Optical Proximity Strategies for Desensitizing Lens Aberrations

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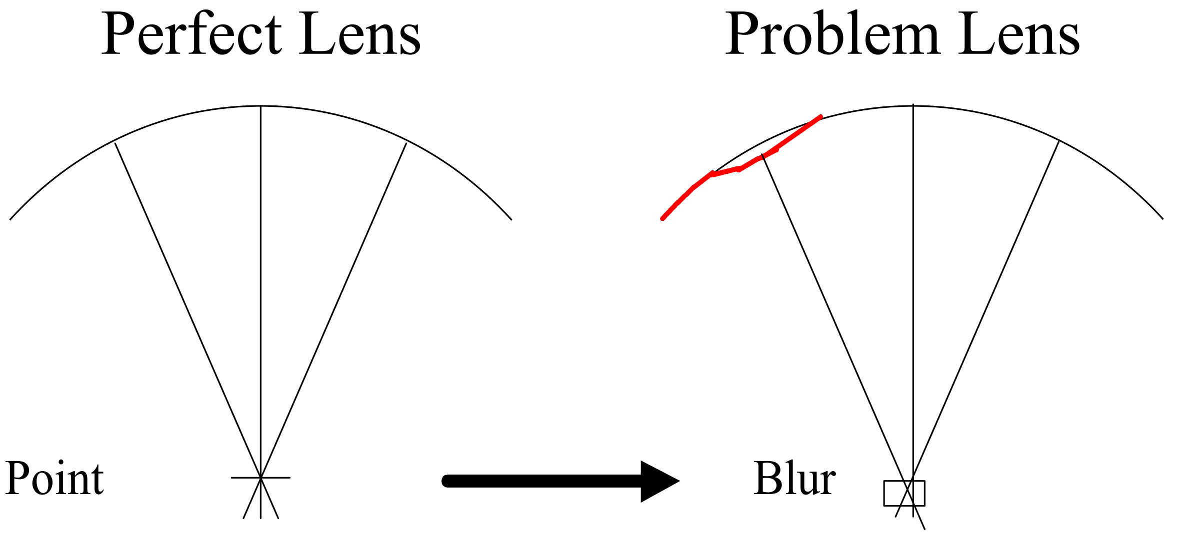
Lithography for Semiconductor Manufacturing II, June 1, 2001
Edinburgh, Scotland

Resolution Loss Contributor: Aberrations

- Aberrations blur

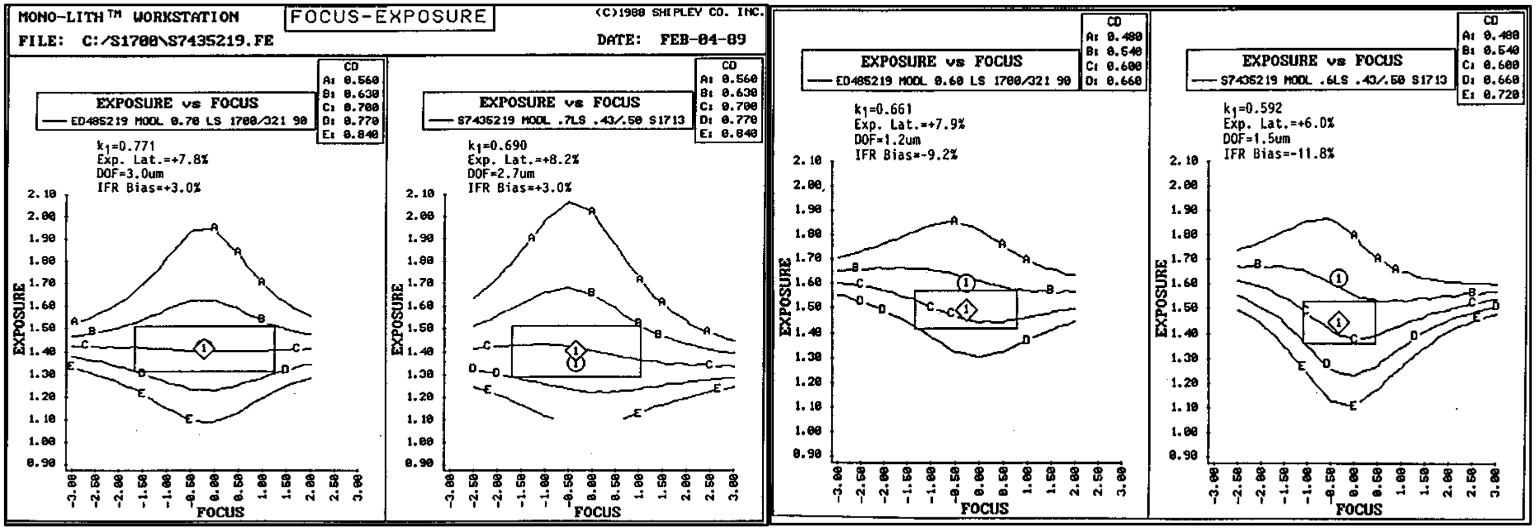


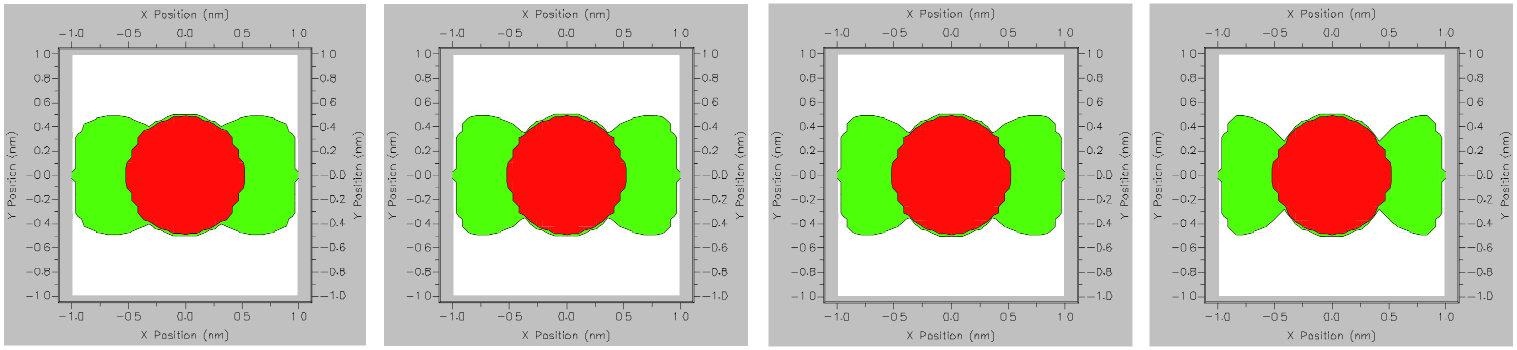
Types of Aberrations
(Seidel Aberrations)

- Monochromatic
  - Spherical
  - Coma
  - Astigmatism
  - Field of Curvature
  - Distortion
- Chromatic
- Defocus

Process Window Loss with Aberrations

k_1 0.771 0.690 0.661 0.592





Less aberration balancing

J. S. Petersen, SPIE Vol. 1088, p. 540 (1989)

Paper 4226-04, Petersen

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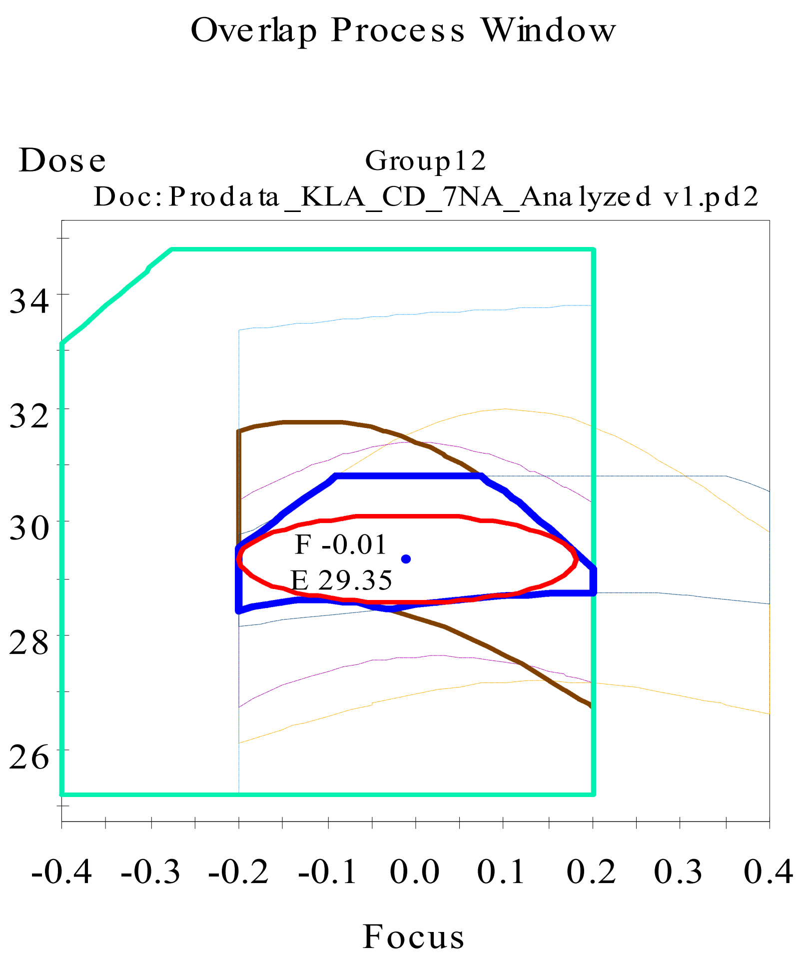
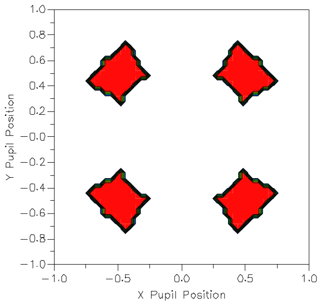
Overlapped Process Window for 0.10mm resist CD (CLM-001 results -- excluding 500 nm pitch data)



Printed by /700 in Velhoven (0.7 NA, 248 nm, 30% Quasar)

Overlapped process window:
0.4mm DOF &
>6% exposure latitude



Quasar
Illuminator

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Paper 4226-04, Petersen

Optical Extension Roadmap

Extrapolated from 248nm Experiment and Simulation

Table of Hypothetically Attainable Feature Sizes

Reduced Aberrations

l		248			193			193		
Feature		**iso**	**dense**	**CH**	**iso**	**dense**	**CH**	**iso**	**dense**	**CH**
Duty Cycle		**1:3**	**1:1**	**1:2**	**1:3**	**1:1**	**1:2**	**1:3**	**1:1**	**1:2**
NA	**0.53**	70	~~140~~	~~187~~	55	109	146	48	96	127
	0.57	65	131	~~174~~	51	102	135	44	89	119
	0.60	62	124	~~165~~	48	97	129	42	84	113
	0.63	59	118	~~157~~	46	92	123	40	80	107
	0.68	55	109	146	43	85	114	37	75	99
	0.70	53	106	142	41	83	110	36	72	97
	0.80	47	93	124	36	72	97	32	63	84
factor		0.25	0.50	0.33	0.25	0.50	0.33	0.25	0.50	0.33
nPitch (Ideal)		0.5	0.5	1.0	0.5	0.5	1.0	0.5	0.5	1.0
nPitch (Full Field)		0.6	0.6	1.2	0.6	0.6	1.2	0.53	0.53	1.05

$$feature\_size = \frac{pitch_{normalized\_Full\_Field} \cdot factor \cdot l}{NA}; factor\_from\_experiment$$

Full Field assumes 20% loss of workable resolution due to aberrations!

Blue=130nm node **Black=100nm node** **Gray=70nm node**

Paper 4226-04, Petersen

J. S. Petersen, et.al., SPIE Vol. 3564, p. 288 (1998)

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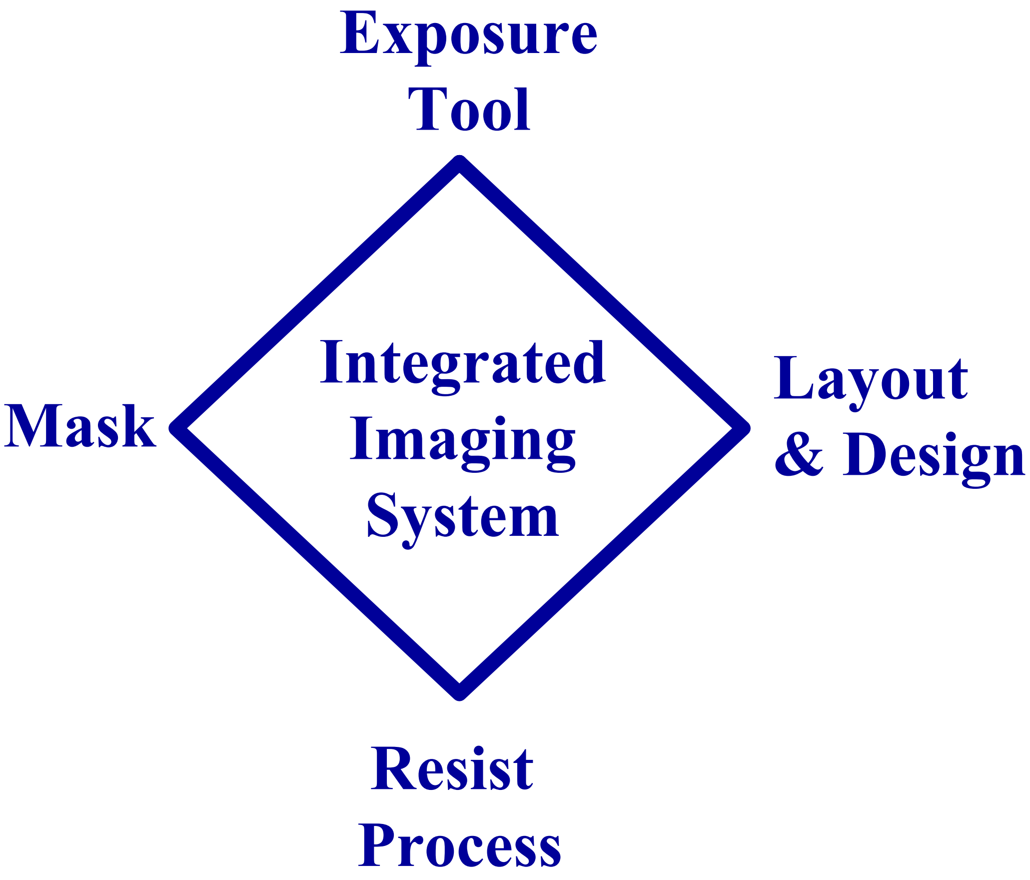
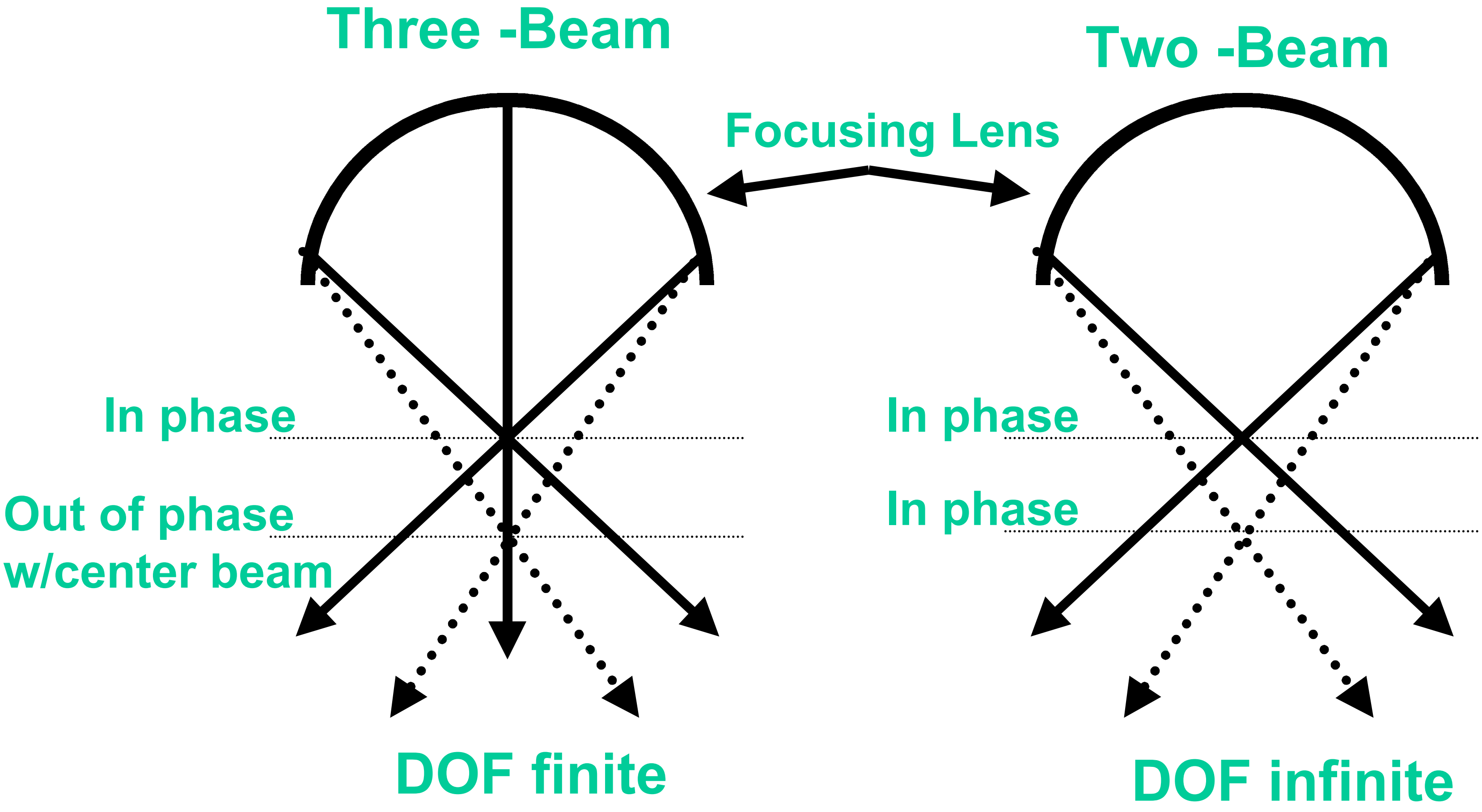
Image Process Integration Examples



Using IPI to Attack Aberrations:

- **Illuminator Shape**
- **Scattering Bars**
- **Phase-Shift Masks**

Ideal 2-Beam Imaging Has Infinite DOF



Three -Beam

Two -Beam

Focusing Lens

In phase

Out of phase w/center beam

In phase

In phase

DOF finite

DOF infinite

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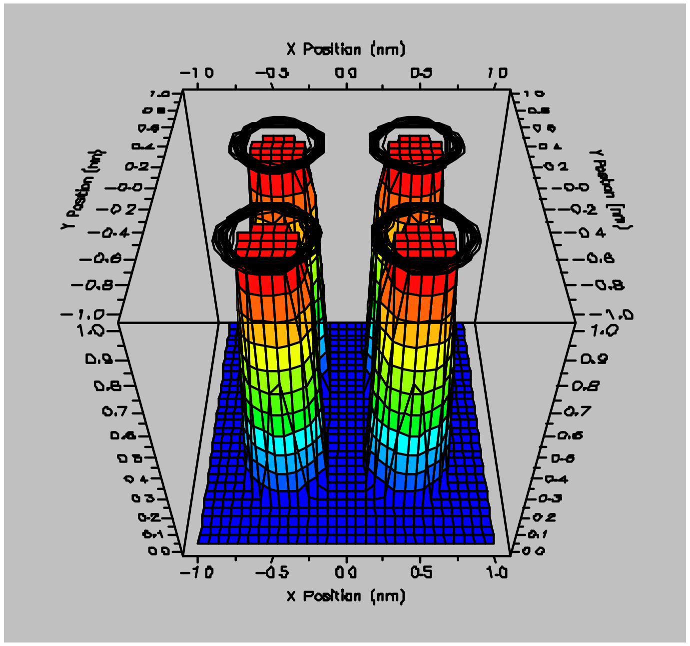
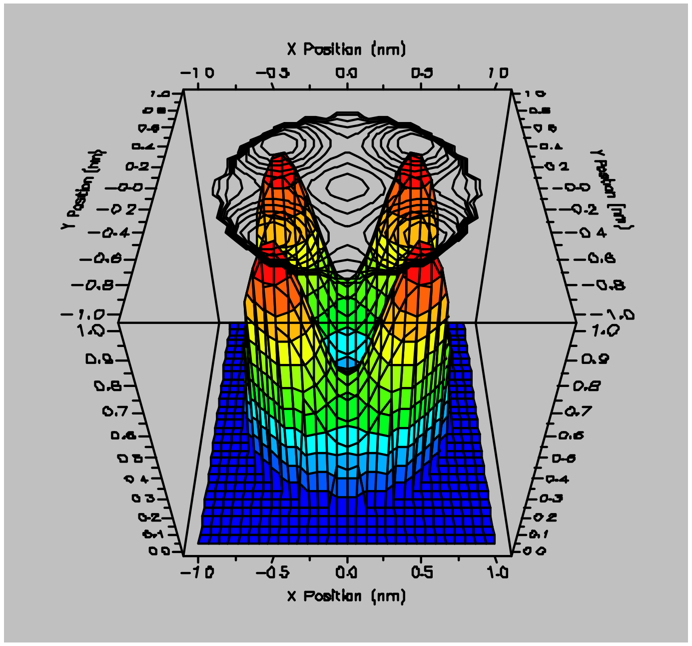
Quad Examples

Strong: 0.60 s_{center}/0.25 s_{radial}
0.74 s_{hard}



Weak: 0.60 s_{center}/0.25 s_{radial}
0.74 s_{hard}



Hard Stop not shown ↑

J. S. Petersen, et.al., <u>SPIE Vol. 3564</u>, p. 288 (1998)

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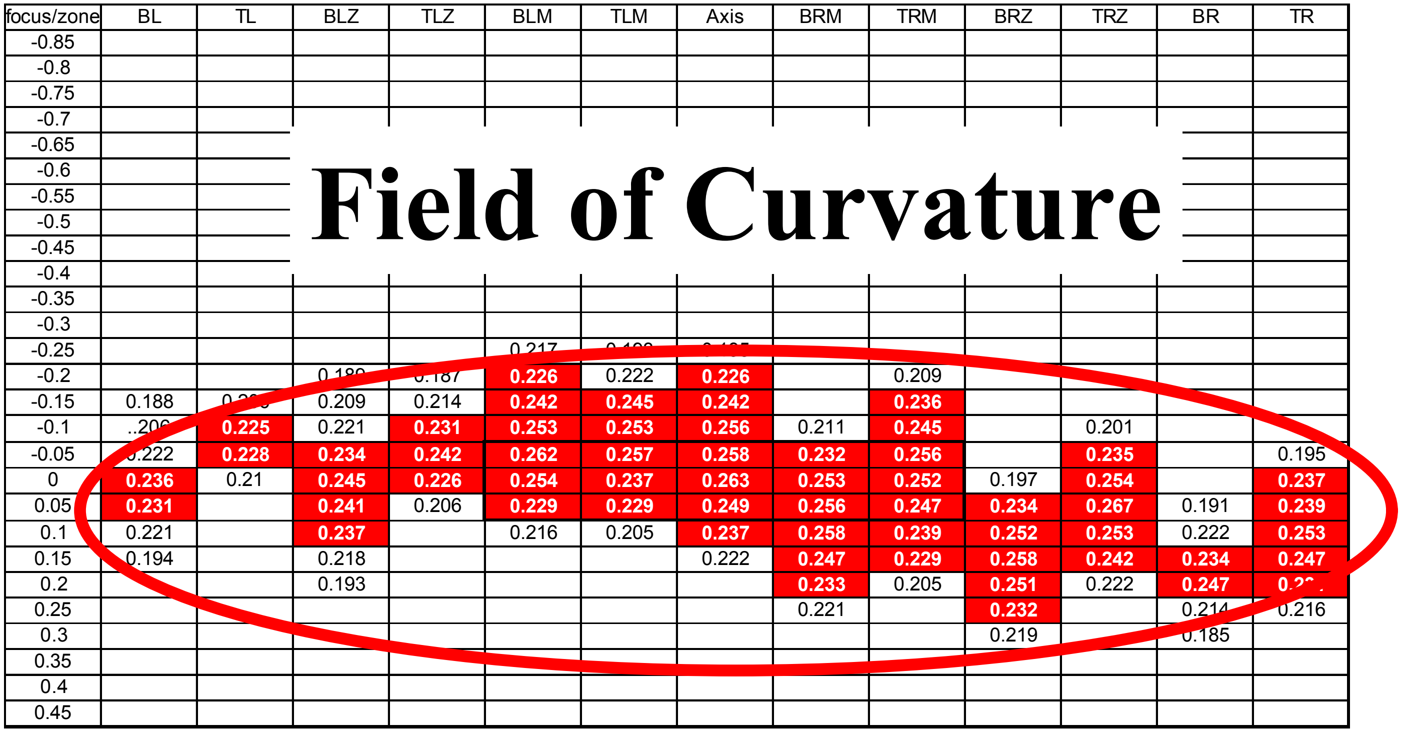
Conventional Illuminator 250nm
Contact Hole DoF Results

Conventional Illumination, sigma=0.74

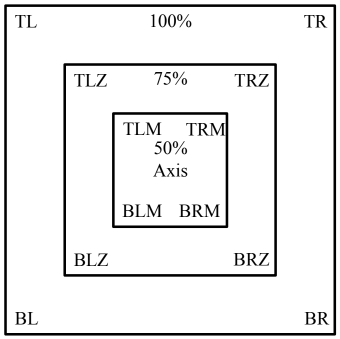


Field of Curvature

focus/zone	BL	TL	BLZ	TLZ	BLM	TLM	Axis	BRM	TRM	BRZ	TRZ	BR	TR
-0.85													
-0.8													
-0.75													
-0.7													
-0.65													
-0.6													
-0.55													
-0.5													
-0.45													
-0.4													
-0.35													
-0.3													
-0.25					0.217	[illegible]	[illegible]						
-0.2			[illegible]	0.187	0.226	0.222	0.226		0.209				
-0.15	0.188	[illegible]	0.209	0.214	0.242	0.245	0.242		0.236				
-0.1	[illegible]	0.225	0.221	0.231	0.253	0.253	0.256	0.211	0.245		0.201		
-0.05	0.222	0.228	0.234	0.242	0.262	0.257	0.258	0.232	0.256		0.235		0.195
0	0.236	0.21	0.245	0.226	0.254	0.237	0.263	0.253	0.252	0.197	0.254		0.237
0.05	0.231		0.241	0.206	0.229	0.229	0.249	0.256	0.247	0.234	0.267	0.191	0.239
0.1	0.221		0.237		0.216	0.205	0.237	0.258	0.239	0.252	0.253	0.222	0.253
0.15	0.194		0.218				0.222	0.247	0.229	0.258	0.242	0.234	0.247
0.2			0.193					0.233	0.205	0.251	0.222	0.247	[illegible]
0.25								0.221		0.232		0.214	0.216
0.3										0.219		0.185	
0.35													
0.4													
0.45													

ISI NA=0.53/248nm
Resist: UVIIHS

Reticle Map



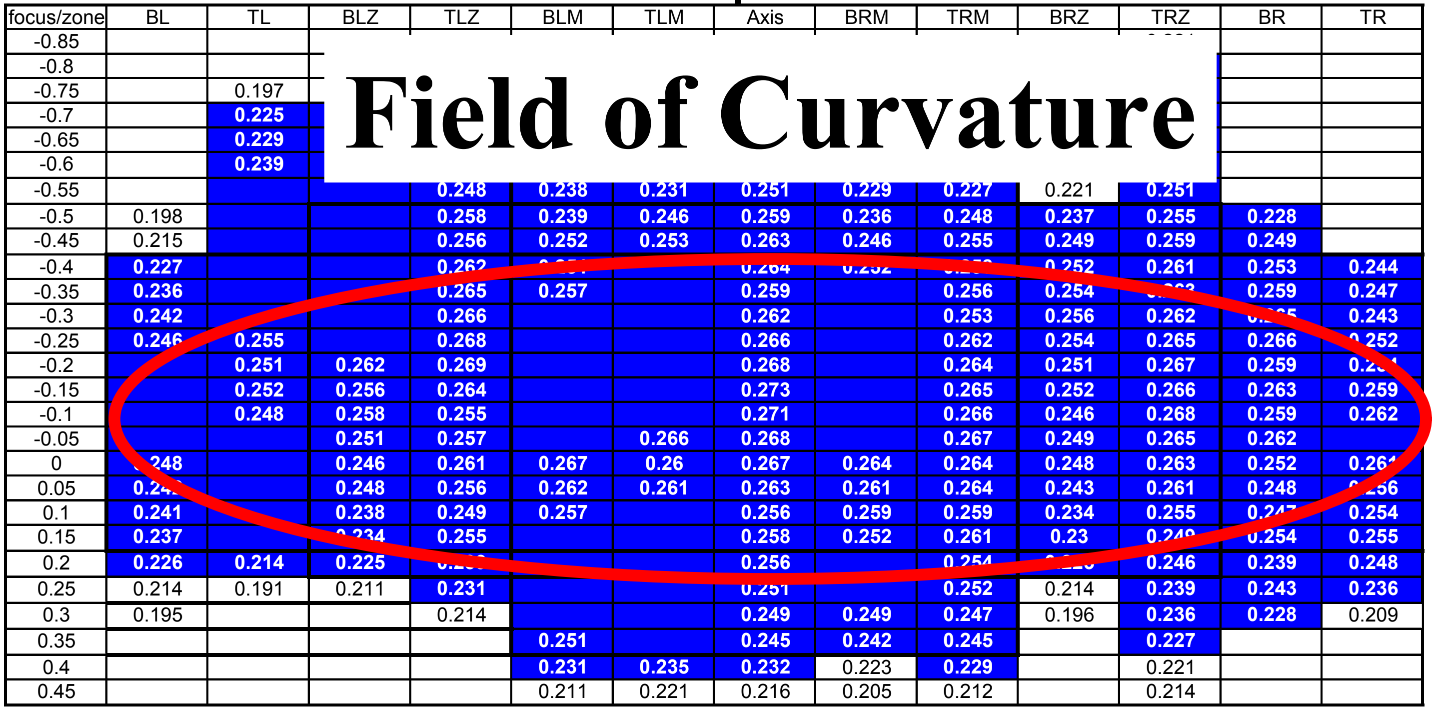
DOF = (0um/22 and 17.5mm, 0.1um/15mm)

dose=15.5mJ

No Common Corridor

Strong Quadrupole Illuminator 250nm Contact Hole DoF Results

0.15/0.59 Quadrupole Illumination



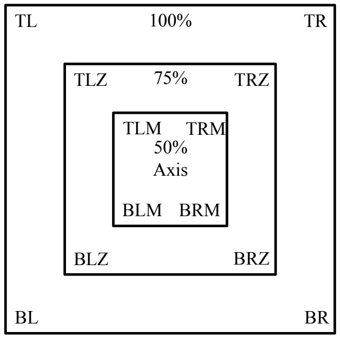
Field of Curvature

focus/zone	BL	TL	BLZ	TLZ	BLM	TLM	Axis	BRM	TRM	BRZ	TRZ	BR	TR
-0.85			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
-0.8			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
-0.75		0.197	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
-0.7		0.225	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
-0.65		0.229	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
-0.6		0.239	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
-0.55				0.248	0.238	0.231	0.251	0.229	0.227	0.221	0.251		
-0.5	0.198			0.258	0.239	0.246	0.259	0.236	0.248	0.237	0.255	0.228	
-0.45	0.215			0.256	0.252	0.253	0.263	0.246	0.255	0.249	0.259	0.249	
-0.4	0.227			0.262	[illegible]		0.264	0.252	[illegible]	0.252	0.261	0.253	0.244
-0.35	0.236			0.265	0.257		0.259		0.256	0.254	0.263	0.259	0.247
-0.3	0.242			0.266			0.262		0.253	0.256	0.262	0.265	0.243
-0.25	0.246	0.255		0.268			0.266		0.262	0.254	0.265	0.266	0.252
-0.2		0.251	0.262	0.269			0.268		0.264	0.251	0.267	0.259	[illegible]
-0.15		0.252	0.256	0.264			0.273		0.265	0.252	0.266	0.263	0.259
-0.1		0.248	0.258	0.255			0.271		0.266	0.246	0.268	0.259	0.262
-0.05			0.251	0.257		0.266	0.268		0.267	0.249	0.265	0.262	
0	0.248		0.246	0.261	0.267	0.26	0.267	0.264	0.264	0.248	0.263	0.252	0.261
0.05	[illegible]		0.248	0.256	0.262	0.261	0.263	0.261	0.264	0.243	0.261	0.248	0.256
0.1	0.241		0.238	0.249	0.257		0.256	0.259	0.259	0.234	0.255	0.247	0.254
0.15	0.237		0.234	0.255			0.258	0.252	0.261	0.23	0.249	0.254	0.255
0.2	0.226	0.214	0.225	[illegible]			0.256		0.254	[illegible]	0.246	0.239	0.248
0.25	0.214	0.191	0.211	0.231			0.251		0.252	0.214	0.239	0.243	0.236
0.3	0.195			0.214			0.249	0.249	0.247	0.196	0.236	0.228	0.209
0.35					0.251		0.245	0.242	0.245		0.227		
0.4					0.231	0.235	0.232	0.223	0.229		0.221		
0.45					0.211	0.221	0.216	0.205	0.212		0.214		

DOF = (0.55um/22mm, 0.7um/17.5mm, 0.9um/15mm)   dose=19mJ

ISI NA=0.53/248nm
Resist: UVIIHS
500 pitch

Reticle Map



Large Common Corridor

Paper 4226-04, Petersen

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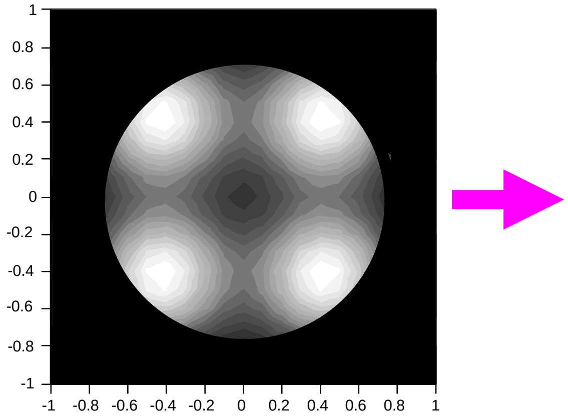
Effect of Source Shape on Aberrations

Simulation result observations:

--> More overlapped DOF
--> More tolerable to lens aberration



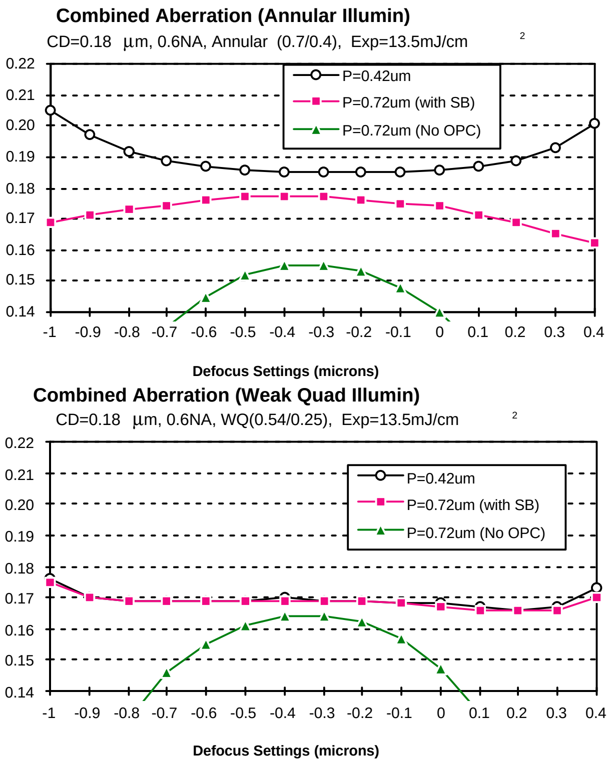
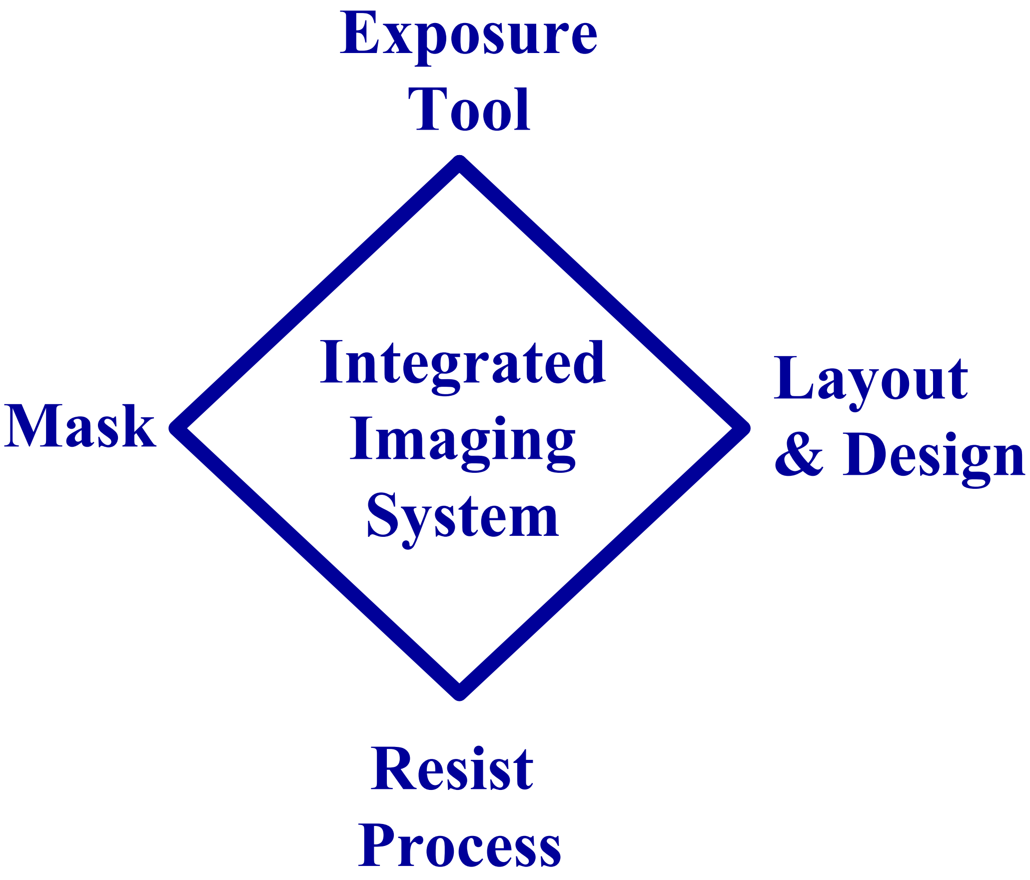


Figure 24. The lens aberration concern can be further minimized with the use of custom illumination aperture (a weak quadrupole type) that combined with SB-OPC.

J. Fung Chen, T. Laidig, K. E. Wampler, R. Caldwell, K. H. Nakagawa, A. Liebchen, “A Practical Technology Path to Sub-0.10 Micron Process Generations Via Enhanced Optical Lithography”, 1999 Semiconductor Technology T-CAD Workshop and Exbition Vol. 3, Hsin-Chu, Taiwan, section 8, paper 2 (1999)

Image Process Integration Examples



Exposure Tool

Mask

Integrated Imaging System

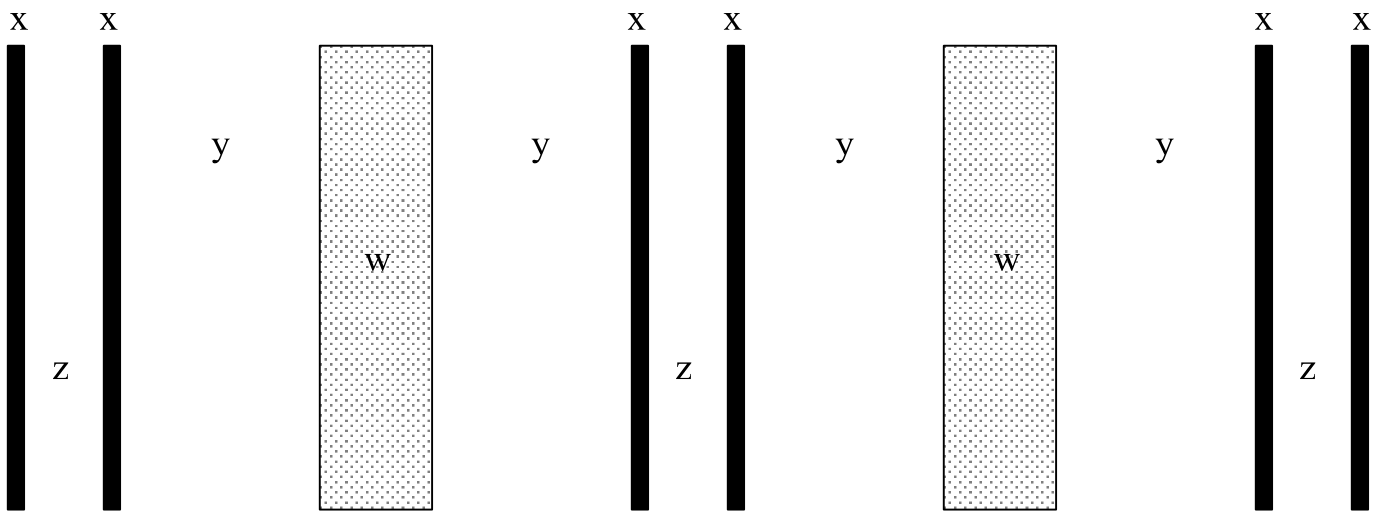
Layout & Design

Resist Process

Using IPI to Attack Aberrations:

- **Illuminator Shape**
- **Scatter Bars**
- **Phase-Shift Masks**

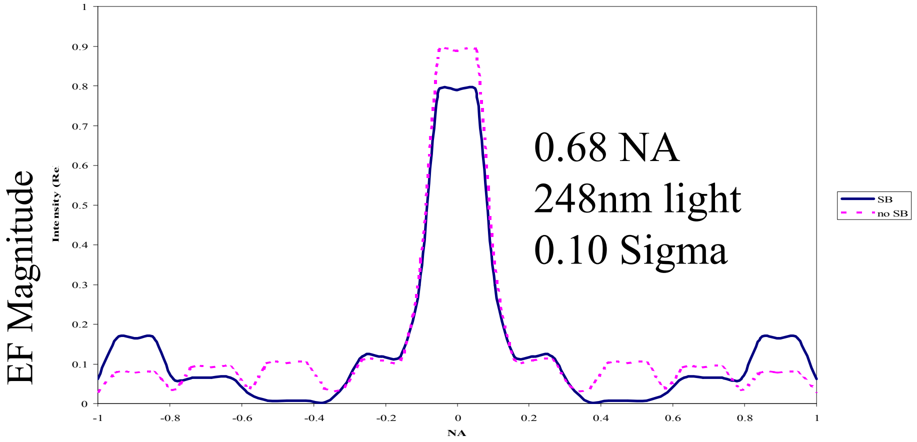
160nm:800nm with Double Scattering Bars



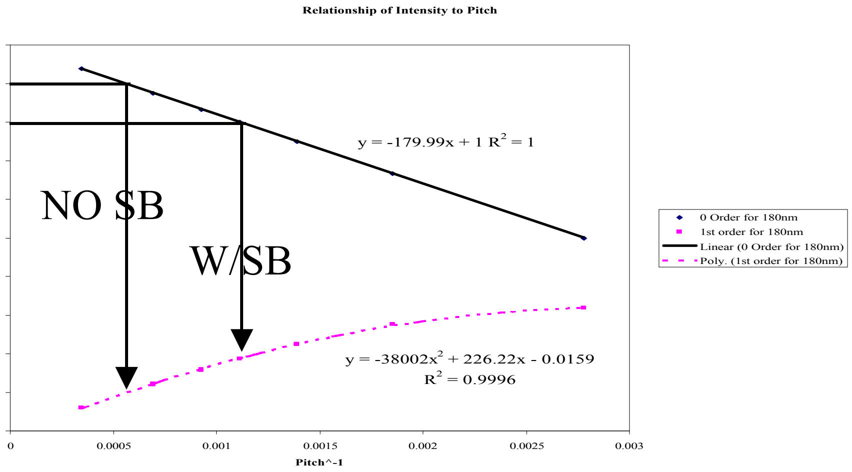
w=160nm; x=60nm;
y=300nm; z=80nm

Nishrin Kachwala, John S. Petersen, J. Fung Chen, Mike Canjemi,
Martin McCallum, SPIE Vol. 3679 Paper 05, Santa Clara, CA (1999)

Why Do Scattering Bars Work?



Relative NA



Pitch^{-1}

Scattering Bar structures move light out of the zero order and move some of the higher order light to the edge of the lens, giving it an appearance similar to that of a dense feature.

Electric Field Amplitude for Isolated Features With and Without Scattering Bars

No Scattering Bars

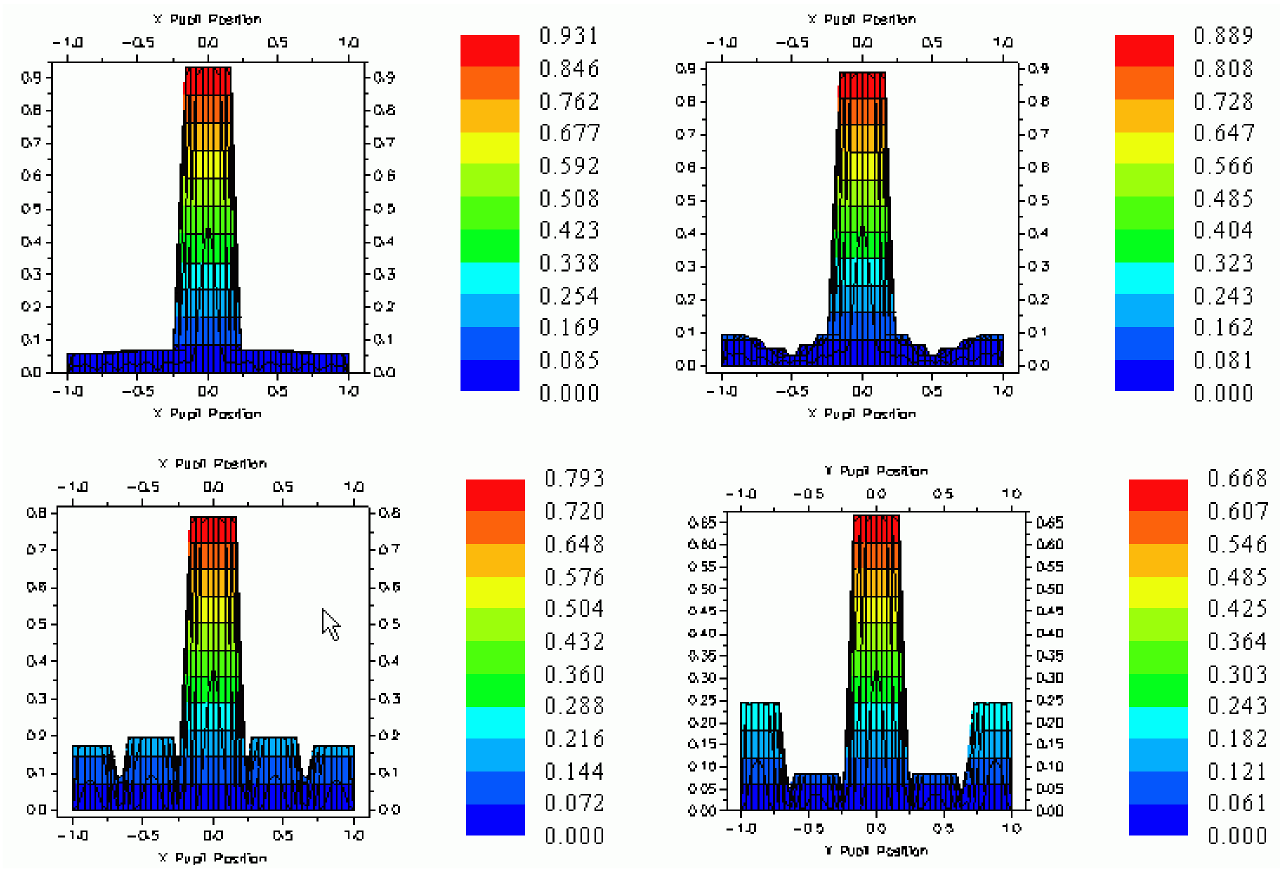
Scattering Bars

Pitch

2960 nm
z=2000 nm

1040 nm
z=1040 nm

Amplitude



X Pupil Position (Normalized NA)

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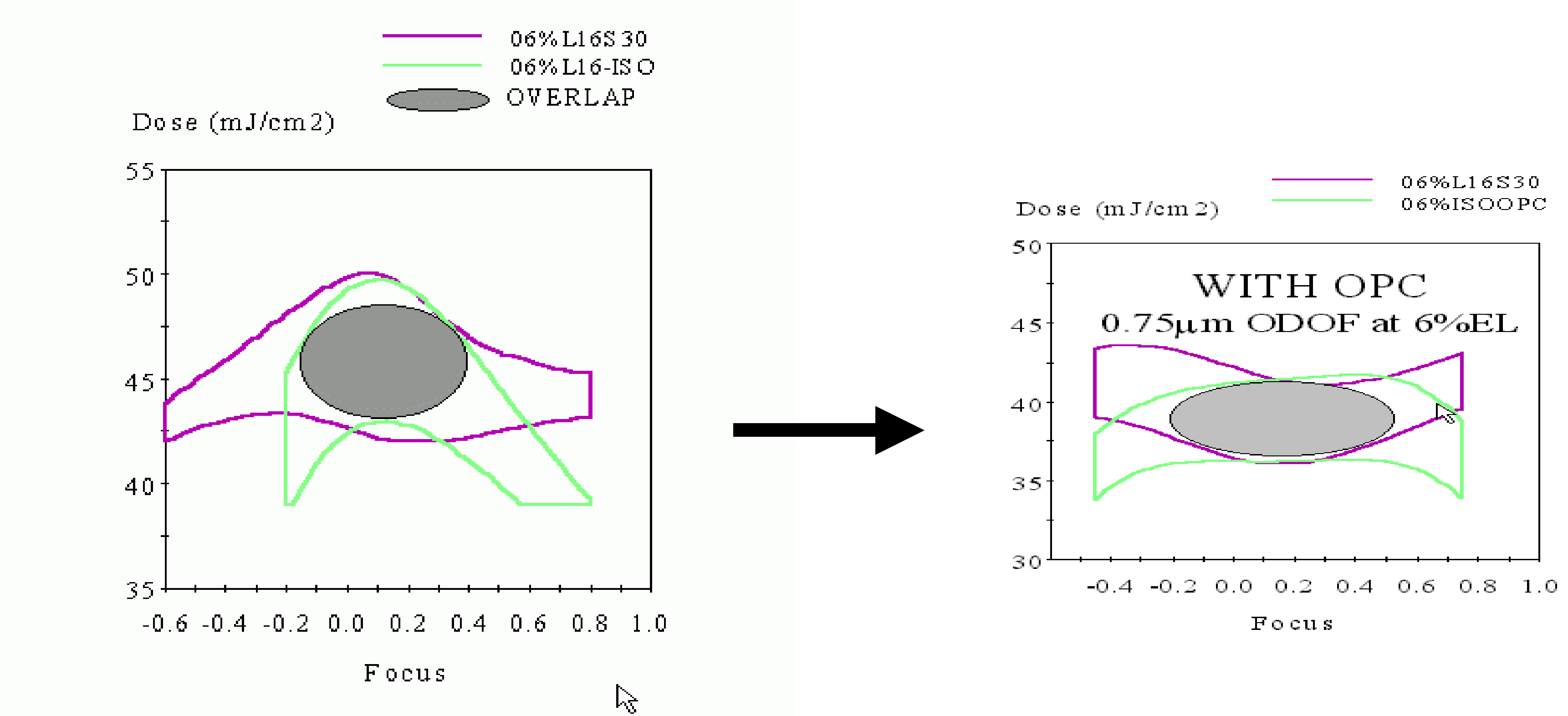
160nm Annular Illumination With 6% Attenuated PSM



Conventional Illumination
No Scattering Bars

0.8-0.6 Annular Illumination
Scattering Bars

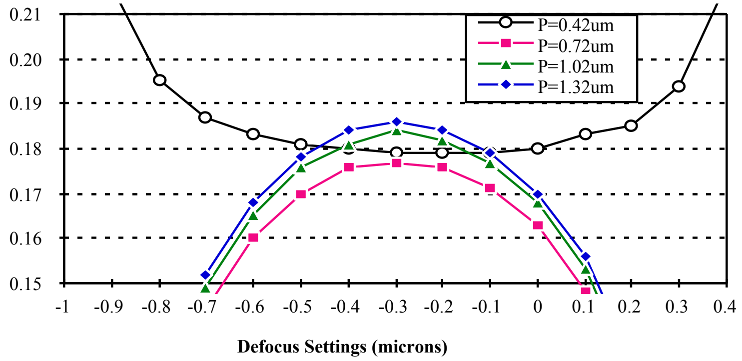
Figure 14: 1:2 and isolated feature with 0.6/0.8 annulus, 0.6NA, 6%attenuated
A) No overlap without OPC B) Overlap with SRF OPC on the isolated feature

Nishrin Kachwala, John S. Petersen, J. Fung Chen, Mike Canjemi,
Martin McCallum , SPIE 3679, p. 55 (1999)

The Effect of Scattering Bars on Aberrations

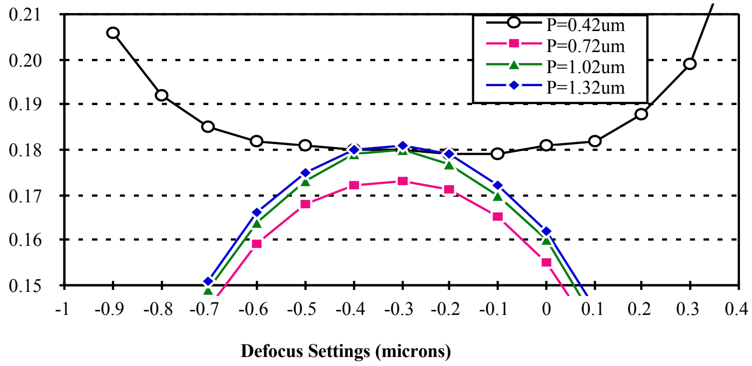
Diffraction Limited Stepper (No OPC)

CD=0.18 µm, 0.6NA, 0.8Sigma, Exposure=13.5mJ/cm^2



Combined Aberration Stepper (No OPC)

CD=0.18 µm, 0.6NA, 0.8Sigma, Exposure=13.5mJ/cm^2



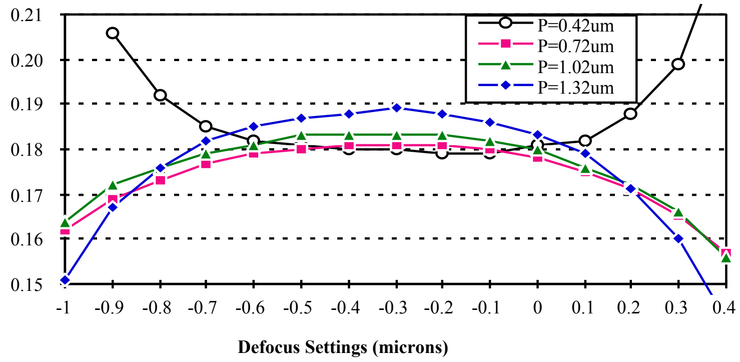
Observations:

1) Dense feature are minimally affected by lens aberration.

2) SB improves DOF for isolated & semi-isolated features.

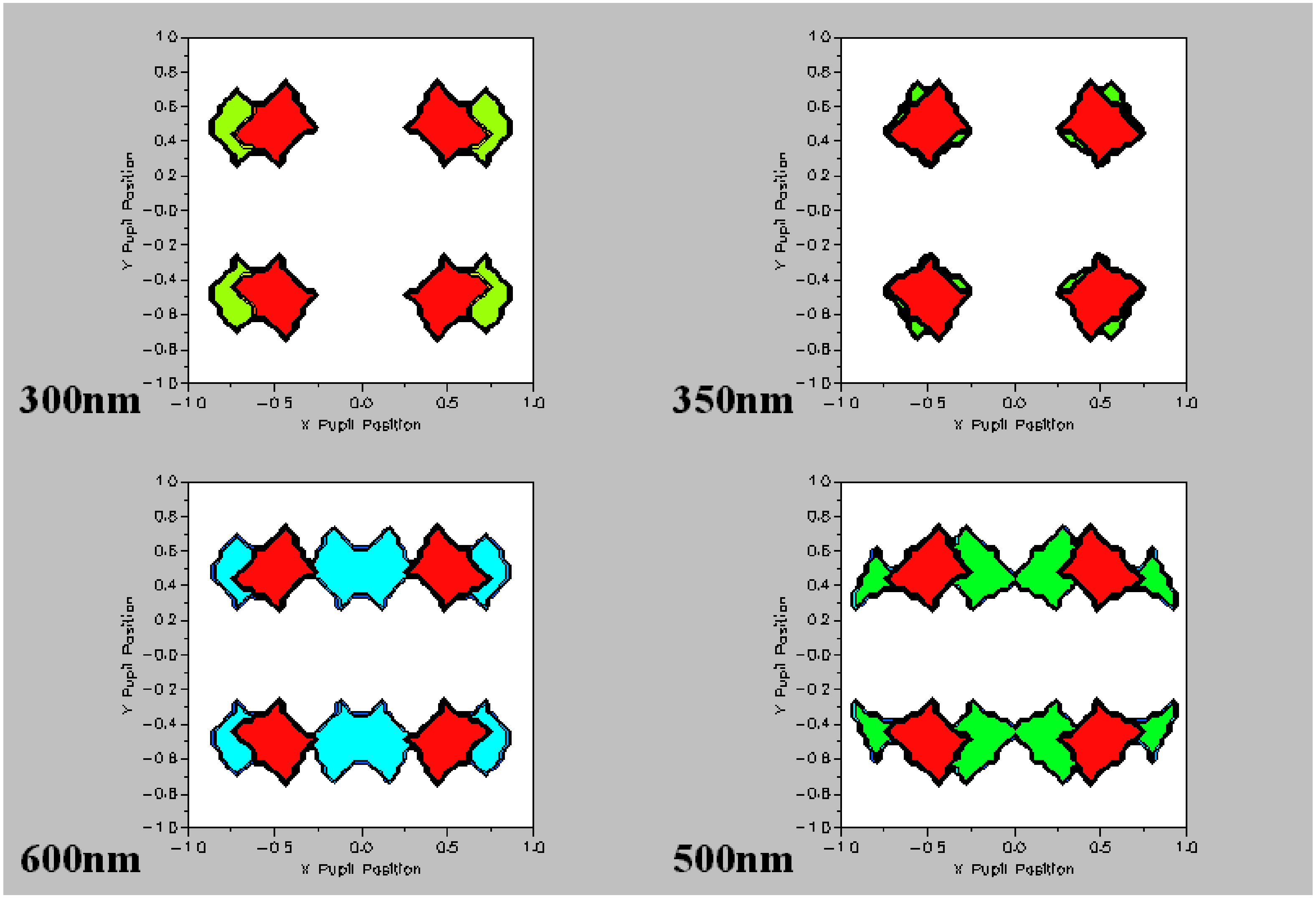
Combined Aberration Stepper (SB-OPC)

CD=0.18 µm, 0.6NA, 0.8Sigma, Exposure=13.5mJ/cm^2



J. Fung Chen, T. Laidig, K. E. Wampler, R. Caldwell, K. H. Nakagawa, A. Liebchen, "A Practical Technology Path to Sub-0.10 Micron Process Generations Via Enhanced Optical Lithography", 1999 Semiconductor Technology T-CAD Workshop and Exbition Vol. 3, Hsin-Chu, Taiwan, section 8, paper 2 (1999)

Diffraction Pattern of 100nm Lines

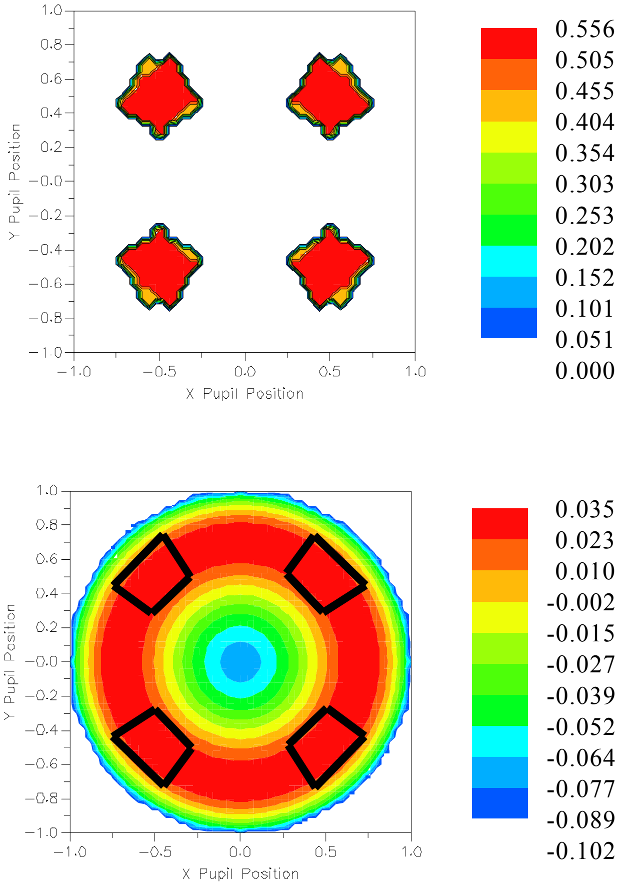


Electric Field Magnitude

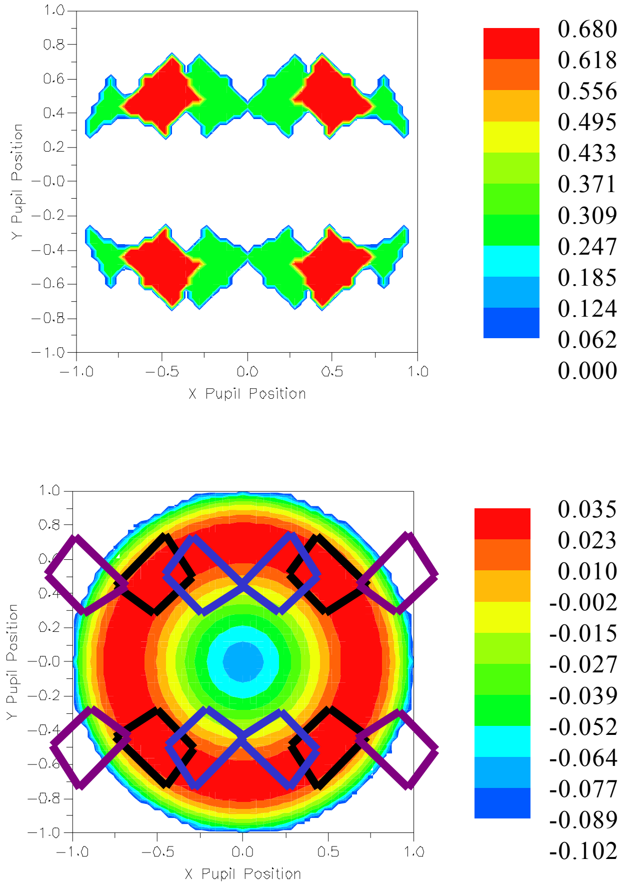
Pitch (nm)	OPC	Electric Field Magnitude		
		Zero Order	First Order	Second Order
300	Bias	0.505	0.374	
350	Bias	0.657	0.327	
500	Bias	0.680	0.307	0.269
600	π-Scatter Bar/Bias	0.702	0.119	0.274

Diffraction Pattern Convolved with Aberrations

350nm Pitch

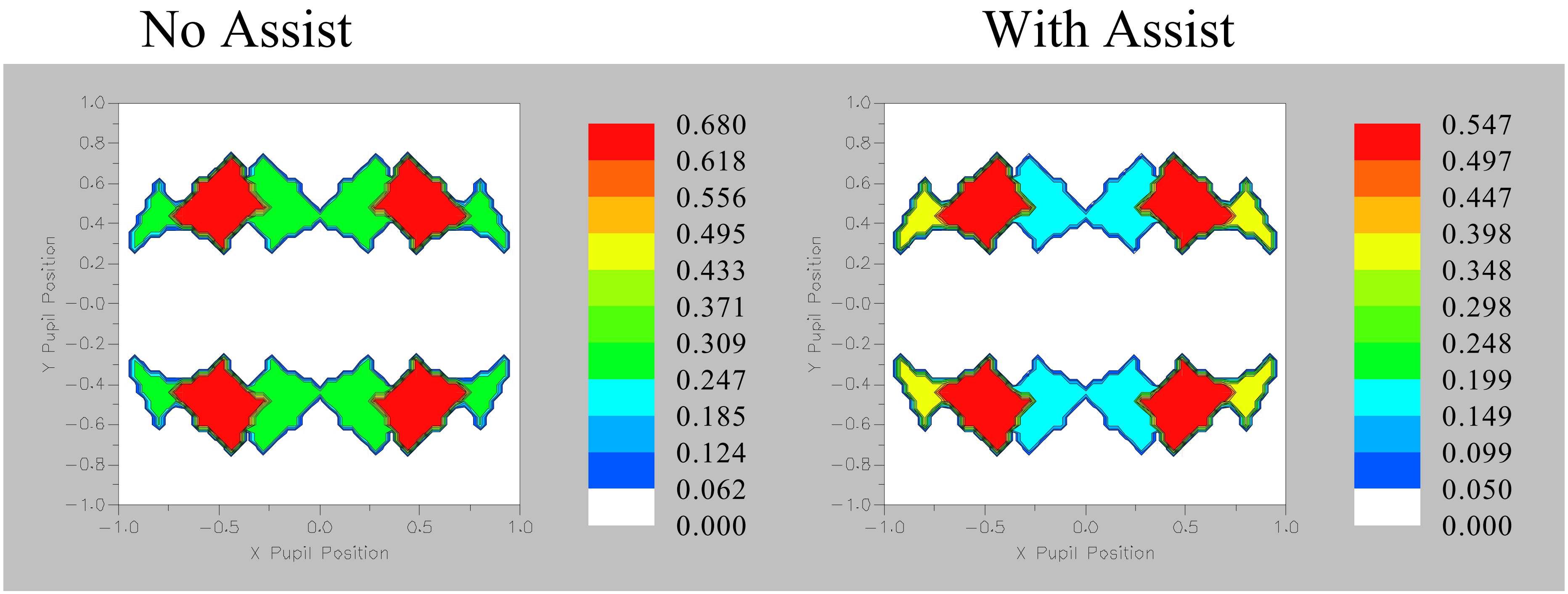


500nm Pitch



-0.07=Z9

Diffraction Pattern for 100nm Line on a 500nm Pitch

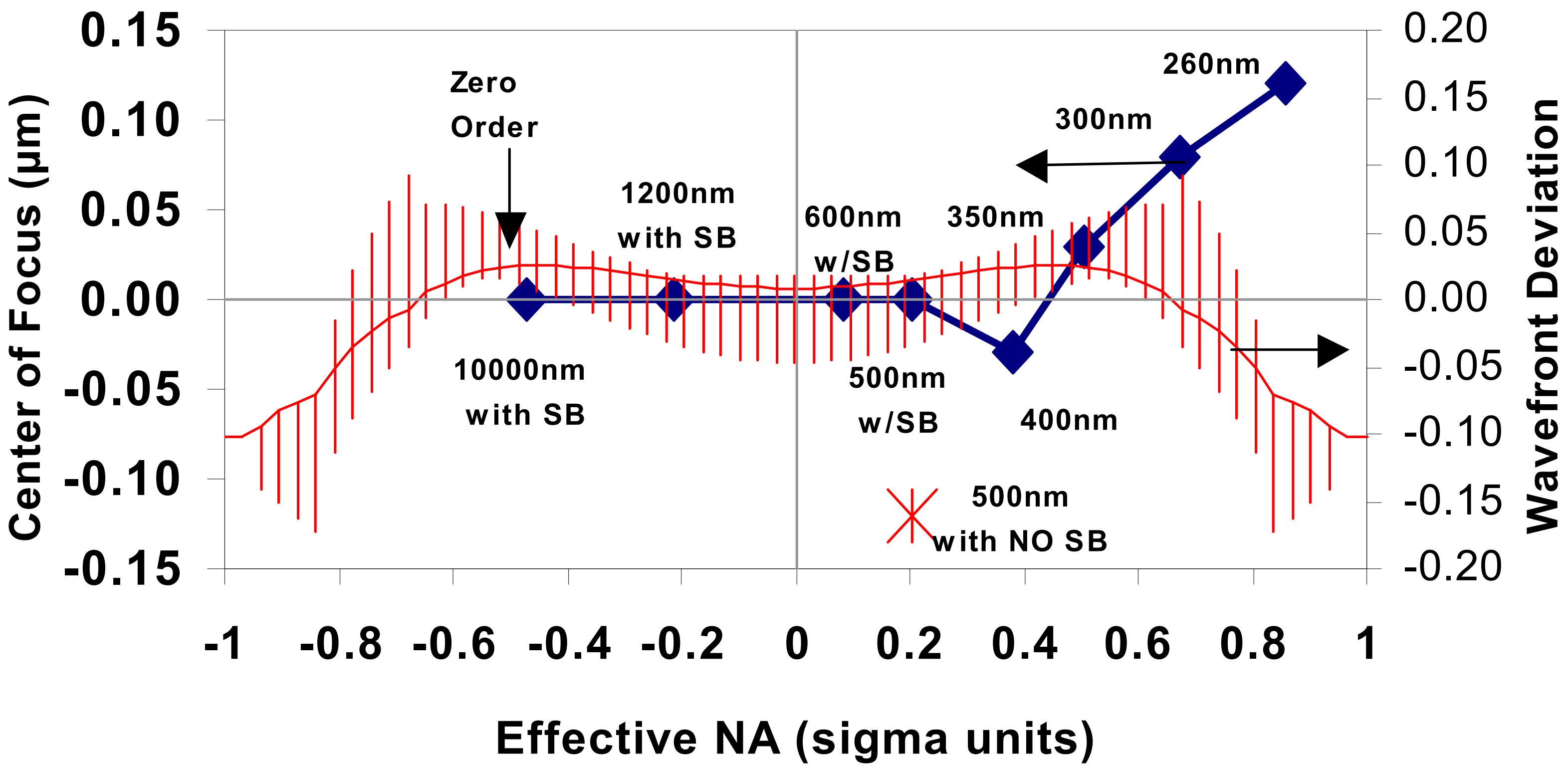

No Assist

With Assist

- Scattering bar pushes energy to the higher order.

100nm Center of Focus Adjust of the 500nm Pitch Using Scattering Bars

Z9-confounded between –0.07 waves



Paper 4226-04, Petersen

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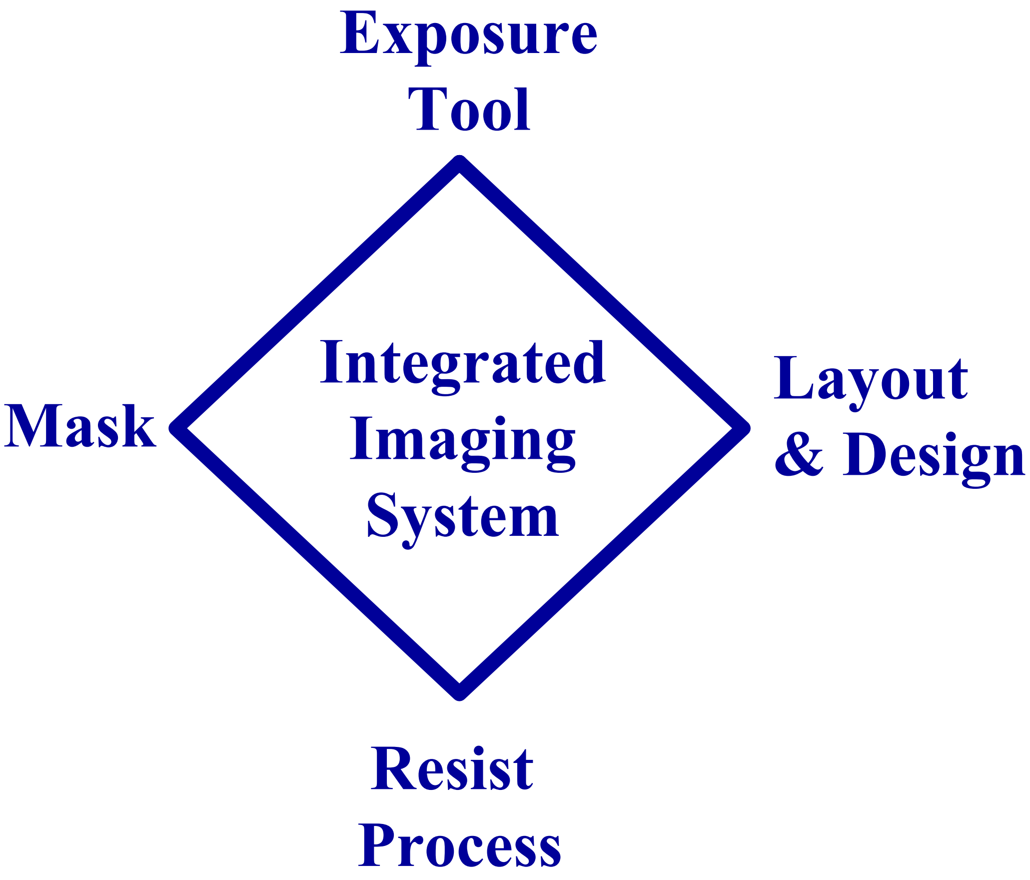
CoF Dependence on Pitch for Z7 and Z9

Z7	Z9	Pitch (nm)			
		260	300	500	600
0.000	0.000	0.00	0.00	0.00	0.00
-0.007	0.000	0.00	0.00	0.00	0.00
-0.070	0.000	0.00	0.00	0.00	0.00
-0.007	-0.007	0.00	0.00	0.00	0.00
-0.070	-0.070	+0.11	+0.08	+0.01	+0.01
0.000	-0.070	+0.12	+0.08	0.00	+0.01
0.000	-0.007	0.00	0.00	0.00	0.00
0.000	-0.070	X	X	-0.10 (no SB)	-0.04 (no SB)

Image Process Integration Examples



Exposure Tool

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Resist Process

Using IPI to Attack Aberrations:

- **Illuminator Shape**
- **Scatter Bars**
- **Use Phase-Shift Masks**

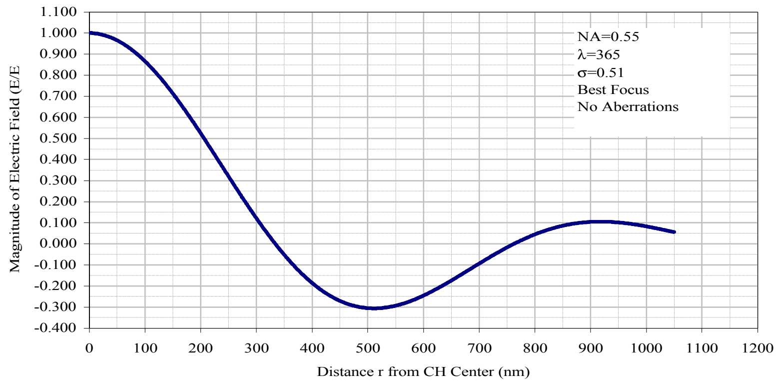
Correcting for Aberrations with Mask Design

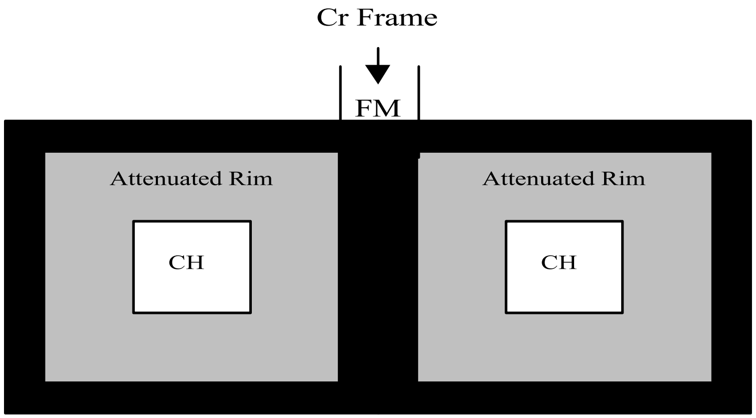
- For contacts, mask design can be used to minimize symmetric aberrations.
- 0.55 NA/ 0.51 sigma/ 365nm
- Compare two masks for making 350nm contacts on 1050nm pitch:
  - **Without Frame**

    510nm contact 8% AttPSM
  - **With 290nm Frame**

    430nm contact 8% Ternary AttPSM

Figure 1: Transmission and Phase Discetization of a Bessel Contact




Cr Frame

FM

Attenuated Rim

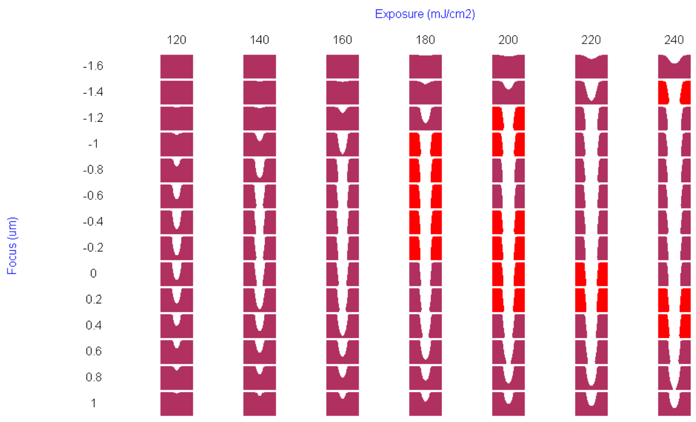
CH

Attenuated Rim

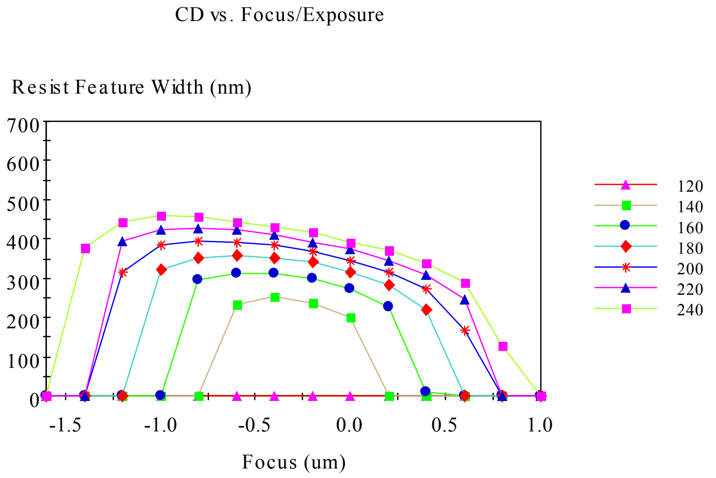
CH

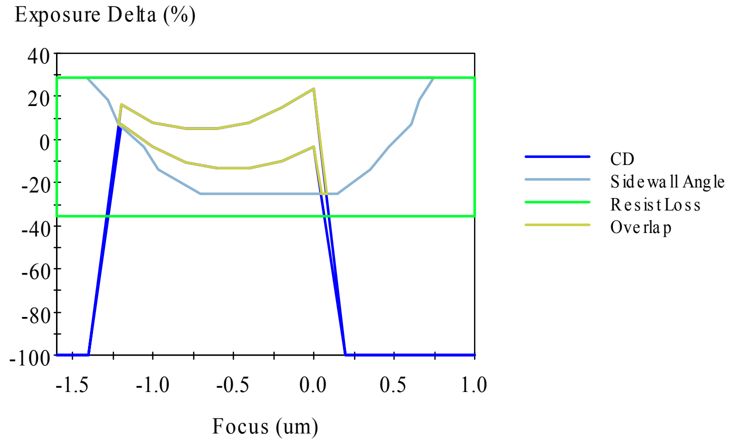
For further discussion of the relationship between chrome frames and aberrations, see Z. M. Ma; A. Andersson, Proc. SPIE Vol. 3334, p. 543-552 (1998).

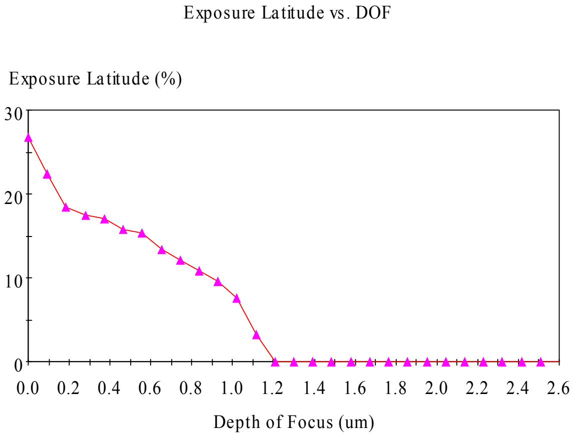
Lithography Results, Without Frame



Process Window







CoF = -0.3μm

E_S = 180 mJcm^{-1}

DoF = 0.8 μm

$$\frac{E_s}{E_{0eff}} = \frac{180}{130} = 1.38$$

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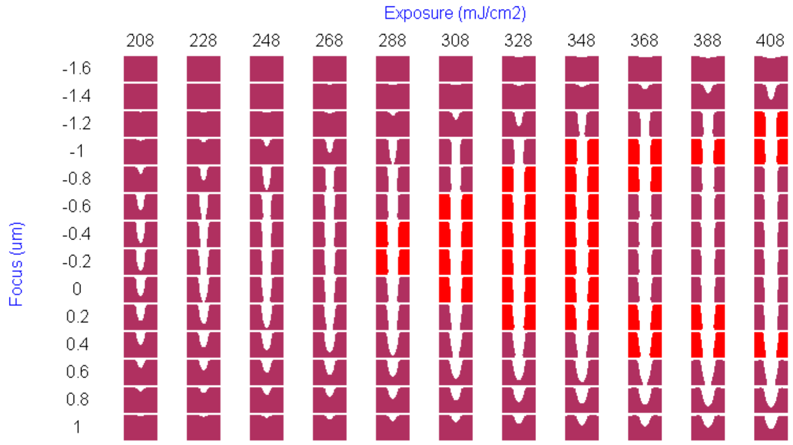
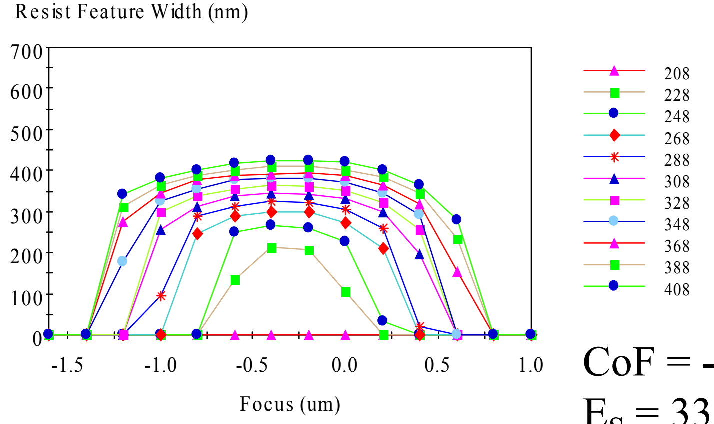
Lithography Results, With Frame



CD vs. Focus/Exposure

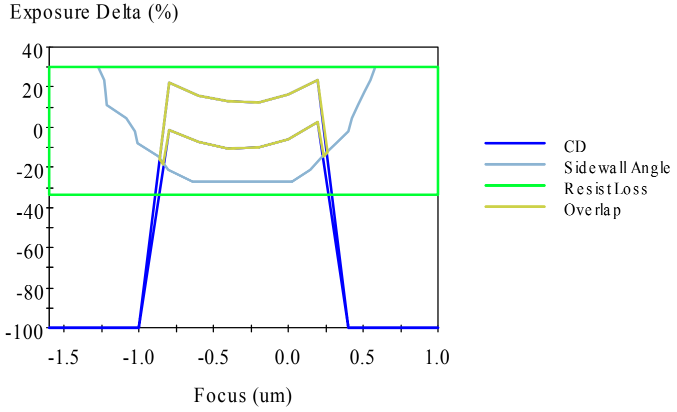


CoF = -0.31μm

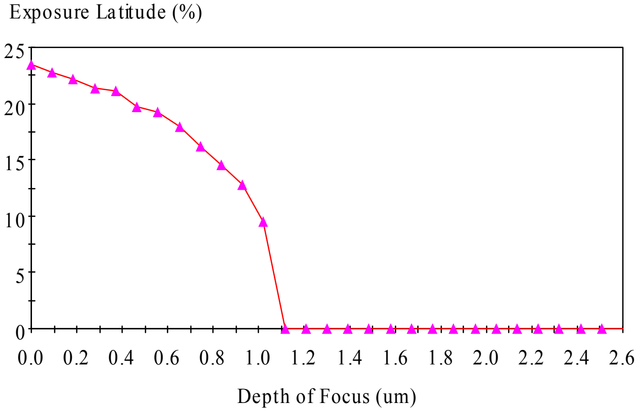
E_S = 337 mJcm^{-1}

DoF = 0.9 μm

Process Window



Exposure Latitude vs. DOF



$$\frac{E_S = 337}{E_{0eff} = 218} = 1.55$$

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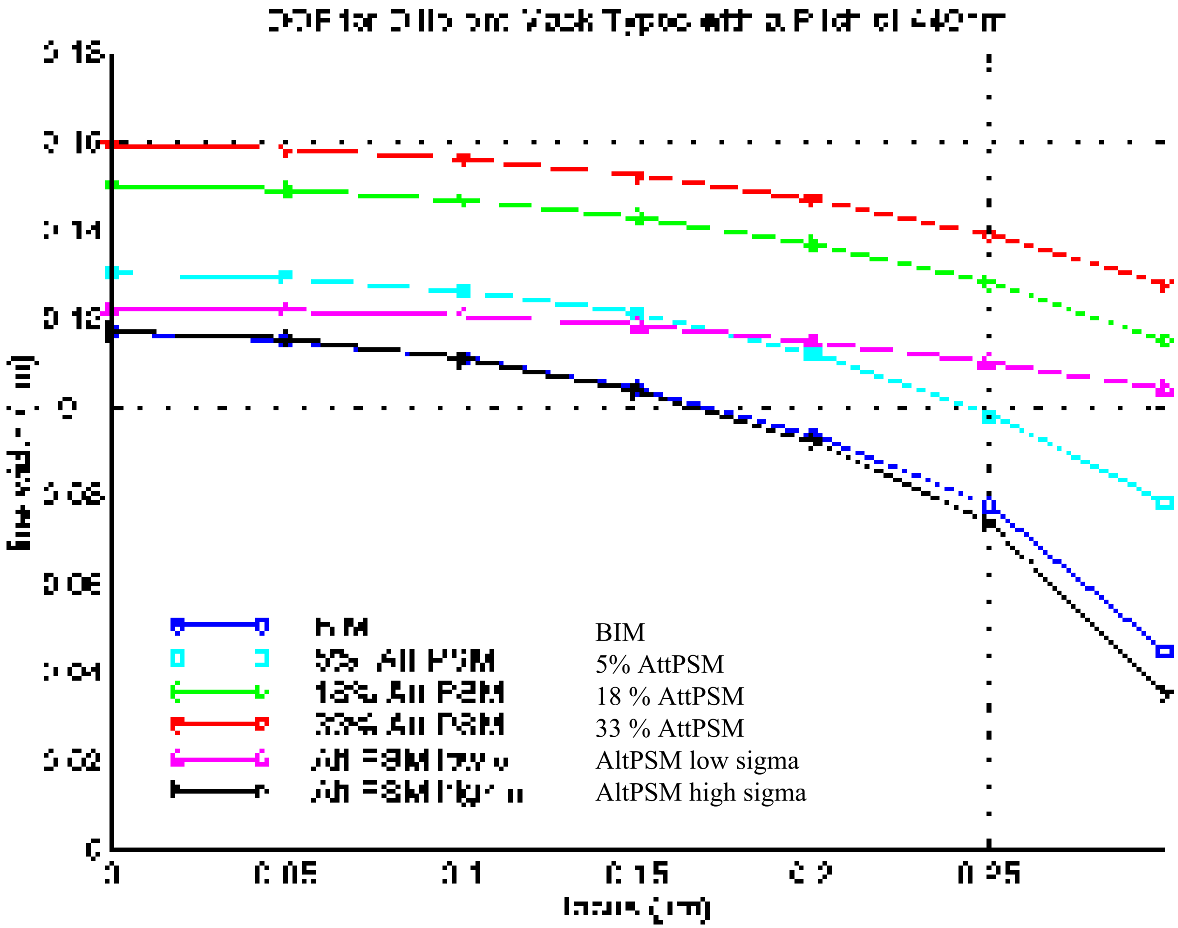
Paper 4226-04, Petersen

PSM Effect on Focal Plane Deviation

Simulated effect of focal plane deviation on CD variation for 0.14µm lines with pitch of 0.44µm



R. J. Socha, et al, SPIE 3748, 290 (1999)

Correcting Lens Aberrations

- Determine aberrations:

  Know your lens and make; the aberrations they have will dictate what can be done with RET.

- Use illuminator and mask design to improve tolerance to aberrations.

My Optical Forecast

Feature Size				Lines					Contact Holes			
Pitch	0.5 Pitch	MPU		Year	k_{pitch}	NA	λ		Year	k_{pitch}	NA	λ
360	180	140		1999	0.54	0.55	365		1999	0.74	0.70	365
260	130	100		2001	0.54	0.52	248		2001	0.74	0.66	248
200	100	70		2004	0.54	0.67	248		2004	0.74	0.86	248
140	70	50		2007	0.54	0.96	248		2004	0.74	0.67	193
140	70	50		2007	0.54	0.74	193		2007	0.74	0.95	193
140	70	50		2007	0.54	0.61	157		2007	0.74	0.77	157
100	50	35		2010	0.54	0.85	157		2007	0.74	0.62	126
100	50	35		2010	0.54	0.68	126		2010	0.74	0.06	13
100	50	35		2010	0.74	0.10	13		2010	0.74	0.09	13
60	30	25		2013	0.74	0.16	13		2013	0.74	0.15	13

Assumes Weak PSM with Dipole or Strong PSM with OPC for Lines

Resolution Enhancement Trek

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