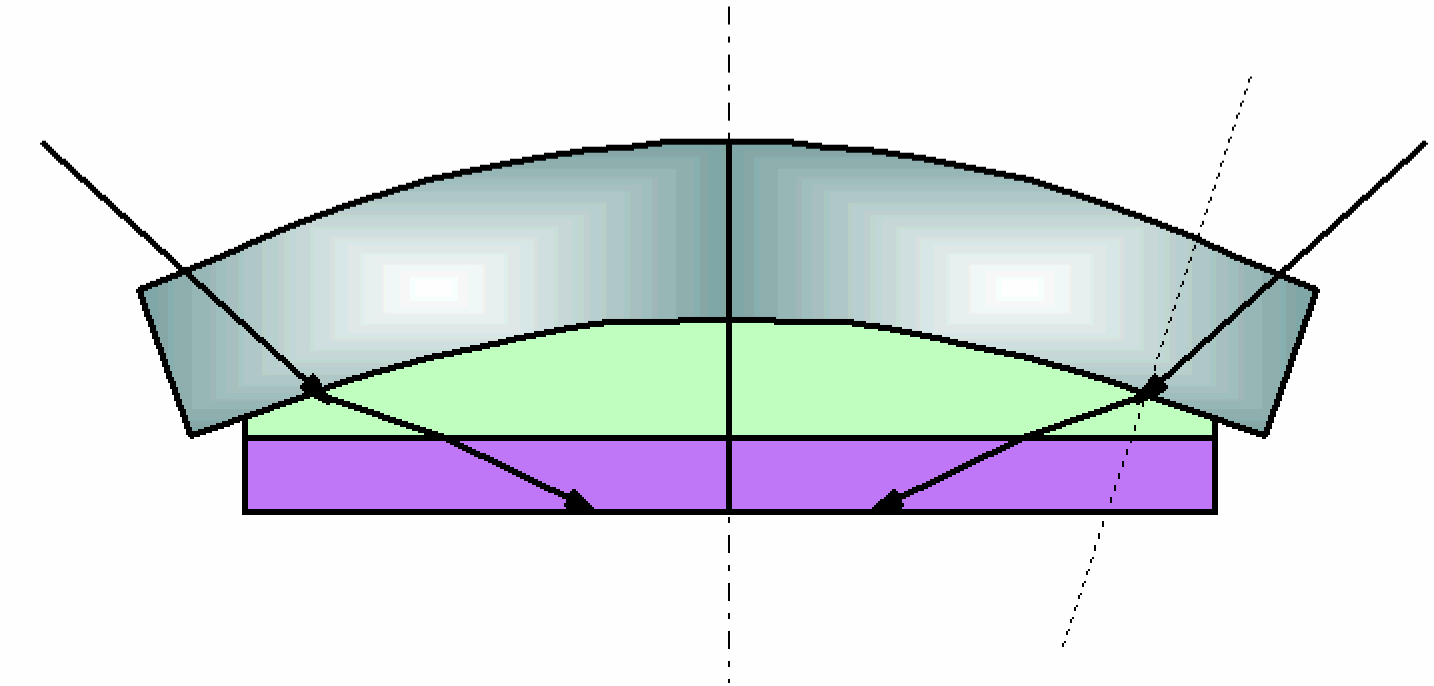
n_{fluid}= 1.56, sinθ_{lens}= 0.95, NA = 1.482 (red line)

n_{fluid}= 1.66, sinθ_{lens}= 0.89, NA = 1.482 (green line)

n_{fluid}= 1.66, sinθ_{fluid}= 0.95, NA = 1.576 (orange line)

n_{fluid}= 1.44, sinθ_{fluid}= 0.95, NA = 1.368

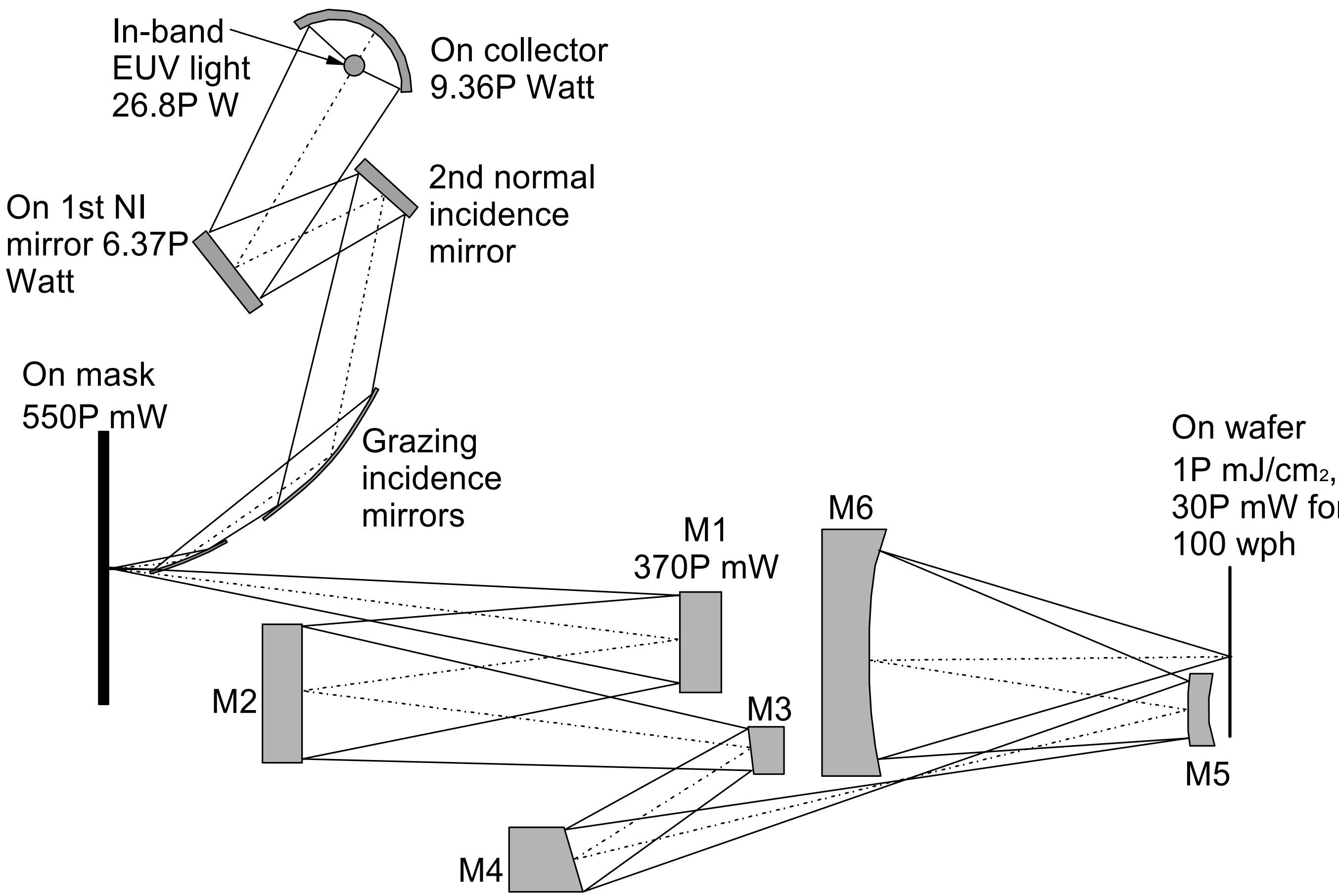
Curved Lens Interface to Sustain Hyper NA



- Uneven fluid thickness puts severe demand on optical transmission of fluid.
- High-index lens material is needed to maintain a flat surface for the last element.

EUV Lithography

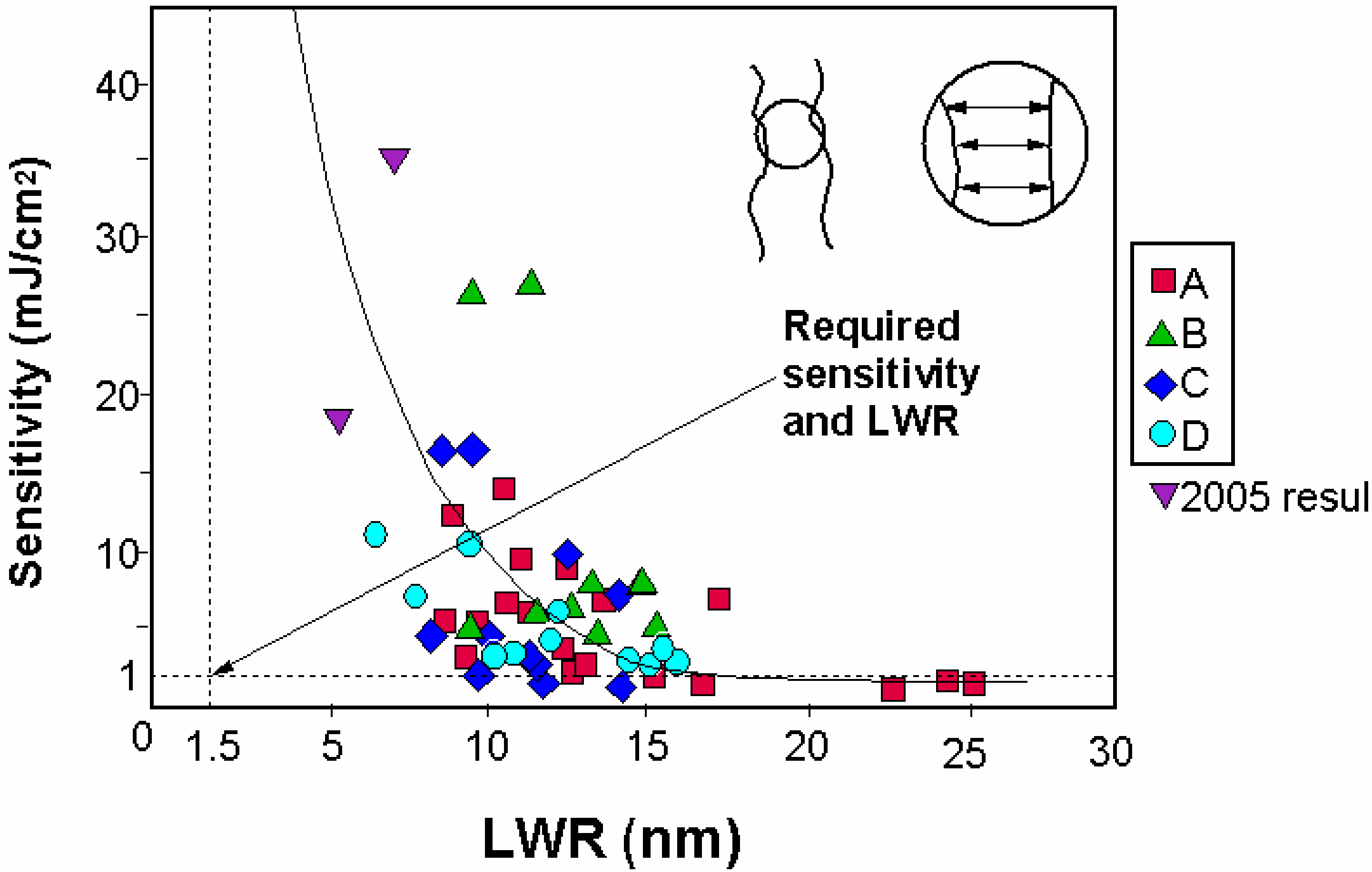
EUV Illuminator and Imaging Lens



EUV Power At Each Component

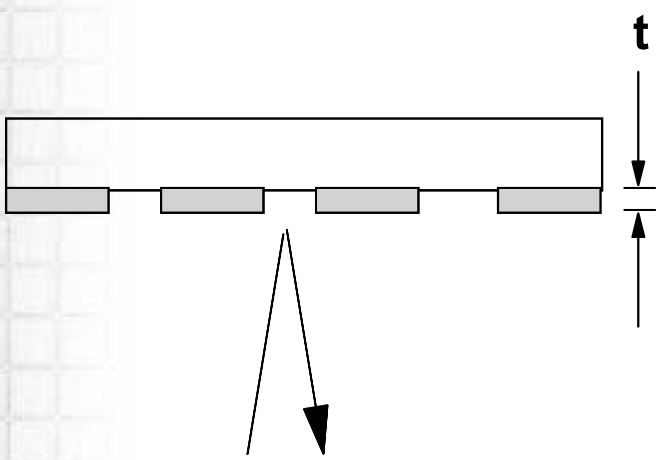
resist dosage (mJ/cm2)	1	2	5	10	20	30	50
wattage for 100 wph	0.030	0.060	0.15	0.30	0.60	0.90	1.50
before BW mismatch (W)	0.033	0.066	0.17	0.33	0.66	1.00	1.66
before propag. atten. (W)	0.037	0.074	0.18	0.37	0.74	1.11	1.85
before 6 NI mirrors (W)	0.37	0.75	1.87	3.73	7.47	11.2	18.7
on mask (W)	0.55	1.10	2.75	5.49	11.0	16.5	27.5
before BW mismatch (W)	0.61	1.22	3.05	6.10	12.2	18.3	30.5
before propagation (W)	0.68	1.36	3.39	6.78	13.6	20.3	33.9
before light integrator (W)	1.88	3.77	9.42	18.8	37.7	56.5	94.2
before 2 GI mirrors (W)	2.94	5.89	14.7	29.4	58.9	88.3	147
before 2 NI mirrors (W)	6.36	12.7	31.8	63.6	127	191	318
on collector (W)	9.4	18.7	46.8	93.6	187	281	468
spread into 2pi sr (W)	13.4	26.7	66.9	134	267	401	669
in-band 2pi sr (W) (before debris mitigation)	26.7	53.5	134	267	535	802	1,337

Tradeoff between sensitivity and LWR

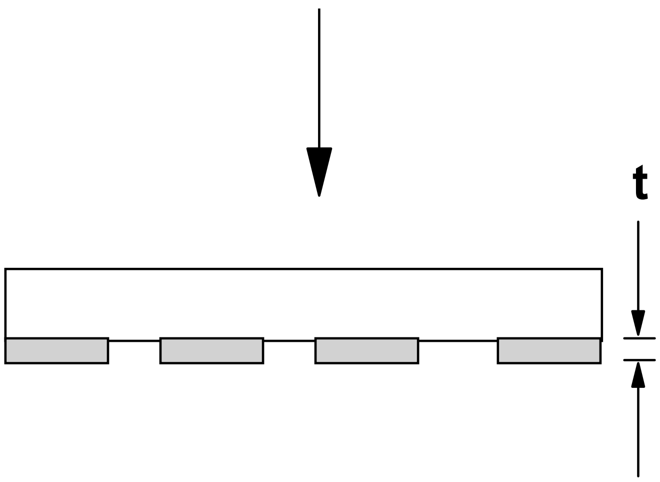


Meilings et al, SPIE Proceedings,
vols. 5374 and 5751.

Vertical Sensitivity 4X Higher for Reflective Systems



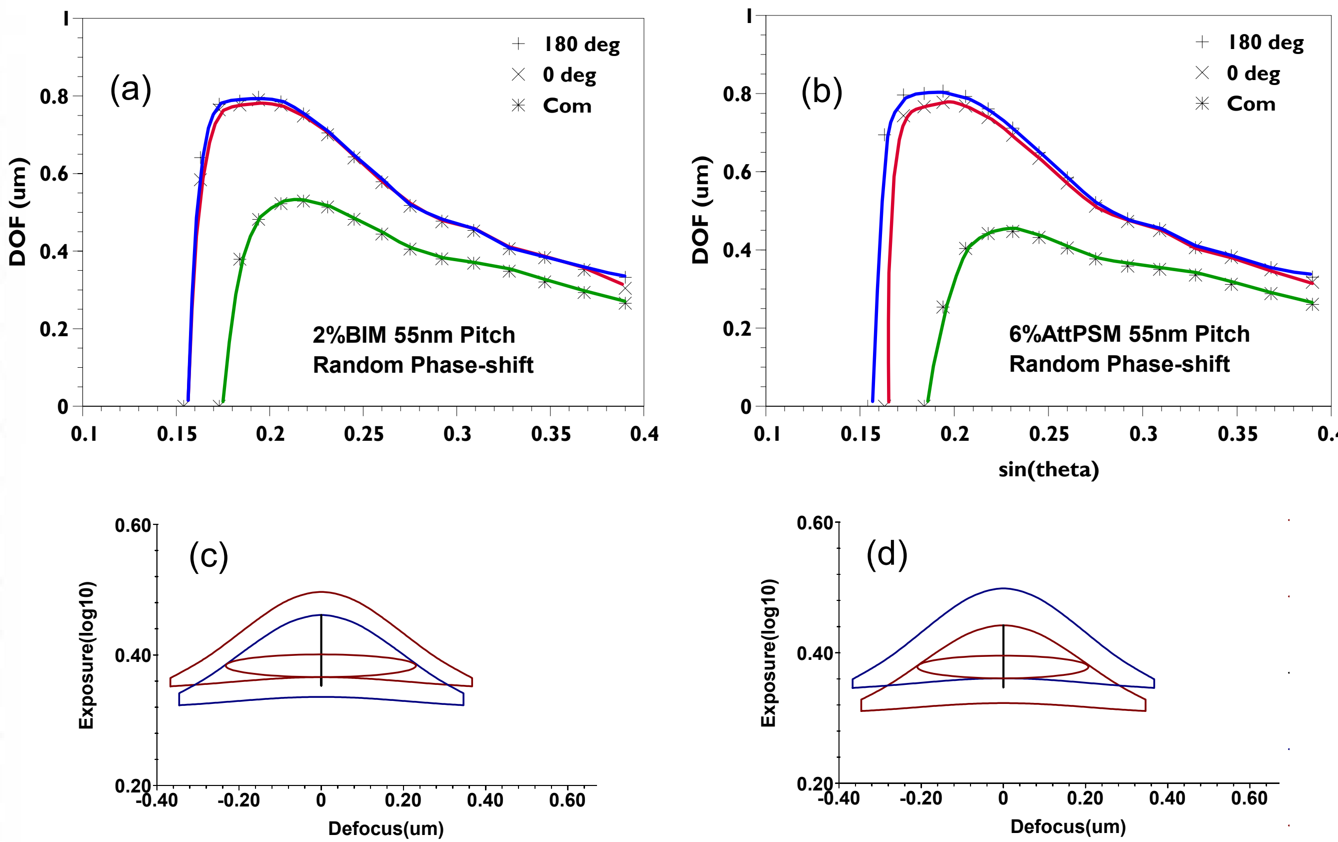
$\phi = 2t*2\pi/\lambda$



$\phi = (n-1)t*2\pi/\lambda$

DOF of (a) 2% BIM and (b) 6% AttPSM with RPS

22-nm resist line at 55-nm pitch. σ_{out}=0.76, σ_{in}=0.32, CD_{tol}=±10%, E_{lat}=8%



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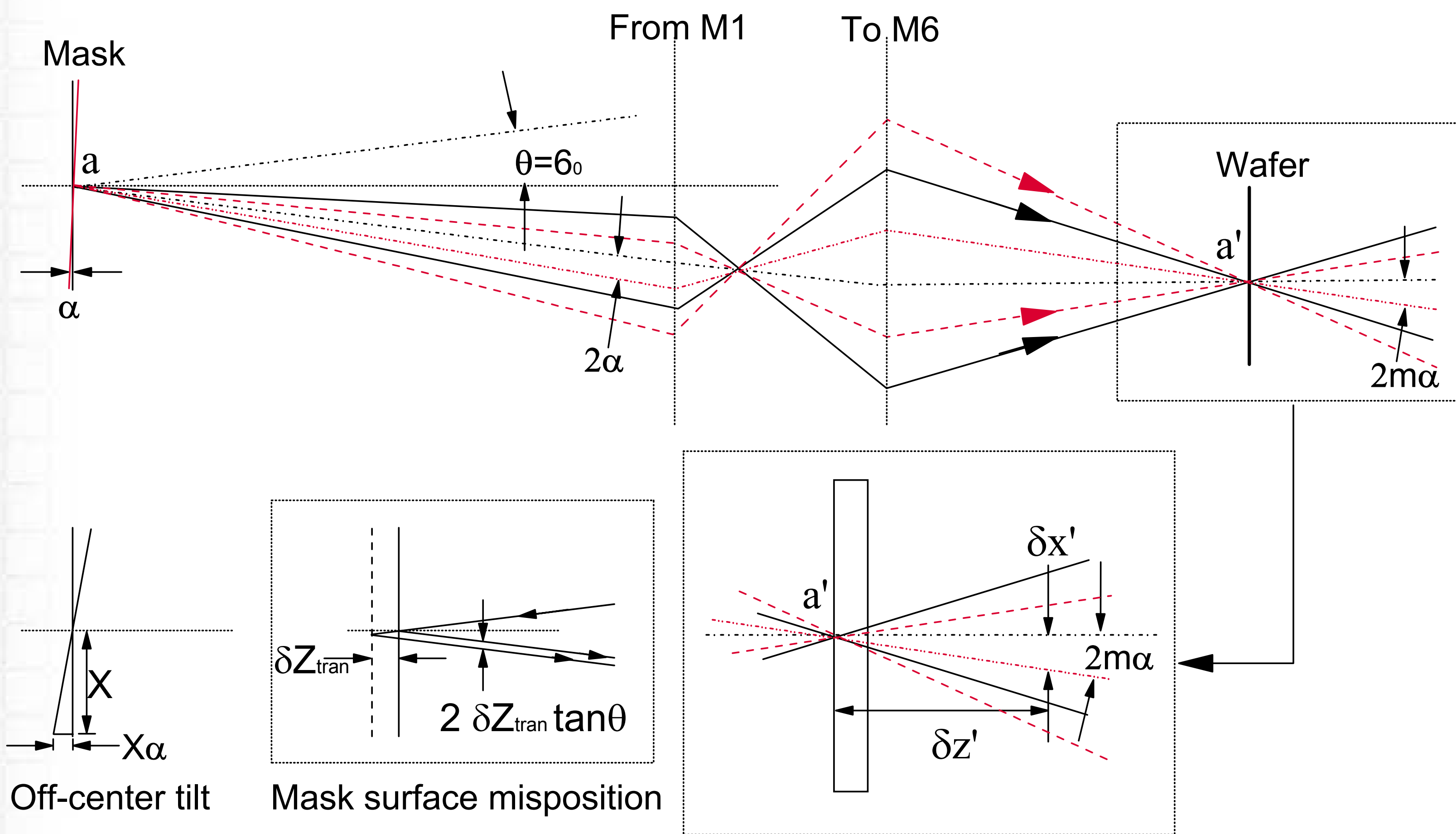
July 2006

Positioning Errors due to Mask Rotation and Translation



EUV Mask Flatness

- Let 1/3 CD be the overlay requirement and 1/3 overlay budget allocated to mask positioning error, $\Delta x' < 2.44$ nm.
- When there is no mask rotation, $\Delta z_{tran} < 46.5$ nm. Mask flatness has to be better than 46.5 nm.
- When there is mask rotation, Δz_{tran} has to be even smaller.

Summary on EUV Lithography

APPEALS

- k_1=0.59, 0.4 for 32nm, 22nm half pitches.
- Ample DOF
- Simpler OPC
- Evolutional mask writing

CHALLENGES

- Laser power/resist sensitivity/LWR impasse
- Stringent mask spec.
- Absence of pellicle
- Mask inspection and repair
- Contamination and life time of optical elements
- Atomic-precision optics
- Cost

Multiple-E-beam Direct Write

Comparison of 1X EB DW and 4X Mask Writing

1X EB DW

- CDU ±3.2 nm for 32 nm node.
- Does not have to share CDU budget with mask.
- No jigs and jugs.
- Negligible line end shortening.
- Negligible proximity correction time .

4X Mask Writing

- CDU ±3.2 nm x 4 x 60% = ±7.7 nm.
- MEF=2, CDU< ±3.9 nm
  MEF=4, CDU< ±2 nm
  MEF=10 for line ends.
- Has to control 16nm jigs and jugs and 32nm scattering bars
- Capability at 65 nm is 12 nm.

Limits of E-Beam Lithography

Aberration-Free Beam

- Scattering in resist
- Shot noise
- Incident power on resist
- Transverse thermal emission velocities
- Space charge

Solutions

- Reduce resist thickness
- Reduce resist sensitivity
- Reduce voltage or current
- Use a brighter source
- Avoid crossovers
- Spread out the electrons

Aberrated Beam

- Spherical aberration
- Astigmatism
- Chromatic
- Diffraction

Solutions

- Improve lens design/precision
- Improve lens design/precision
- Reduce energy spread
- Use higher energy beam

Shot Noise and Incident Power

- Assume 6000 electrons are required in a 32x32nm^2 area.
- At 40% pattern density, 37μC/cm^2 resist sensitivity is required.
- For the next node with 22x22nm^2 area, 79μC/cm^2.
- Assume 15 wph and 79μC/cm^2
  - *At 5keV, power incident on resist is 0.14 watt/cm^2.*
  - *At 100keV, 2.7 watt/cm^2.*

Estimated Cost of 22nm Litho Technologies

	H_2O Imm Single Pass	H_2O Imm Double Pass	EUV 40M/100	EUV 40M/20	EUV 50M/100	EUV 50M/20	MEB DW 20M/10
Expo Tool Cost (M Euro)	30	40	40	40	50	50	20
Track Cost (M JPY)	700	700	700	300	700	300	300
Raw Througput (wph)	120	200	100	20	100	20	15
Exposure cost per layer (US$)	16	31	27	126	33	156	88
Mask cost per layer (US$)	80,000	160,000	120,000	120,000	120,000	120,000	N/A
Exposure+materi al per layer (US$)	24	56	35	134	41	164	93
DW Breakeven Wafers	1,159	4,324	2,069	∞	2,308	∞	Ref
DW Breakeven Wafers after 5 yrs	19,048	∞	38,710	∞	48,000	∞	Ref

Estimation include tool utilization, availability, rework, installation, utility, laser pulse, resist, HMDS, developer, topcoat(if applicable), BARC(if applicable), and etching(if applicable)

Conclusions

- Water immersion and pitch splitting can be made to work at the expense of cost and complexity. DOF is not relieved.
- High-index fluid needs high-index lens material whose development is not trivial.
- EUV relieves DOF but still has many problems.
- MEB DW has the potential for low cost but needs much work and innovation.

End of Presentation