The Status and Future of Imaging Metrology Needs for Lithography.

Joost Sytsma

International Technology Roadmap for Semiconductors 1999

	1999	*2002*	*2005*	*2008*	*2011*	*2014*
Half Pitch DRAM (nm)	**180**	**130**	**100**	**70**	**50**	**35**
Development (nm)	**90**	**35**	**45**	**-**	**-**	**-**

CD =Controllable minimal linewidth

To be achieved via $CD = k_1 \cdot \frac{\lambda}{NA}$

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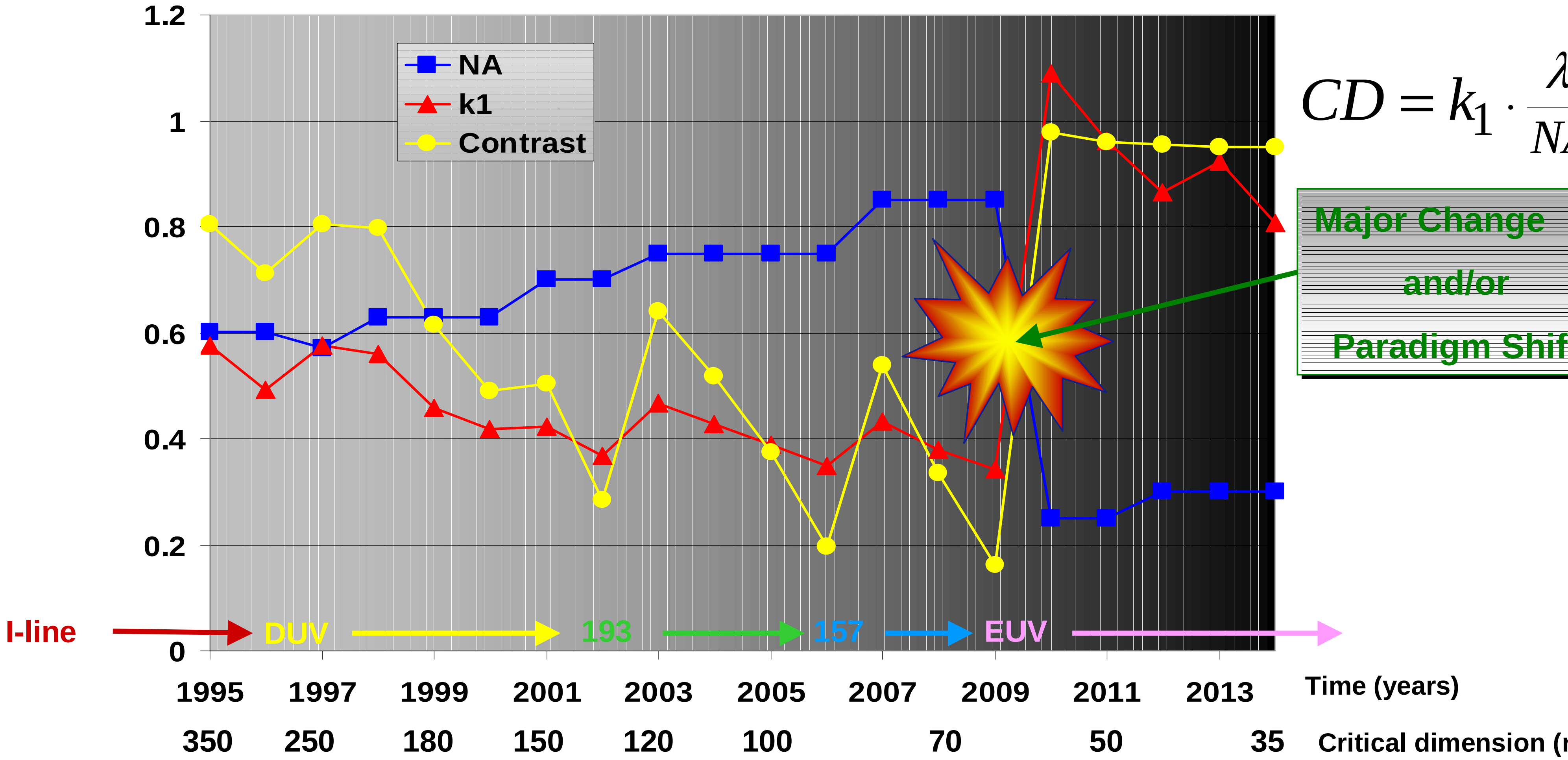
Defining the challenge-1



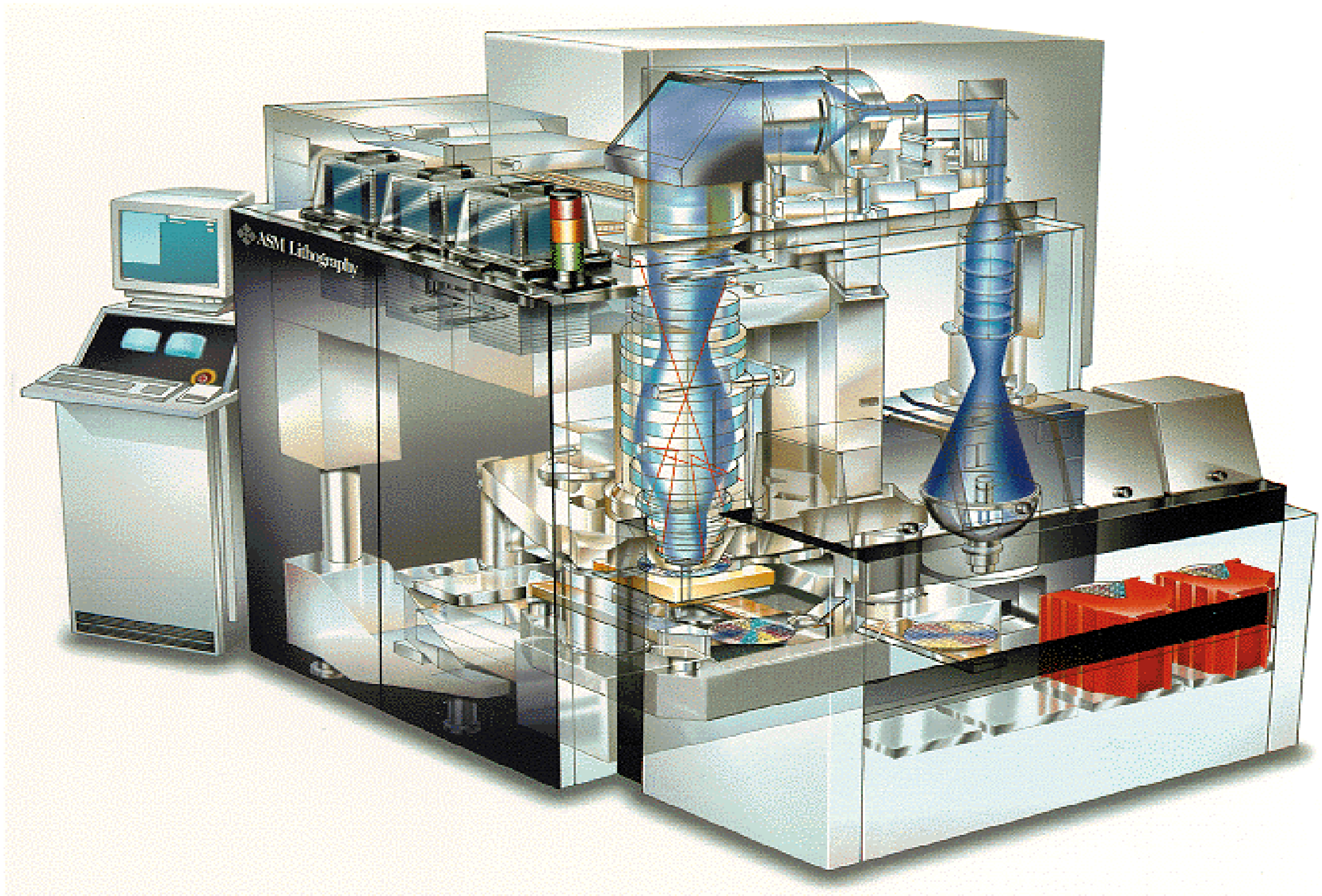
$$CD = k_1 \cdot \frac{\lambda}{NA}$$

Defining the challenge-2

- **Major steps by λ and NA**
- **The process factor k_1 and contrast still decreases $\Rightarrow$ Need for:**
  - **Improved System Dynamics**
  - **Improved System's Imaging Capabilities**
- **Future Needs (EUVL)**

"What you can not measure, you can not make, nor control"

Good System Dynamics



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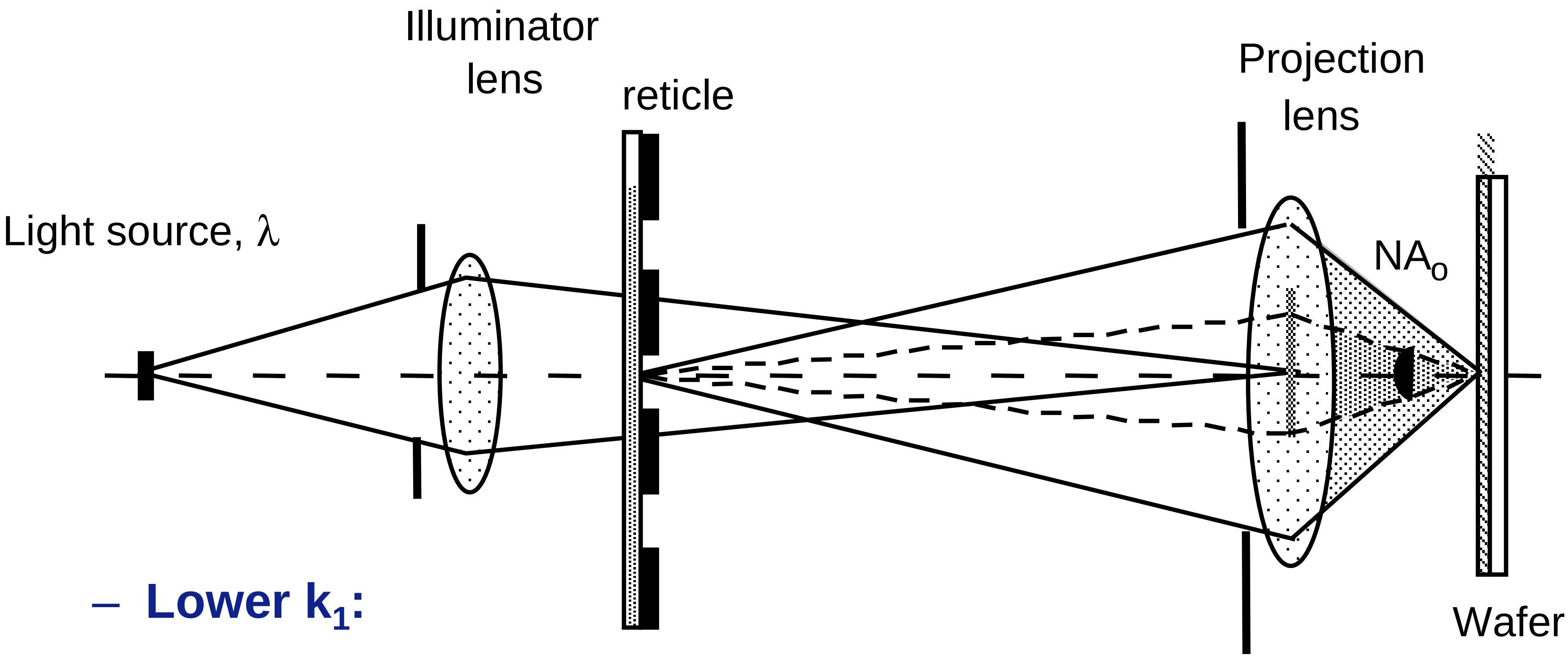
Even better System Dynamics

Improved System's Imaging Capabilities



– **Lower k_1:**
  - **Resolution enhancement techniques**
  - **Optics utilization improvement**
  - **Process improvement**

system = scanner + reticle + process (+ SEM/ELM….)

The Status and Future of Imaging Metrology Needs for Lithography.

- Illumination enhancement techniques:
  - Off-axis illumination
- Optimal use of Projection Optics
  - Case Study L_1-L_2
  - Aberration measurements
  - Lithographic Correlation and Aberration control
- Reticles:
  - Optical Proximity Correction
  - Phase shifting mask
  - Reticle quality
- Process improvement

“What you can not measure, you can not make, nor control”

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  - **Reticle quality**

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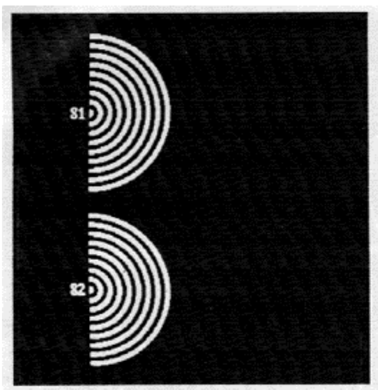
Illumination enhancement techniques

(a) Two Huygen sources formed at S1 and S2

S1

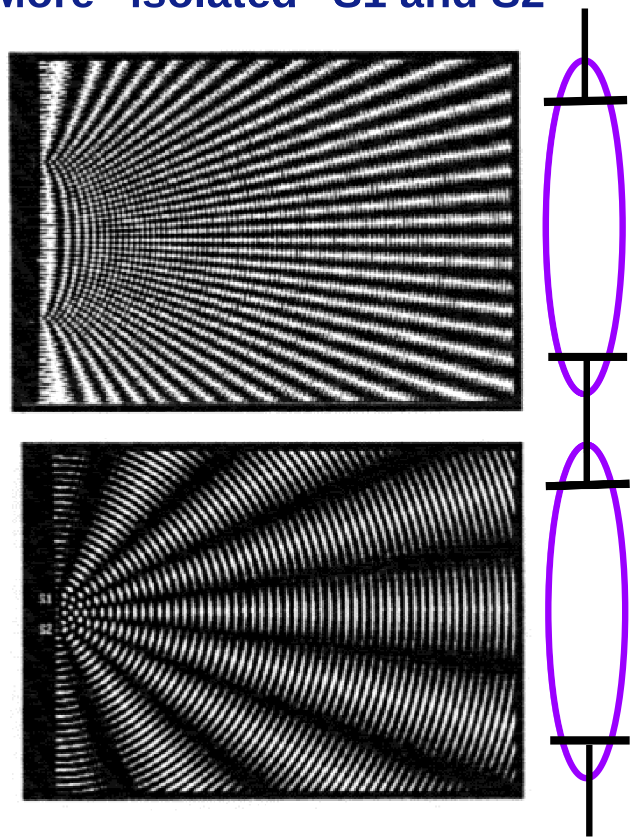
S2



(b) More "isolated" S1 and S2

S1

S2



S1
S2

(c) "Densely" packed S1 and S2

Observations:

1) Diffraction patterns are not the same from dense to isolated

2) Lens act as "low-pass" filter, only lower diffraction order light beams can get through lens

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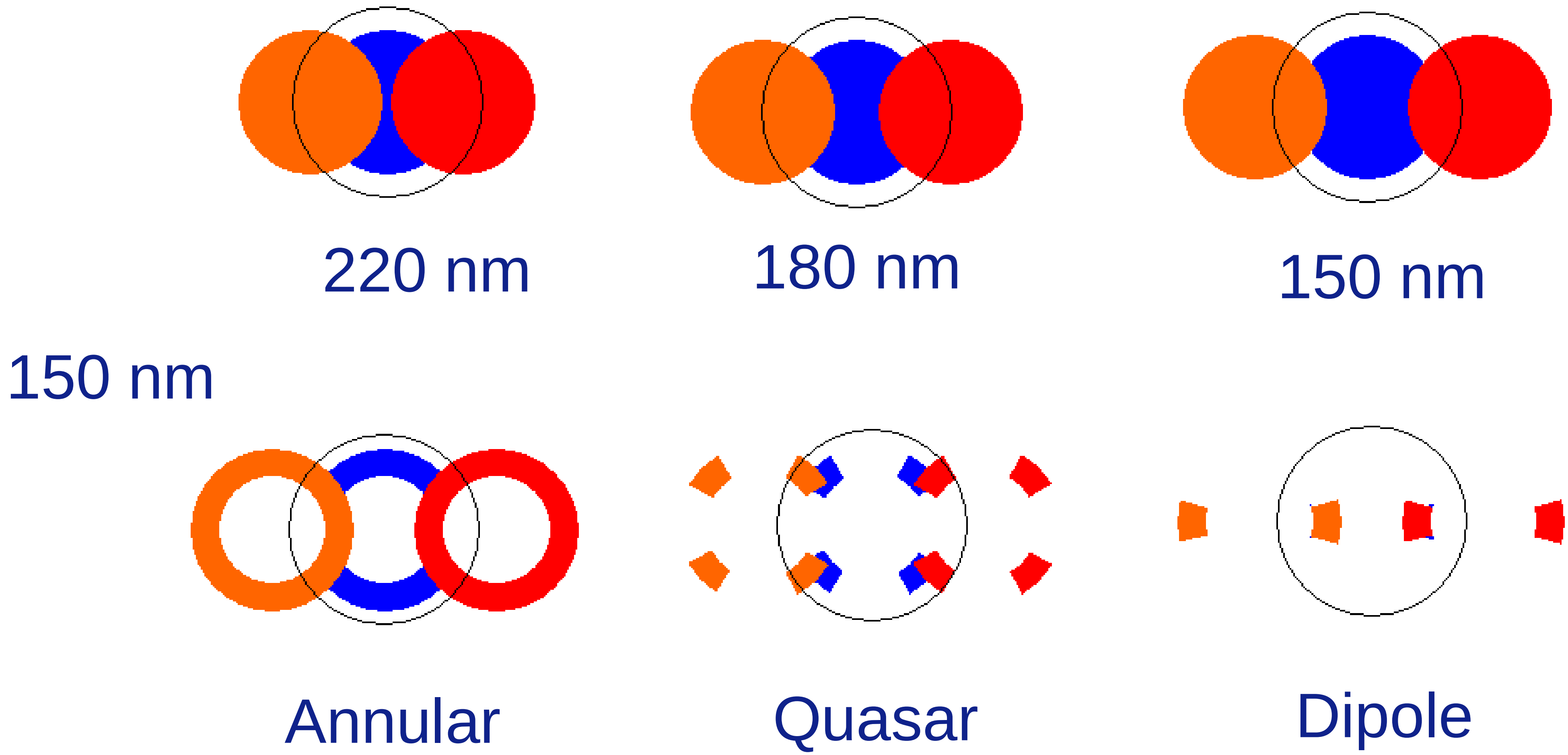
Illumination enhancement techniques

Off-axis illumination (OAI)



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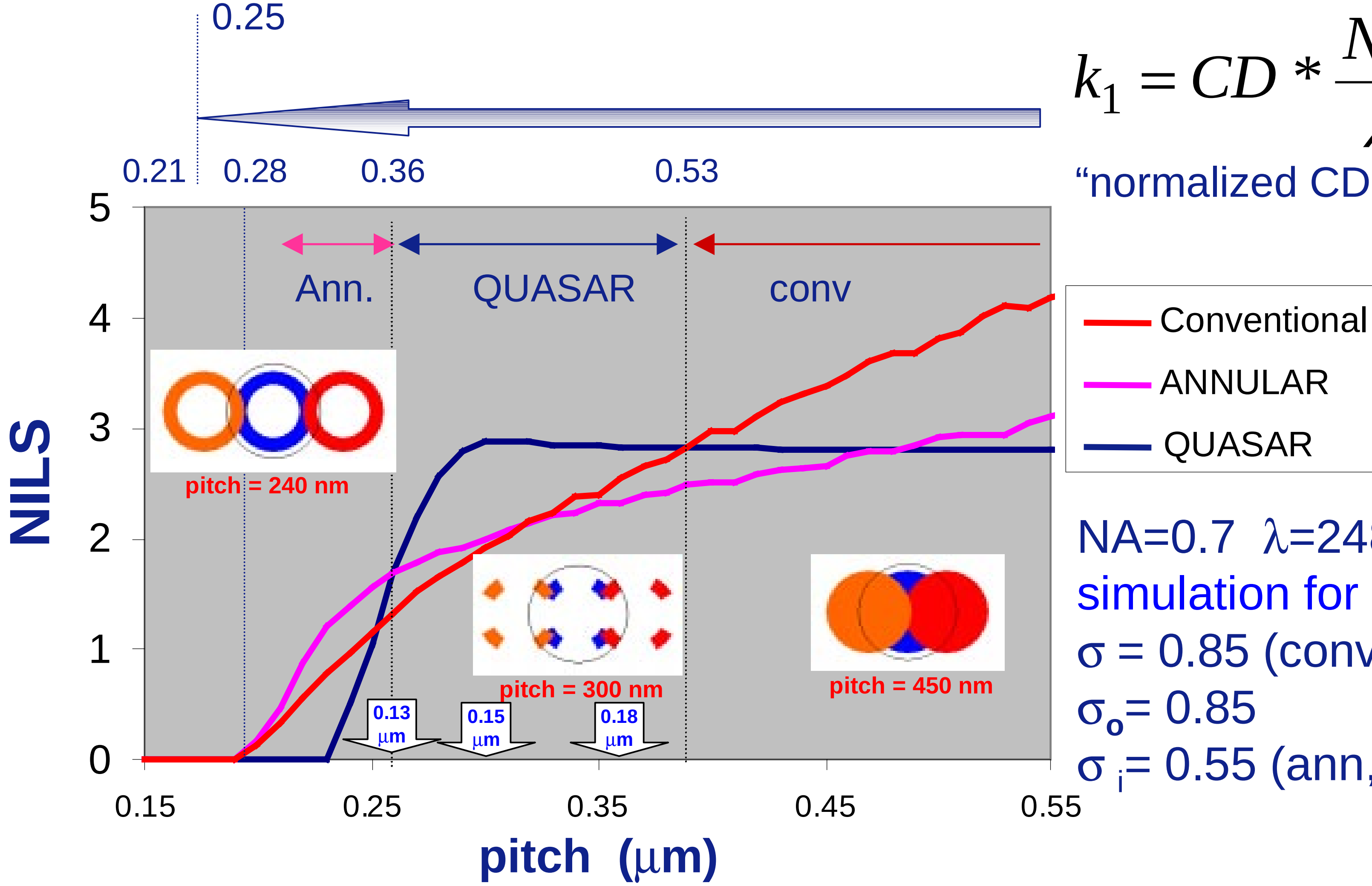
Illumination enhancement techniques

OAI and Normalized Image Log Slope



$$k_1 = CD * \frac{NA}{\lambda}$$

"normalized CD"

NA=0.7 λ=248 nm

simulation for L/S (1:1)

σ = 0.85 (conv.)

σ_o= 0.85

σ_i= 0.55 (ann, QUASAR

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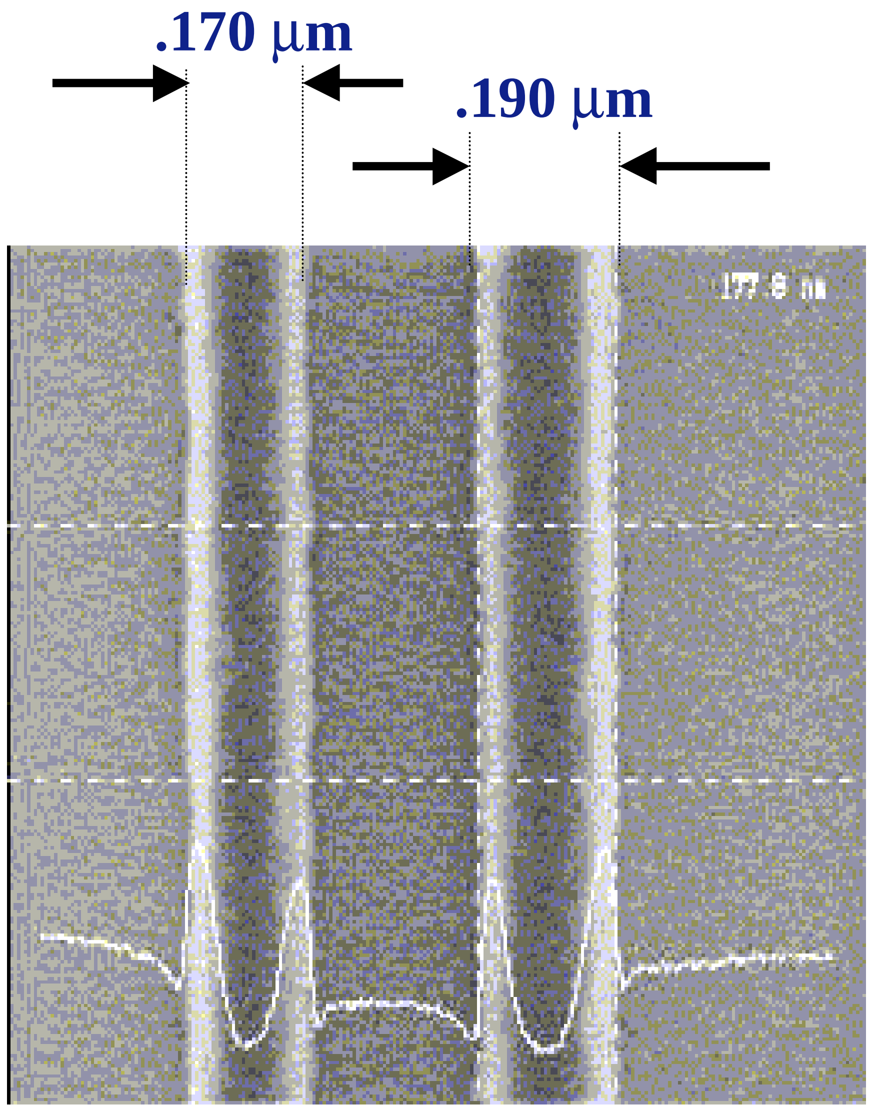
Optimal use of Projection Optics

Case study L_1L_5

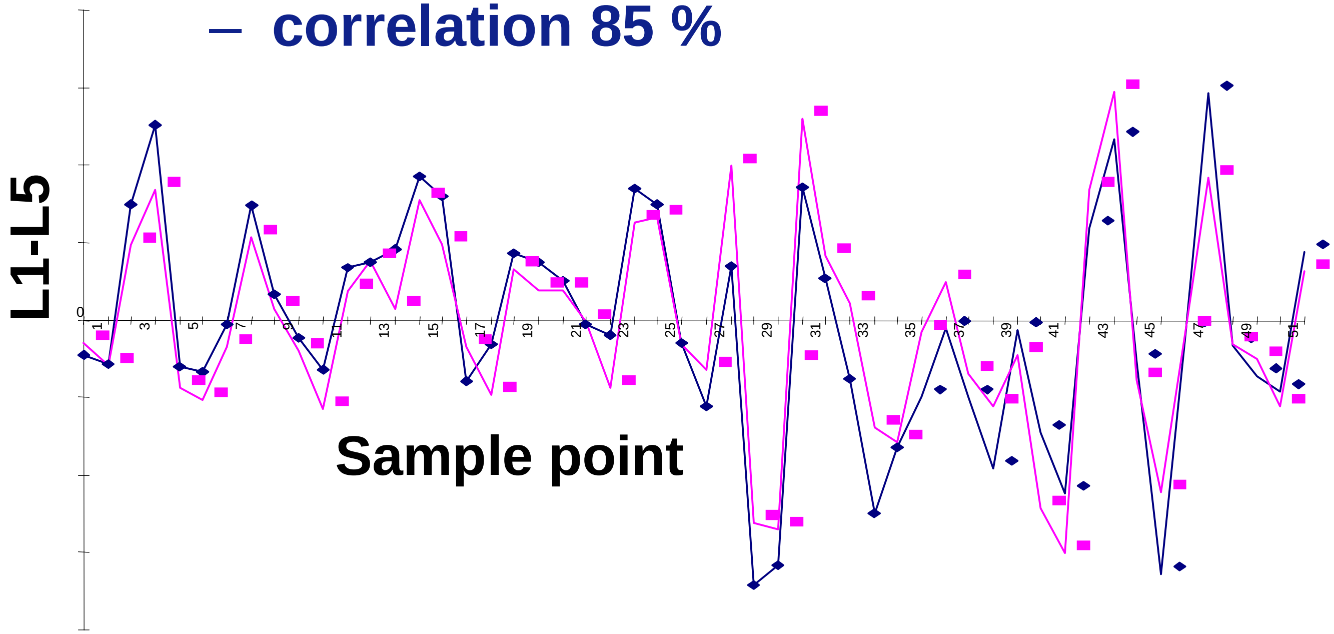


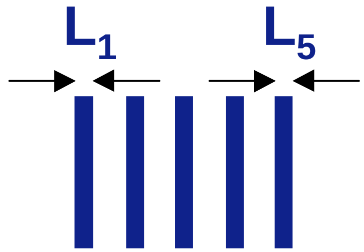
Target .180 µm

Optimal use of Projection Optics

Case study L_1L_5

- **Understanding L_1-L_5**
  - Measured and calculated
  - two feature orientations
  - correlation 85 %

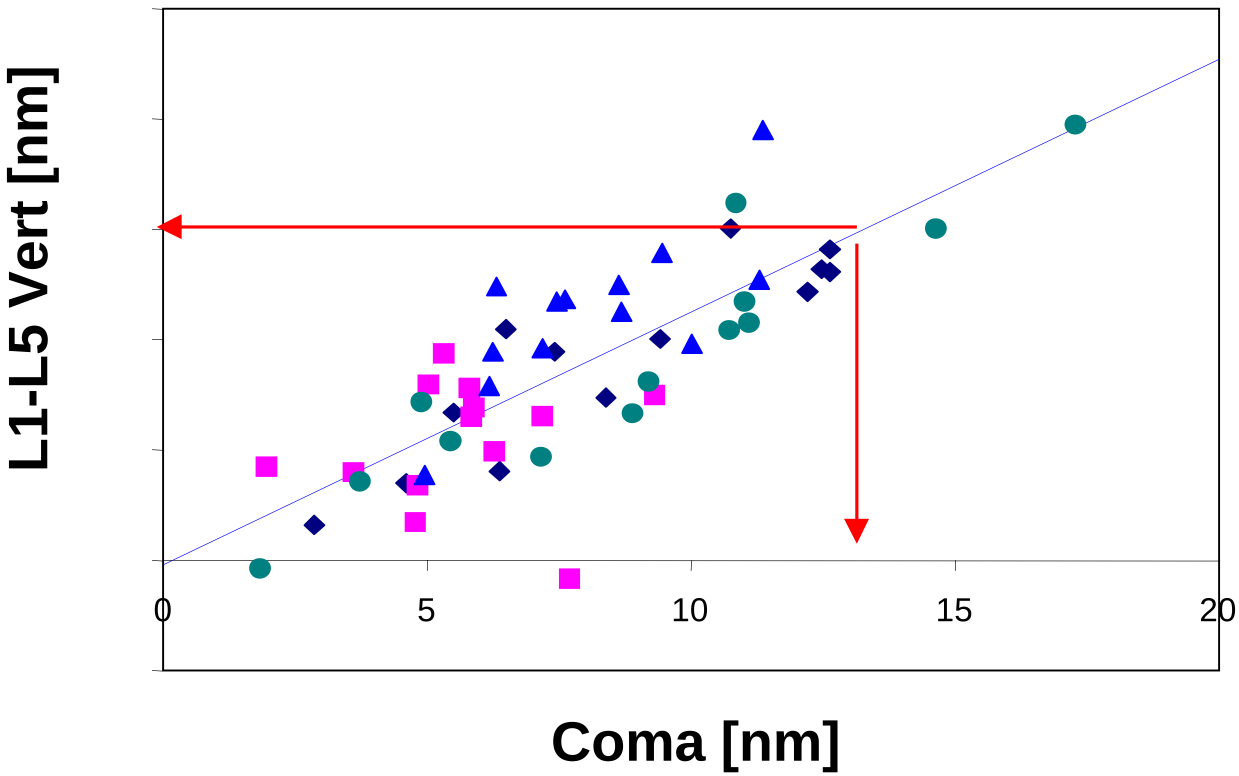




Optimal use of Projection Optics

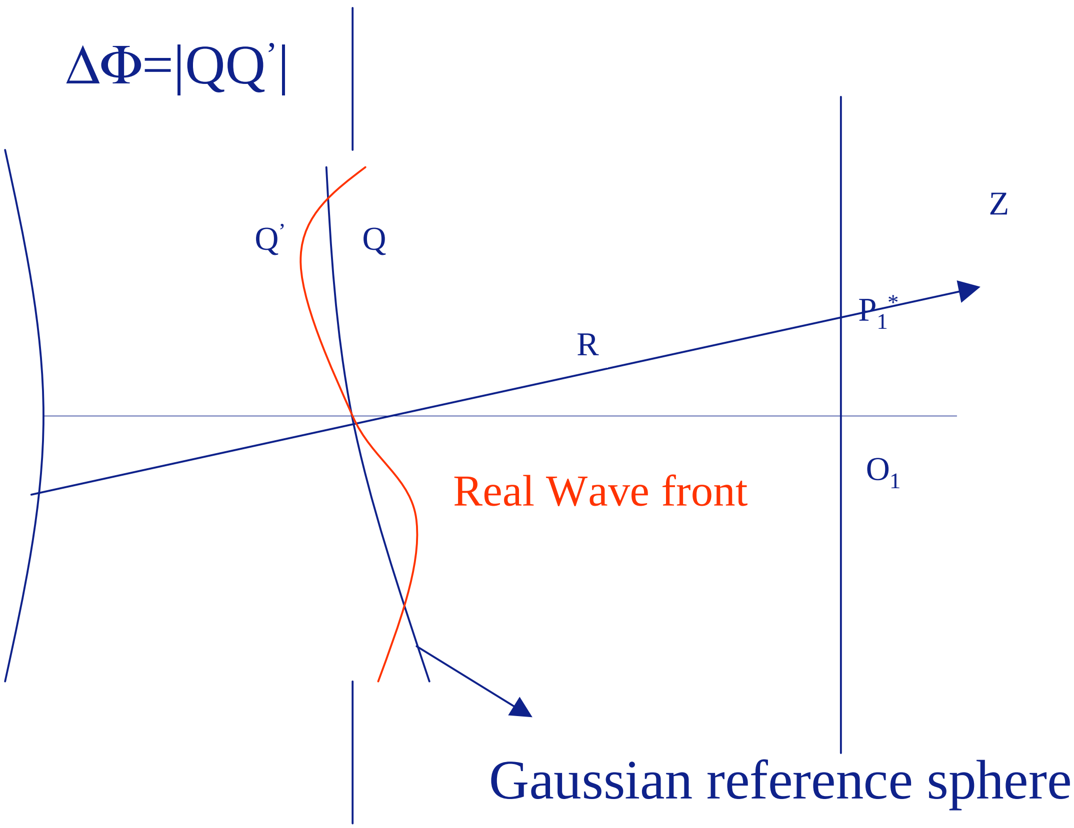
Case study L_1L_5

- **Correlation with coma aberration:**

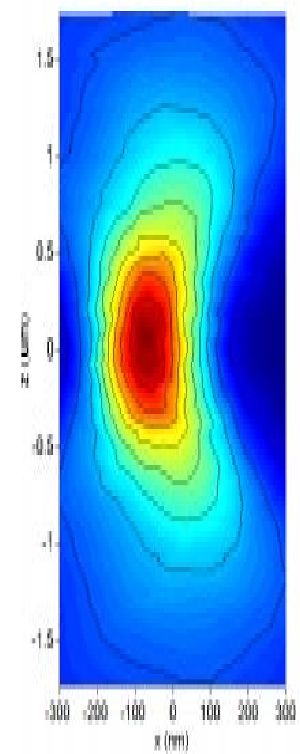


Optimal use of Projection Optics

Case study L_1L_5



Coma



Coma= 13 nm: $\Delta\phi = (n-1)*d$, ➨ d=26 nm on a track length of 1 mete

distributed over 50 to 60 surfaces.

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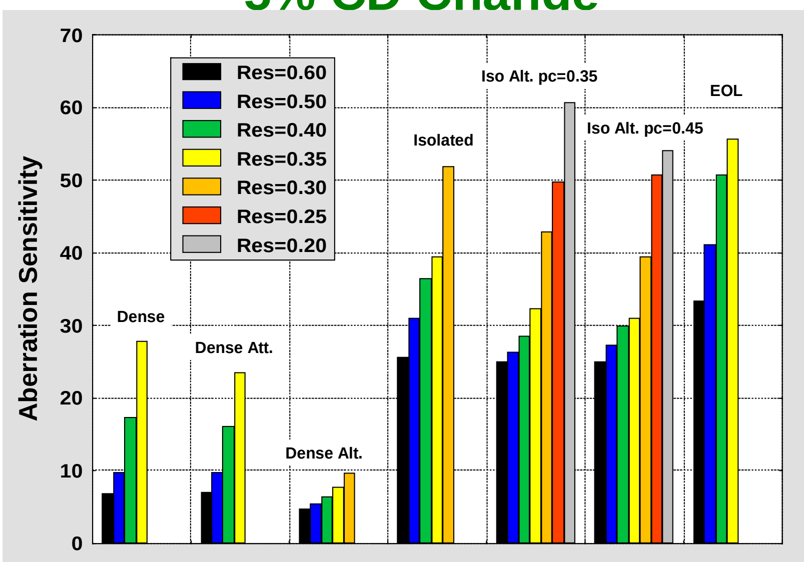
Optimal use of Projection Optics

Aberration levels

- Quality in RMS wavefront aberration (Progler, 1998)
  - Gold: 0.025 λ (6.2 nm for 248 nm)
  - Silver: 0.04 λ
  - Bronze: 0.06 λ

- Set a target at 5% CD change due to aberration
  - Extract the RMS aberration level that results from the target
  - Define an aberration sensitivity parameter as SA=RMS-1

5% CD Change

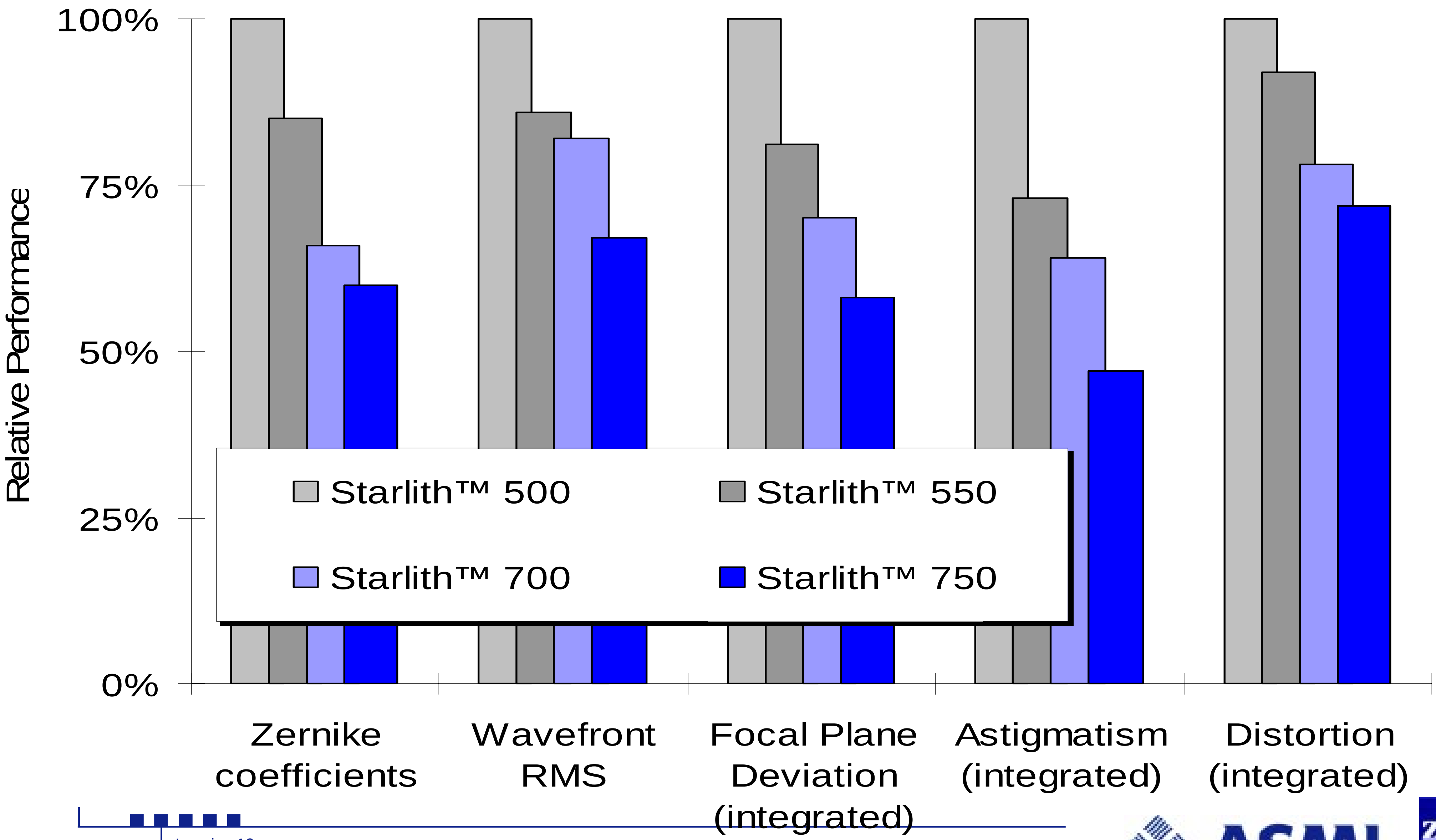


- More accurate description needed: Zernike fringe polynomials

- Zeiss makes ‘golden’ lenses

Optimal use of Projection Optics

Aberration levels

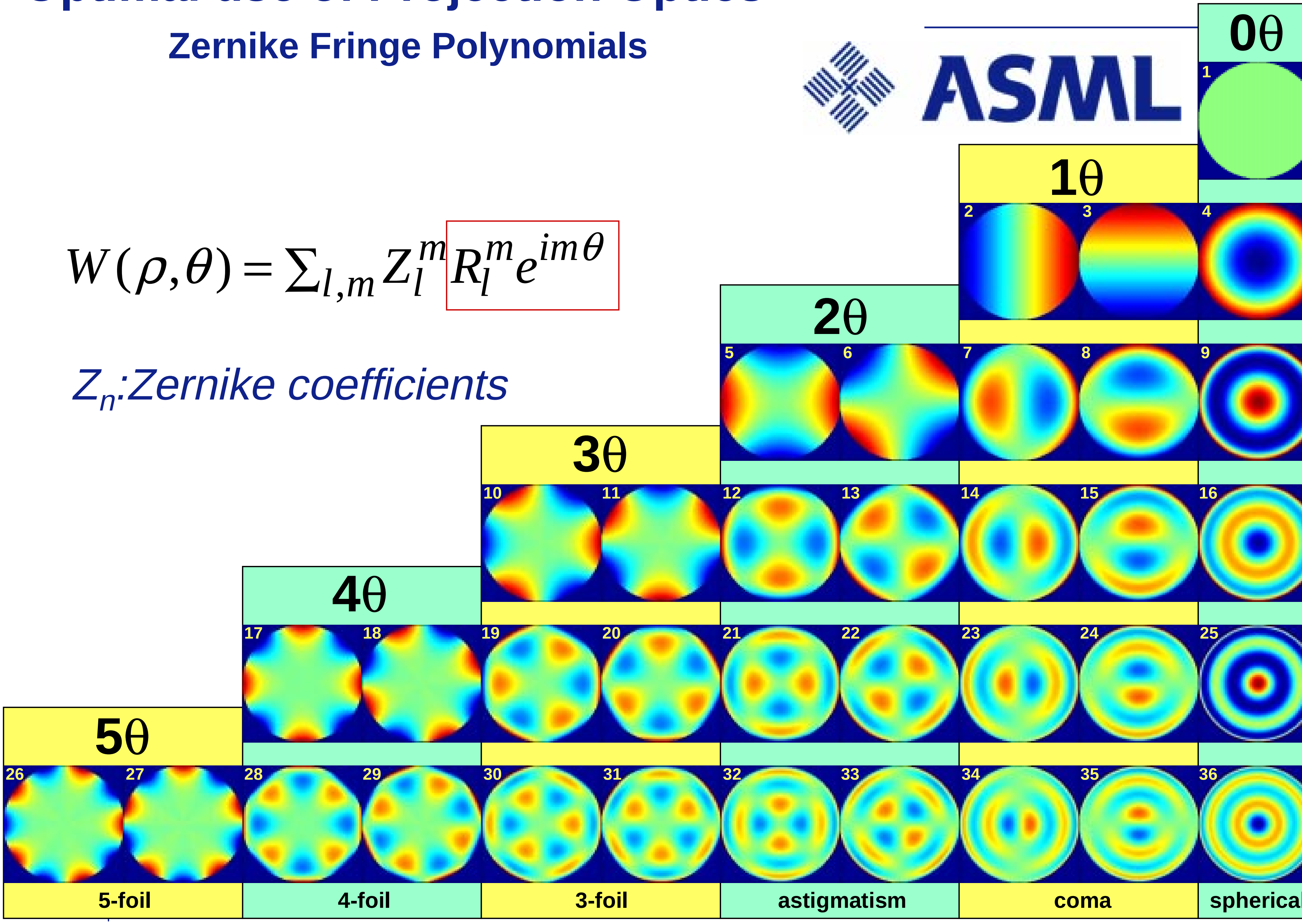


Optimal use of Projection Optics

Zernike Fringe Polynomials

$$W(\rho,\theta)=\sum_{l,m} Z_l^m R_l^m e^{im\theta}$$

Z_n:Zernike coefficients



Optimal use of Projection Optics
Aberration measurements

- **All lens manufacturers use phase measuring interferometry (PMI) during manufacturing.**

- **In situ by sampling the pupil**
  - **Select angles (Litel)**
  - **Use structures with different diffraction patterns**
  - **Use Multiple Illumination Settings (NA/s)**
    - **Quick and extension on established methods: FAMIS/DAMIS**
    - **Full lens qualification: Artemis**

Optimal use of Projection Optics

Aberration measurements At Multiple Illumination Settings

- **FAMIS: Focal At Multiple Illumination Settings**
  - Best Focus changes due to spherical aberration: $Z_{4,}$ $Z_{9,}$ Z_{16},…
  - Sensitivity depends on NA/σ and can be calculated
  - Solve linear matrix equation:

$$\begin{bmatrix} BF_{meas}(1) \\ BF_{meas}(2) \\ \ldots \\ BF_{meas}(n) \end{bmatrix} = Z4 \cdot \begin{bmatrix} 1 \\ 1 \\ \ldots \\ 1 \end{bmatrix} + Z9 \cdot \begin{bmatrix} BF_{sim@1nm\_Z9}(1) \\ BF_{sim@1nm\_Z9}(2) \\ \ldots \\ BF_{sim@1nm\_Z9}(n) \end{bmatrix} + Z16 \cdot \begin{bmatrix} BF_{sim@1nm\_Z16}(1) \\ BF_{sim@1nm\_Z16}(2) \\ \ldots \\ BF_{sim@1nm\_Z16}(n) \end{bmatrix}$$

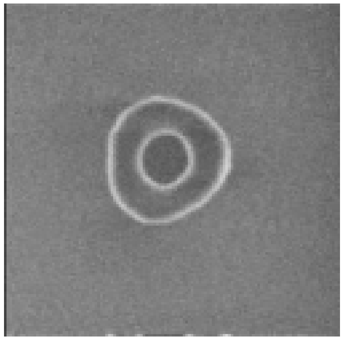
- **Generalized: C=W·Z**

Optimal use of Projection Optics

Aberration measurements At Multiple Illumination Settings

- **Famis:**
  - Spherical aberration, Astigmatise: $Z_{9,16}$, $Z_{12,21}$
- **Damis: Distortion at MIS**
  - Coma: $Z_{7,8}$, $Z_{14,15}$
- **Artemis: ART at MIS (Philips)**
  - Full set, $Z_{5\text{-}37}$,

- **Artemis: Prints a phase dot**

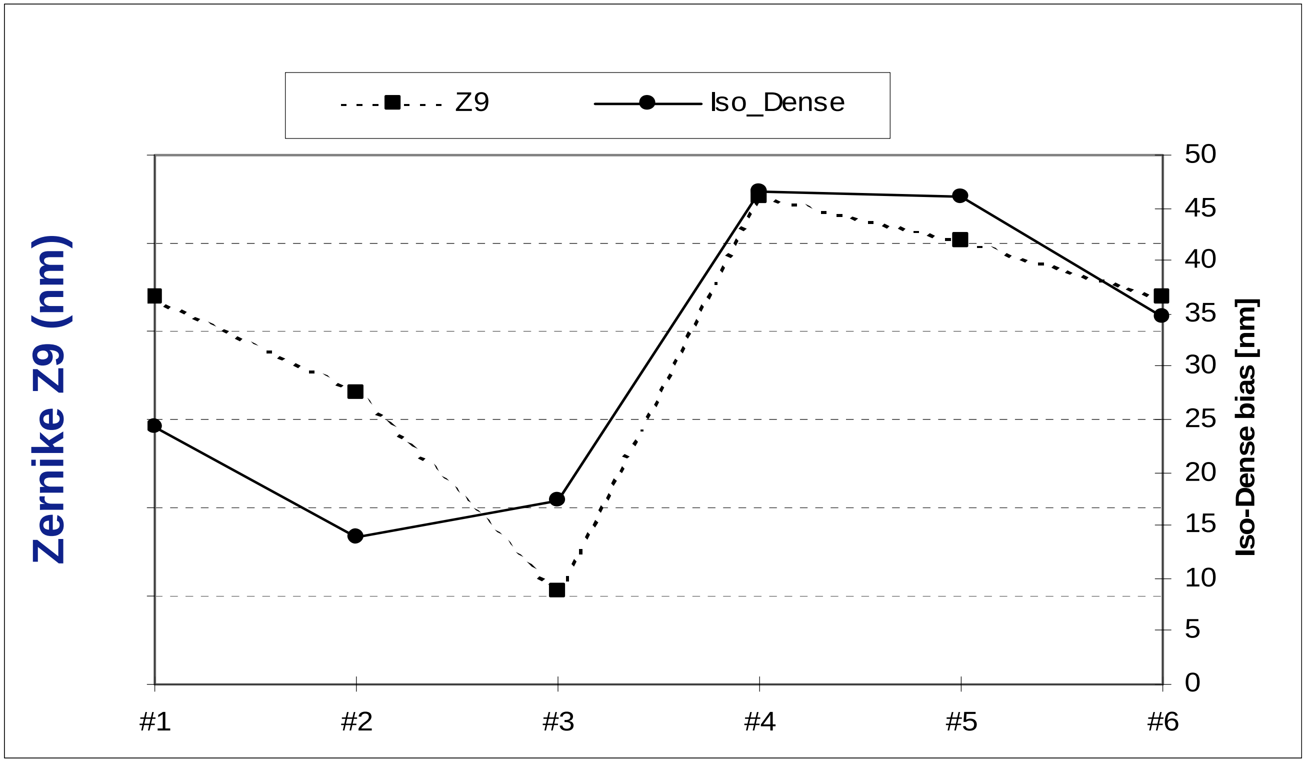


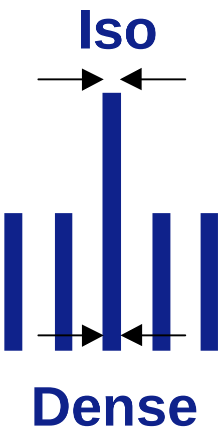
- **Deformation is written as a Fourier series.**
- **Order of Fourier components correspond to angular Zernike coefficients**
- **MIS allows separation of radial term**

Optimal use of Projection Optics

Lithographic Correlation and Aberration control

- **Controlling Iso-dense bias**
  - Related to Spherical Aberration, measurable with FAMIS
  - Process optimization reduces Iso-dense bias

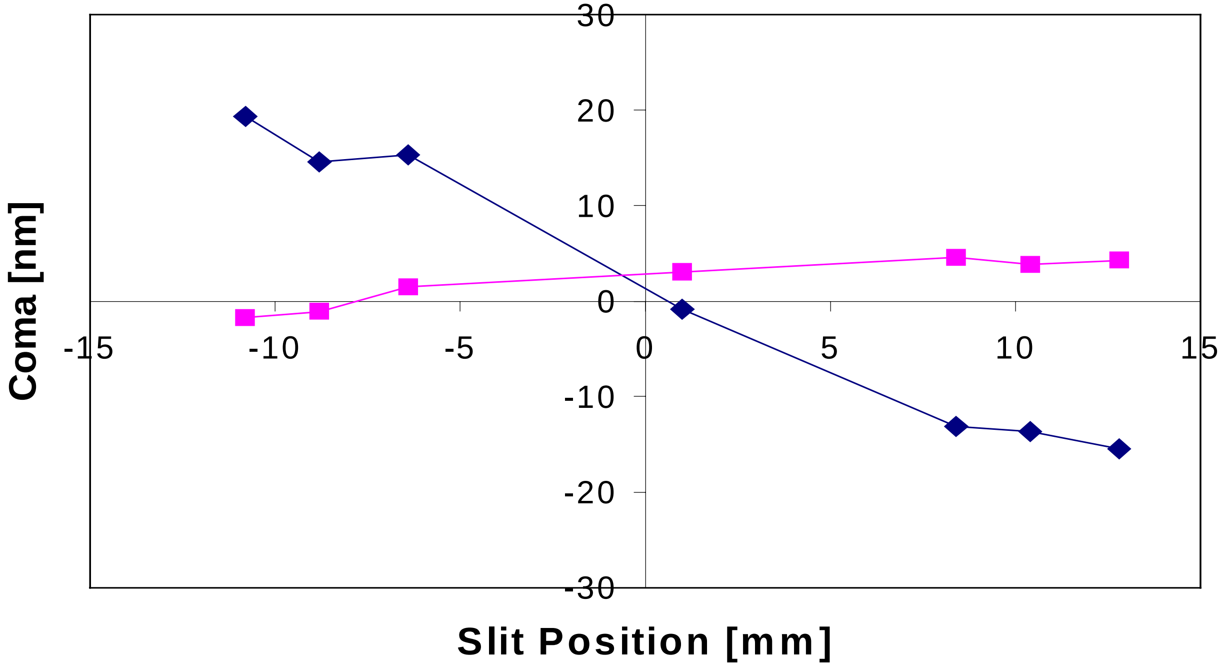




Optimal use of Projection Optics

Lithographic Correlation and Aberration control

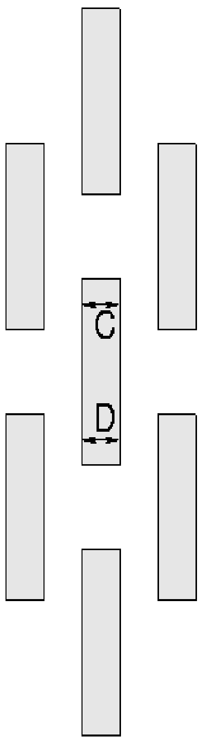
- **Controlling L_1L_2**
  - Caused by coma, measurable by DAMIS
  - Wavelength shift reduced coma
  - L_1L_2 reduced from 50 to 10 nm

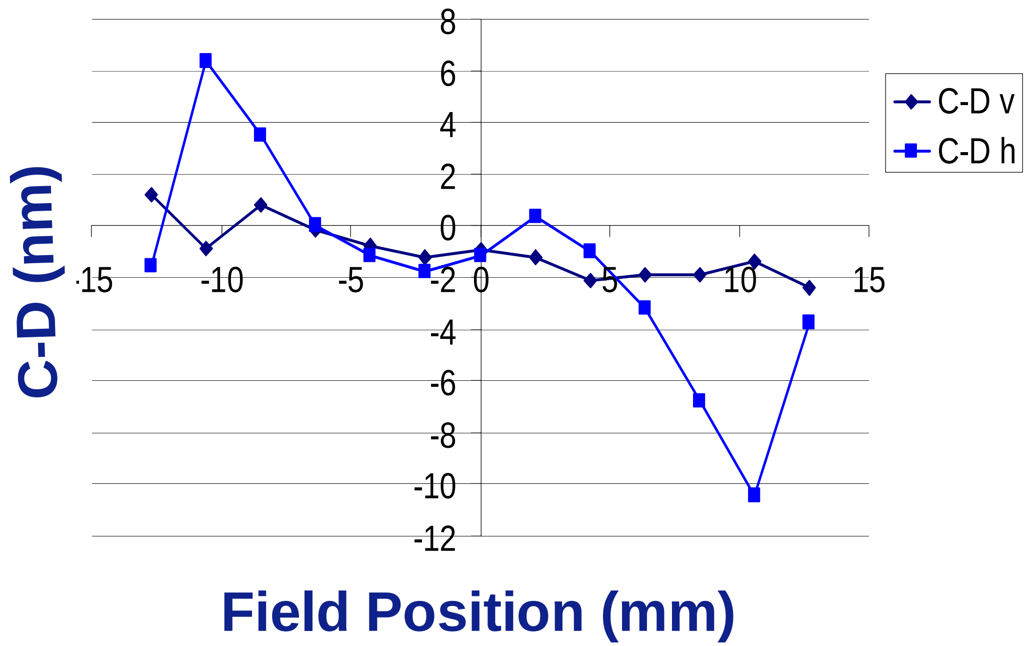


Optimal use of Projection Optics

Lithographic Correlation and Aberration control

- **Isolation properties of DRAM cells at $k_1 = 0.37$**
  - **C-D is critical metric , Threewave and coma sensitive**
  - **Predicted performance of a 'golden' lens**





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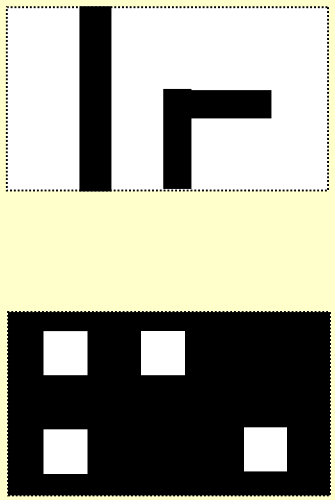
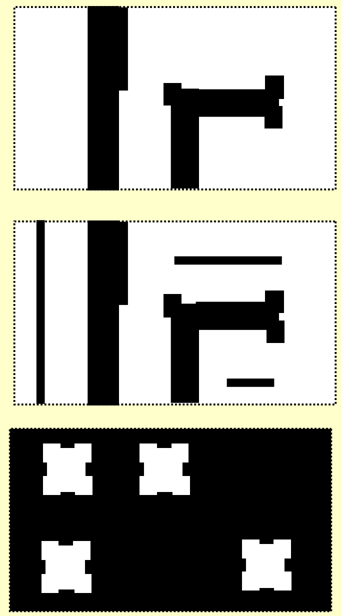
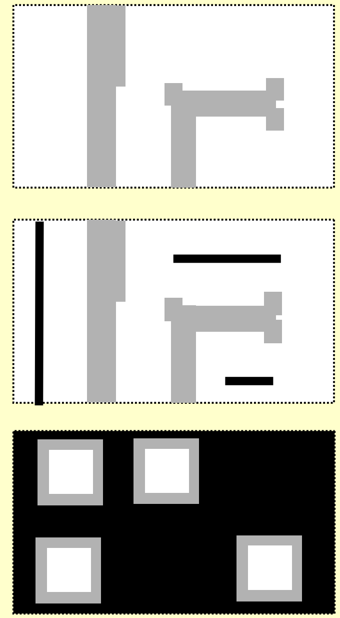
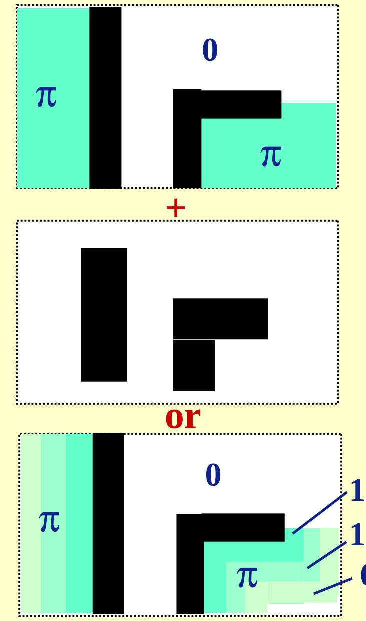
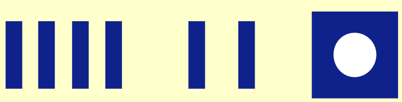
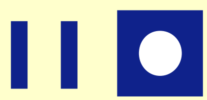
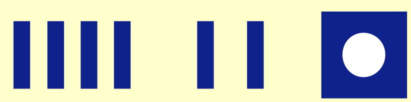
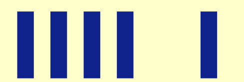
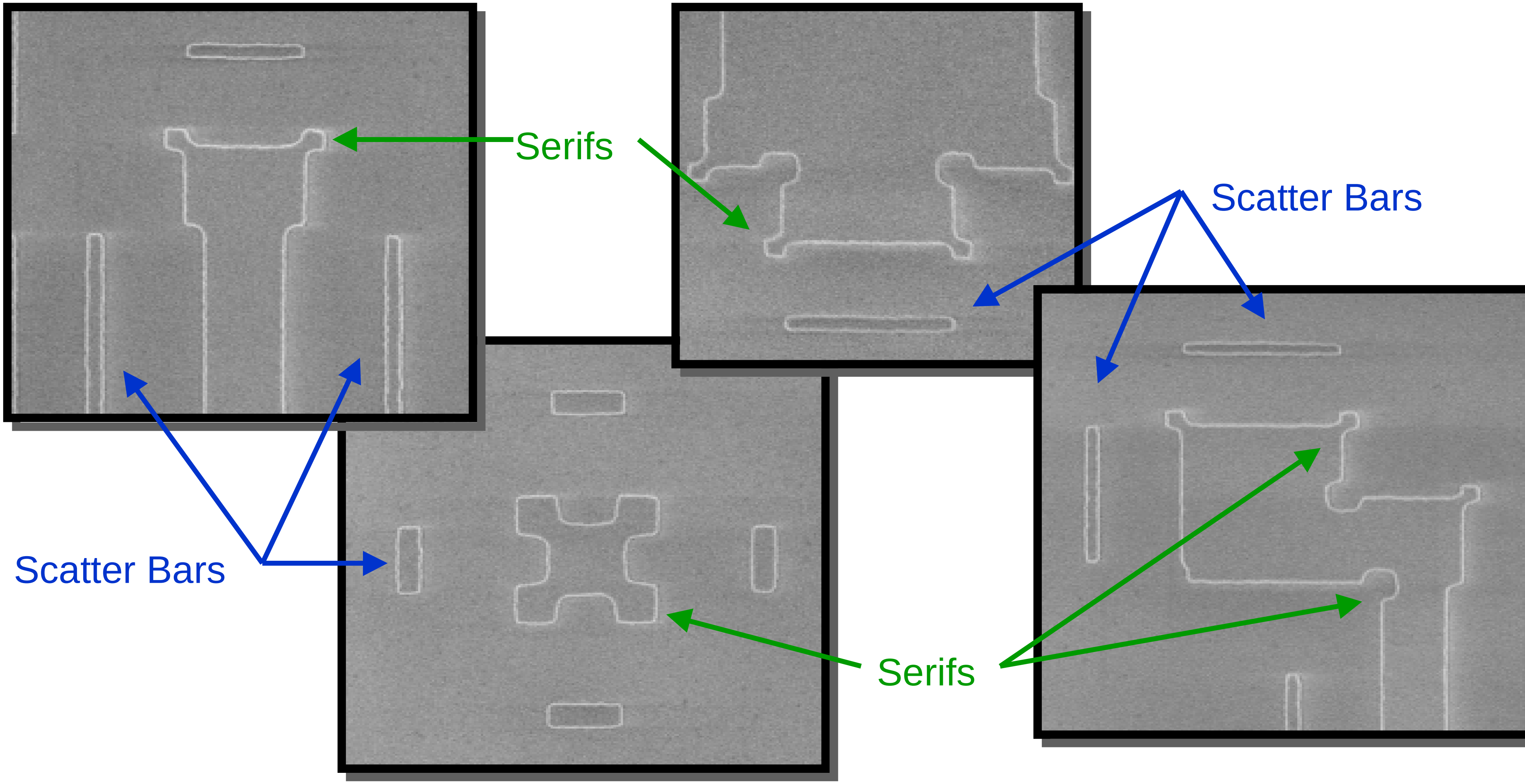
Reticles

Resolution Enhancement Techniques

Masks				
Mask Type	Binary or Chrome on Glass	OPC & Assist Features	Half Tone or Attenuated PSM	Levenson or Alternating PSM
Structure(s)				
Challenges	Low k1 Imaging	Writing, Inspection	Material, Repair	CoO, Phase errors, inspection & repair

Reticles

Optical Proximity Correction

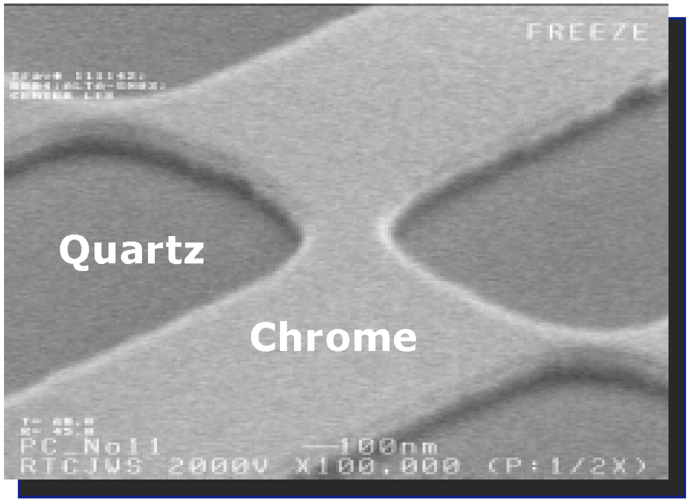


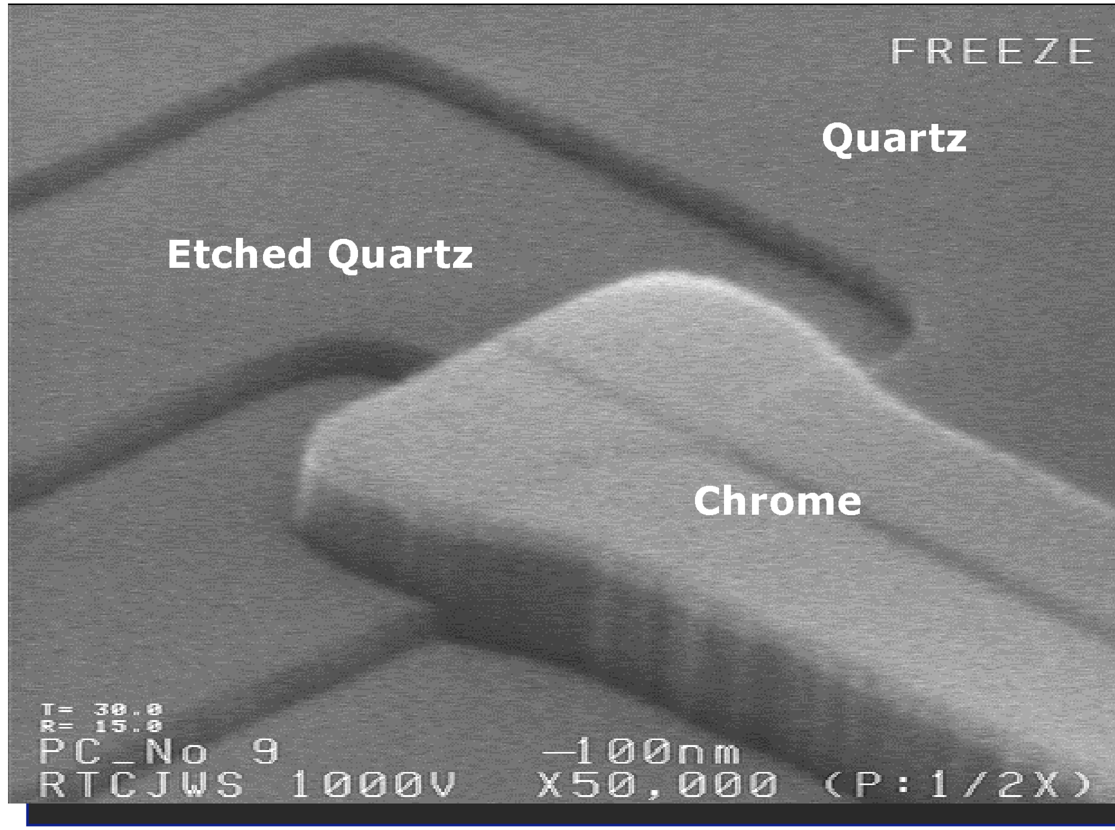
Reticles

Phase Shifting Masks

DuPont

Binary Mask





Multi-Phase Shift Mask

Reticles

Quality: CD-uniformity

Feature	Setting	CD-uniformity [3σ, nm]					
		@BF	*MEF*	*Reticle contr.*	±0.1µm	±0.2µm	±0.3µ
180nm DL	NA=0.60 σ=0.70/0.40	11	*2.1*	*8*		12	14
180nm iso	NA=0.56 σ=0.60/0.30	9	*1.2*	*5*		23	
150nm DL	NA=0.66 σ=0.75/0.45	14	*3.2*	*12*	14	15	
150nm DL*	NA=0.70 σ=0.85/0.55	11	*2.0*	*8*		15	
150nm iso	NA=0.62 σ=0.85/0.55	11	*1.3*	*5*	19		

* : Quadrupole

20 points per field, 2 orientatio
Averaged over 6 dies
AMAT 7830SI CD-SEM

Reticles

Why is MEF $\neq$ 1?

- Lower Aerial Image Contrast -> Higher MEF
- Position of Resist Threshold strongly affects MEF

Acknowledgements

- Projection Lenses group, especially Hans van der Laan, Marco Moers, Rob Willekers
- Jan van Schoot, Jo Finders, Henk van Greevenbroek, Jan Mulkens, Donis Flagello, Kevin Cummings, Anton van Dijsseldonk, Hans Meiling
- Christian Wagner of Carl Zeiss

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