Impact of Imaging Optics Quality on Actinic Mask Blank Inspection

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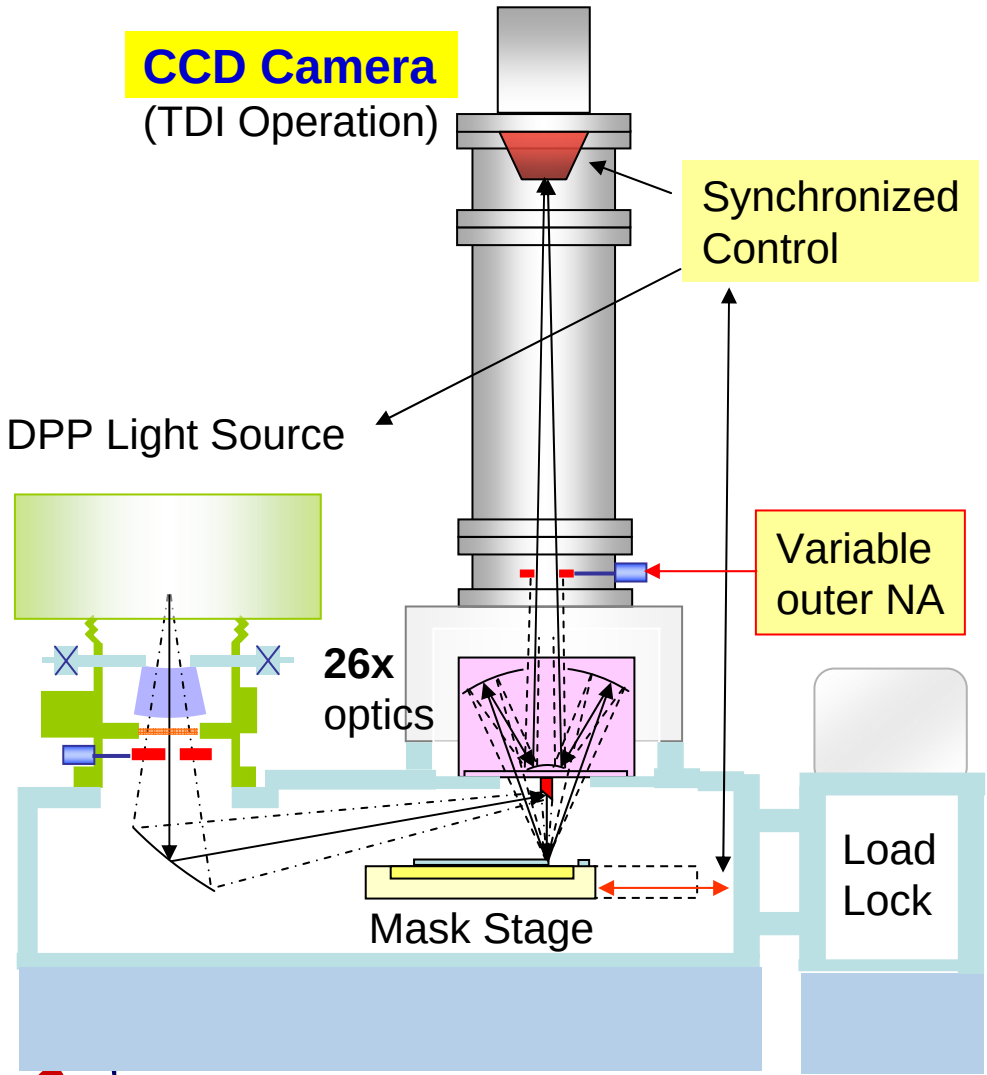
Outline

- Introduction
  - Prototype design
  - Sensitivity-limiting factors
- Impact of imaging optics quality
  - Defect image with 26x optics
  - PSF extraction from defect signal
  - Dark-field flare evaluation
- Discussion
  - Comparison with optics MSFR
  - Requirement for optics quality
- Summary

Full-field Prototype Design

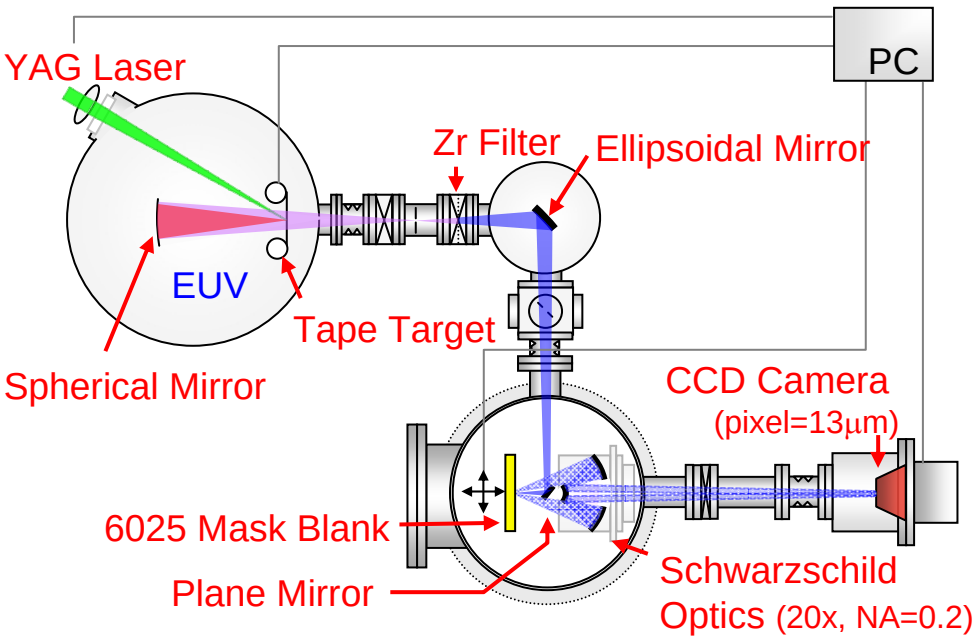


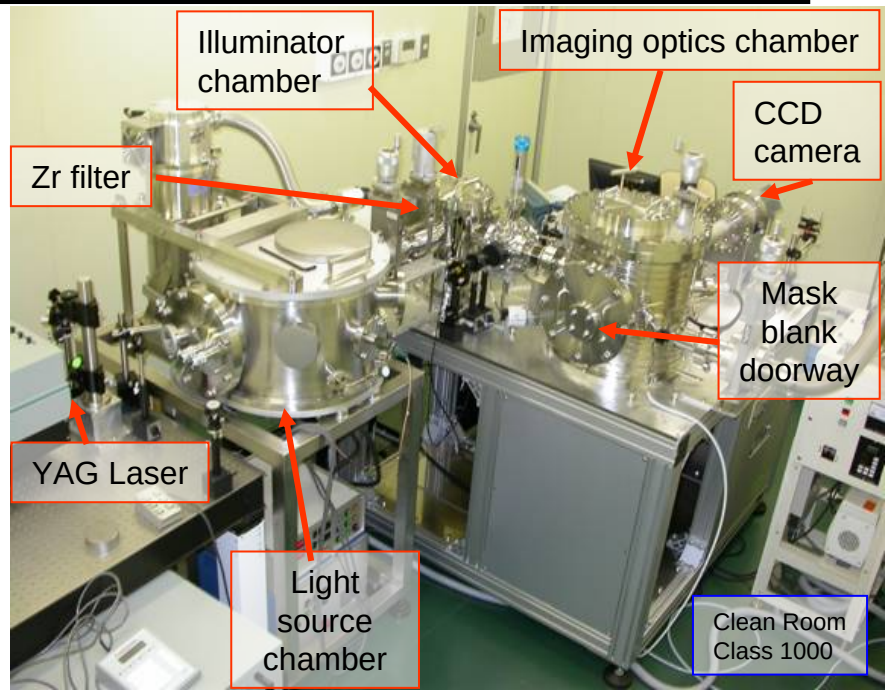
Model	MIRACL-1000 (1)
Specification	
Objects	6025 EUVL Mask Blanks
Sensitivity	< $40nm^{w}$ x $2nm^{h}$ (2)
Throughput	2hrs/blank
Pos. Accuracy	< 250nm
Configuration	
Light Source	wavelength=13.5nm, DPP, Every pulse Triggerble
Illumination	Critical Illumination, Ellipsoidal mirror + Plane mirror, Illum. area >0.5mm sq.
Imaging Optics	26x Schwarzshild Optics, Inner NA = 0.1, Outer NA = 0.2~0.3
Sensor	Back-illuminated CCD, TDI Operation, Synchronized with light source pulses
Stage	Continuous move, Interferometer feedback
Software	Automatic defect cllasification, Size inference, Position identification
Add-on Func.	Angular dist measurement with variable aperture for shape inference
Alignment	Focus / Position alignment function by fiducal mark
Interface	SMIF-capable, EUV mask handling standard compliant

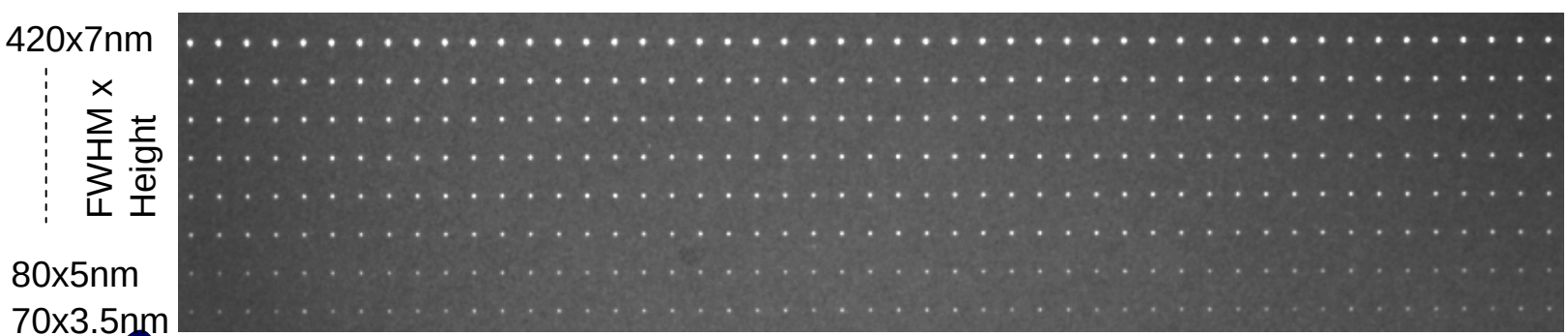
(1: **M**askblank **I**nspection for **R**eflective multilayer by **AC**tinic **L**ight)

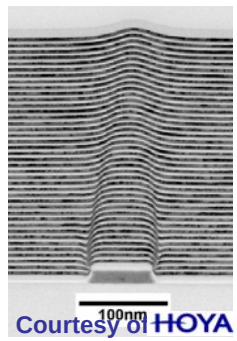
(2: in use of ultra smooth blank)

POC Tool & Inspection Image



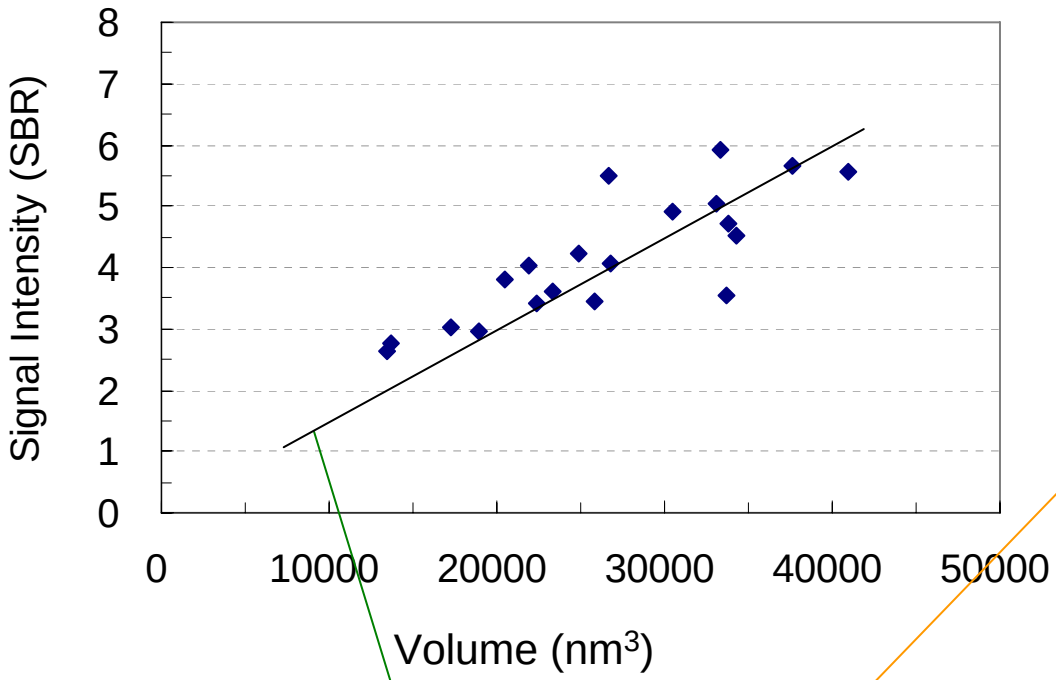


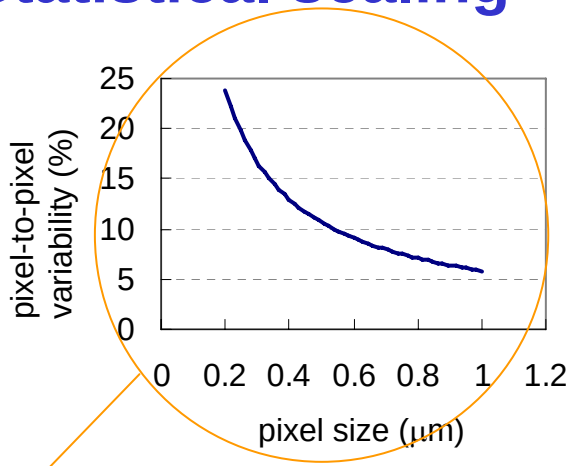


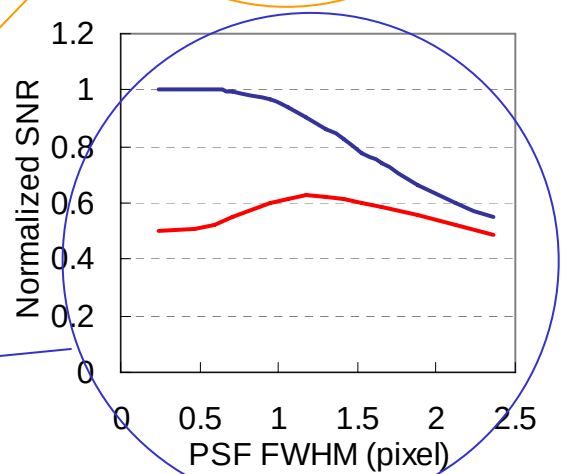


Sensitivity Derivation

Extrapolation from Experiments + Statistical scaling



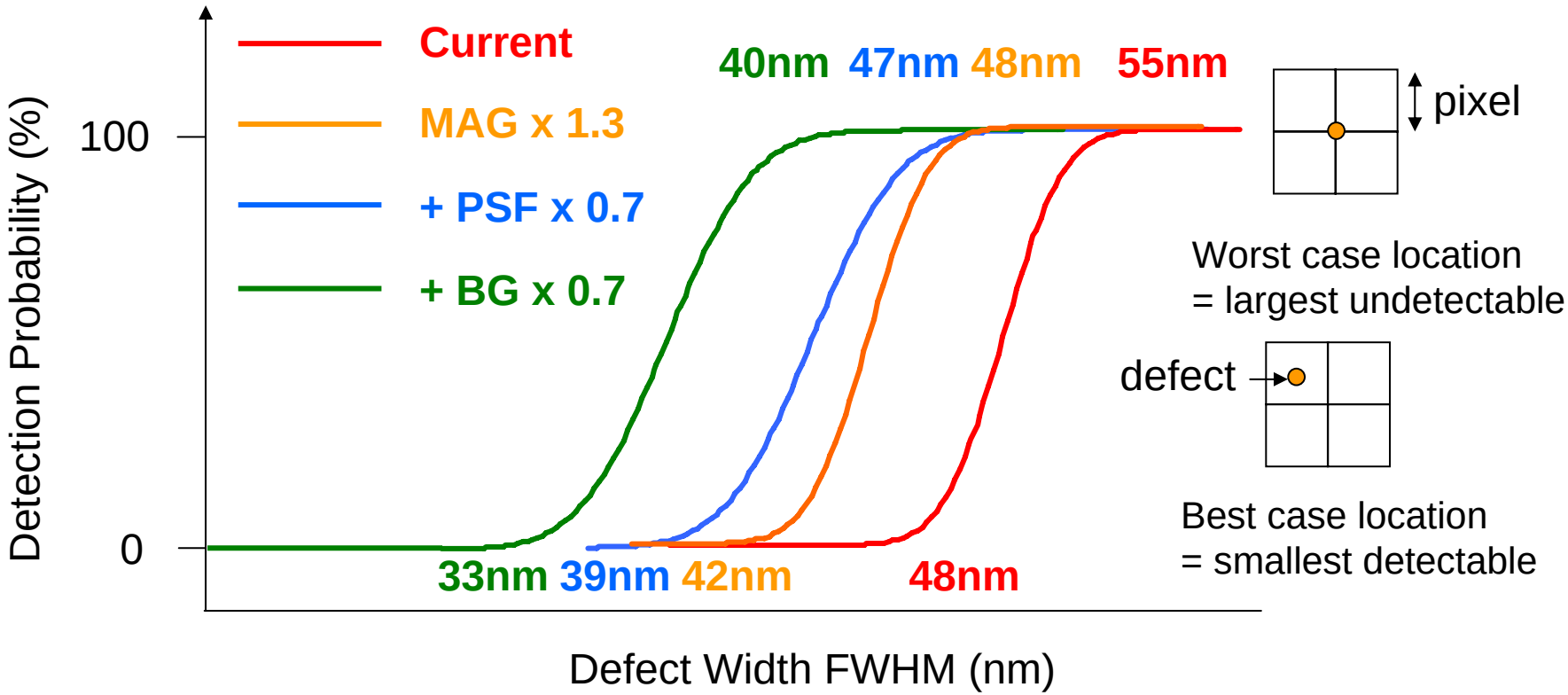




$$SNR = \frac{S(volume)}{B(roughness, pixel)\cdot\sigma_r(pixel)}\cdot\frac{\xi(PSF)}{f(PSF)}$$

Sensitivity Prediction

FWHM of 2nm-high Detectable Defects at SNR>7

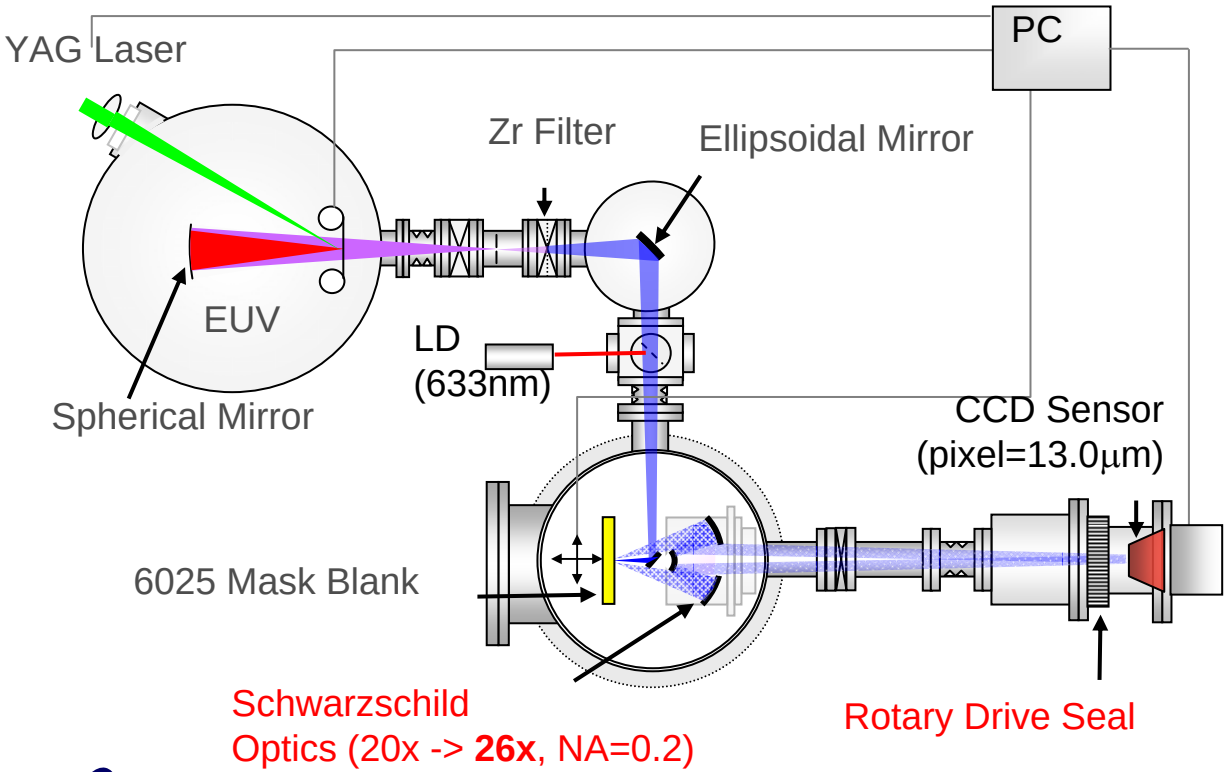


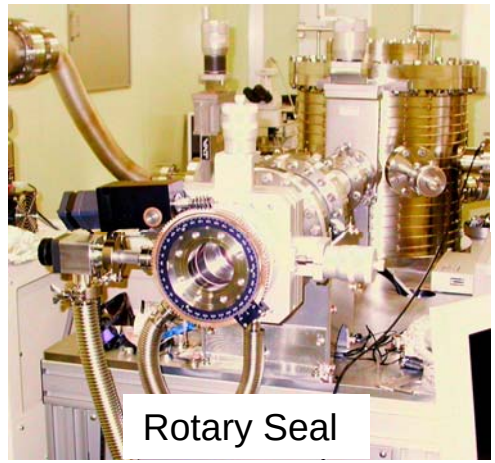
Blank Roughness Reduction is Essential !

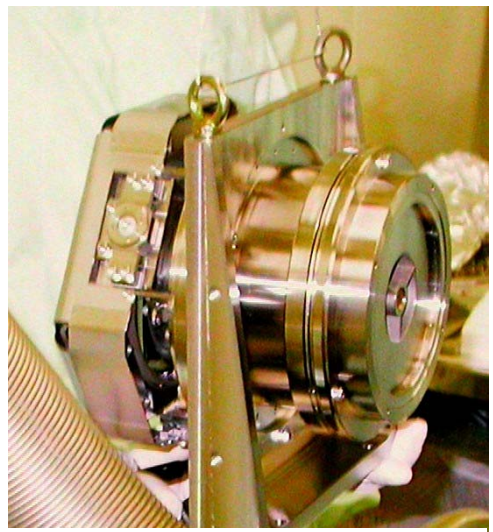
POC Tool Upgrade

Latest Upgrade

- Schwarzschild Optics: 20x -> 26x
  - best effort-based quality within limited time frame
- CCD Rotary Stage



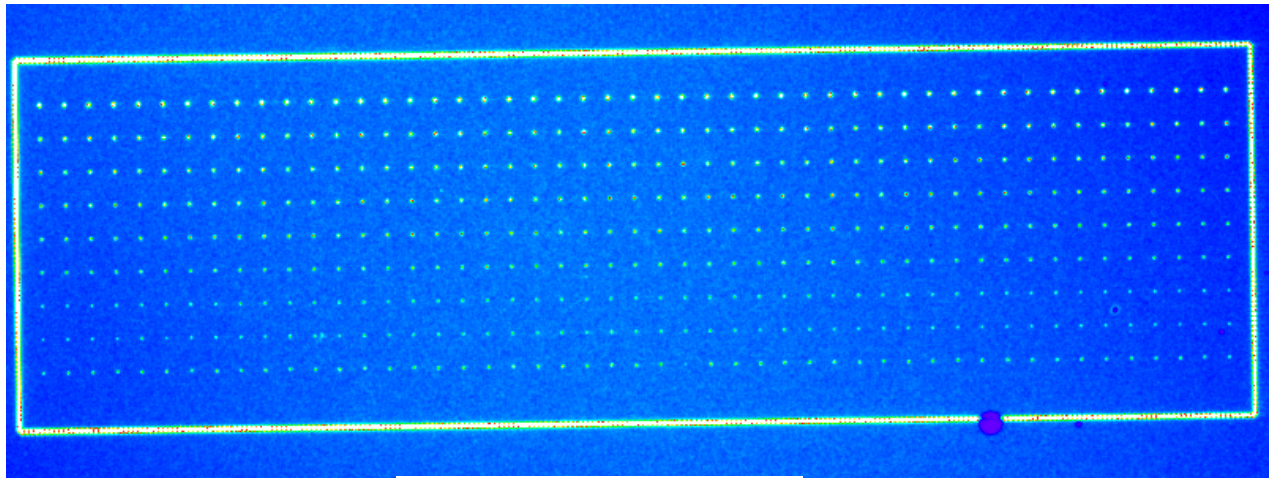




26x Schwarzschild Optics

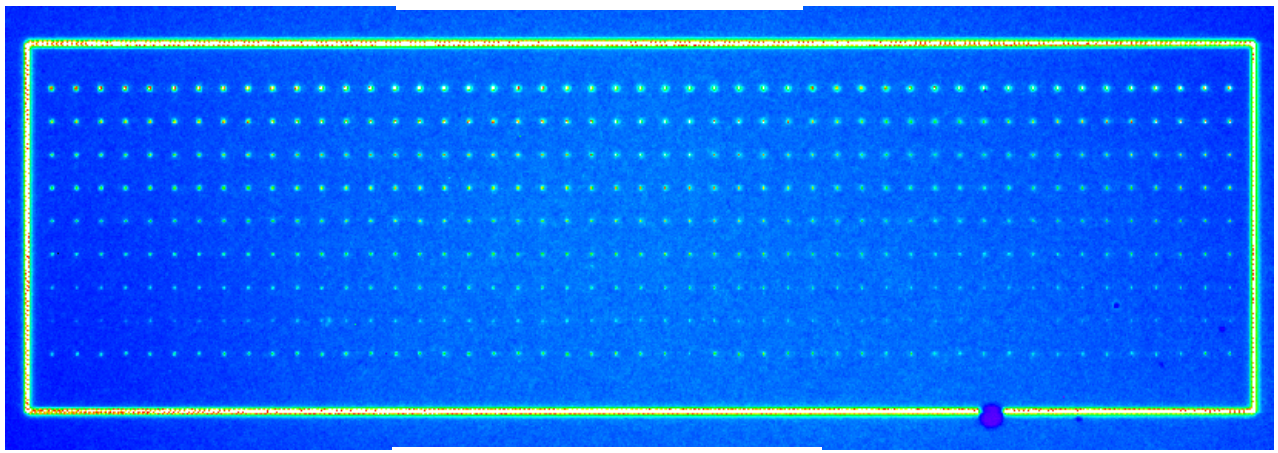
Inspection Image Comparison

20x, May'05



500μm (=770 pixel)

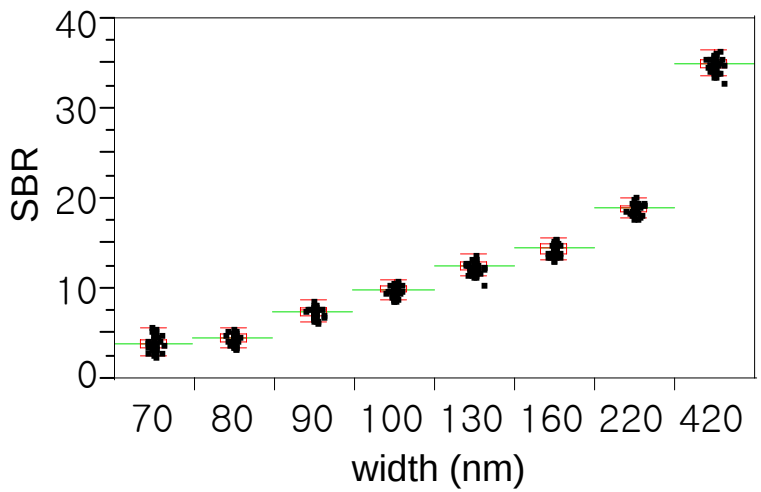
26x, Jan'06



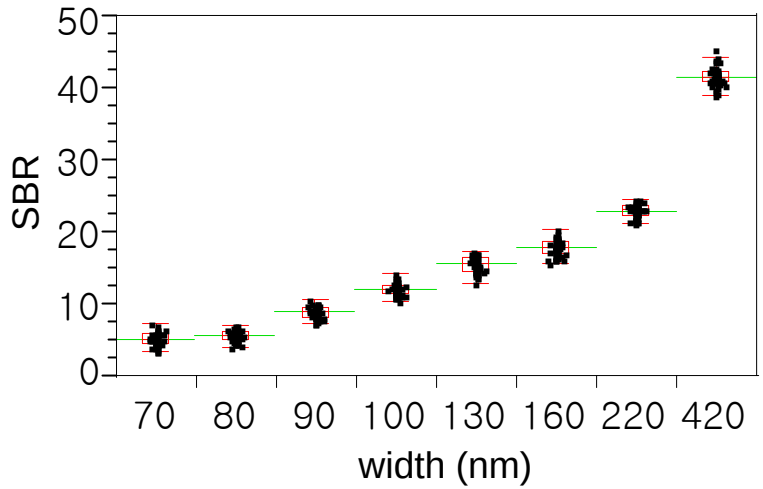
500μm (=1000 pixel)

Gross Intensity Comparison

20x (5x5 pixel)



26x (6.5x6.5 pixel)



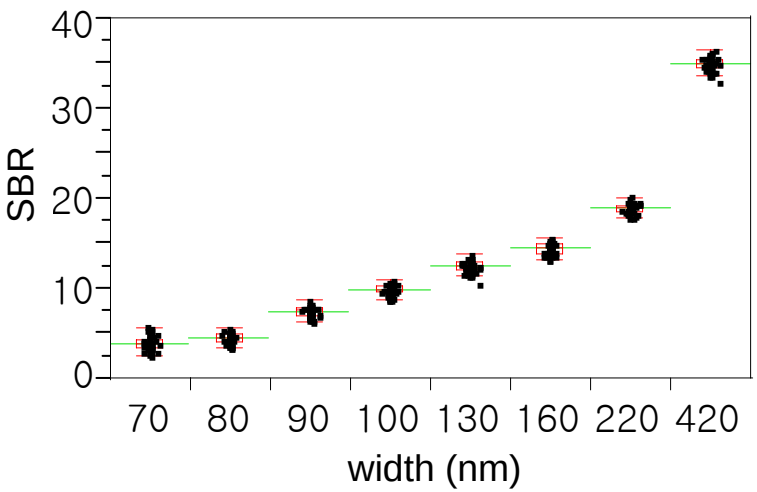
$$SBR = \sum_{i,j}^{5\times5 \text{ or } 6.5\times6.5} \frac{A_{i,j} - \langle BG \rangle_{Local}}{\langle BG \rangle_{Local}}$$

Theoretical Prediction: 1.69x improvement if optic finish is the same
Experiment: 1.25x improvement

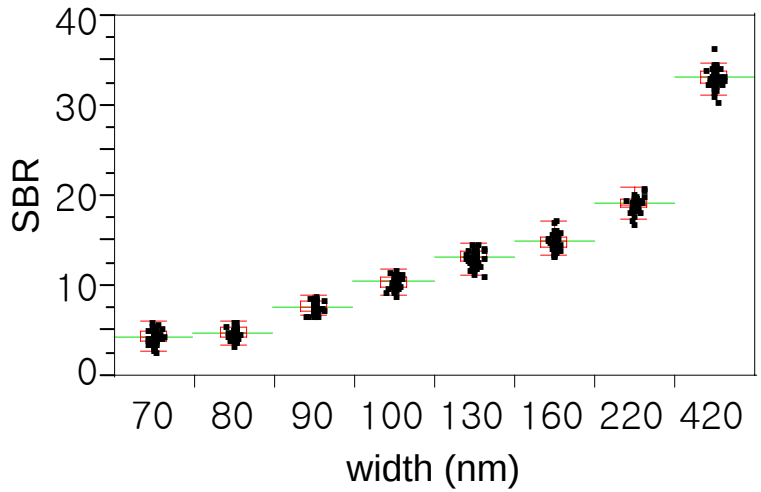
EUV after MSFR loss of 26x optics can be only 74%(=1.25/1.69) of 20x optics.

Normalized Intensity Comparison

20x (5x5 pixel)



26x (5x5 pixel)



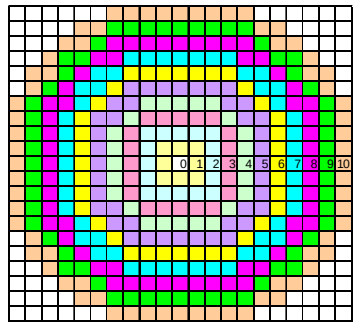
$$\mathrm{SBR} = \sum_{i,j}^{5\times5} \frac{A_{i,j} - \langle BG \rangle_{Local}}{\langle BG \rangle_{Local}}$$

Fair comparison metric in working sensitivity

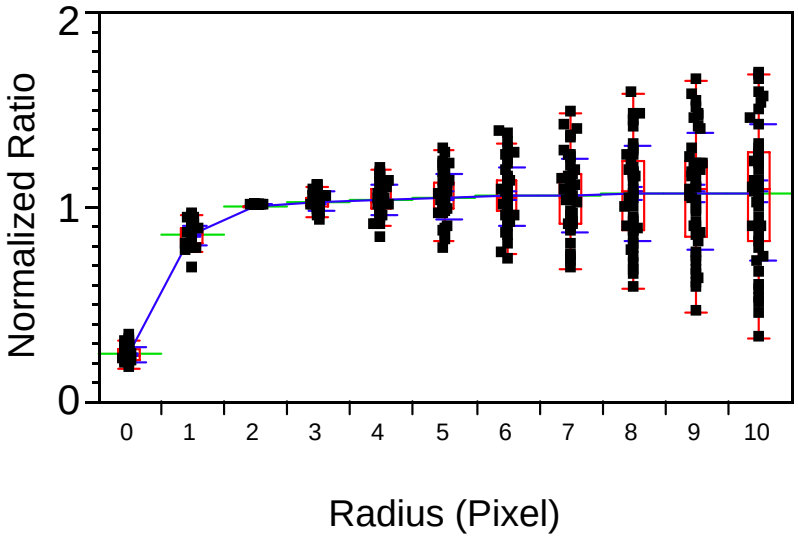
Prediction: 1.69x improvement **provided that PSD improves by 1.3x**
Experiment: 1.06x improvement -> virtually no improvement

Encircled Energy Comparison

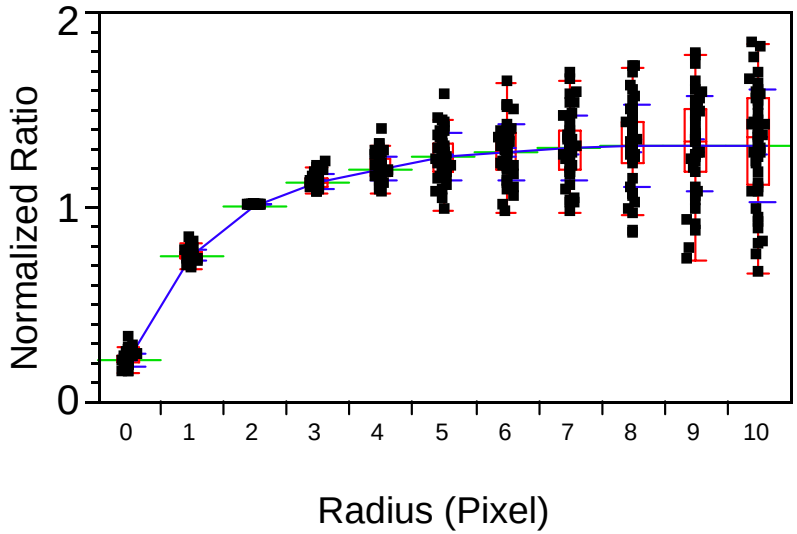
- Integrated PSF extraction from images



20x optics



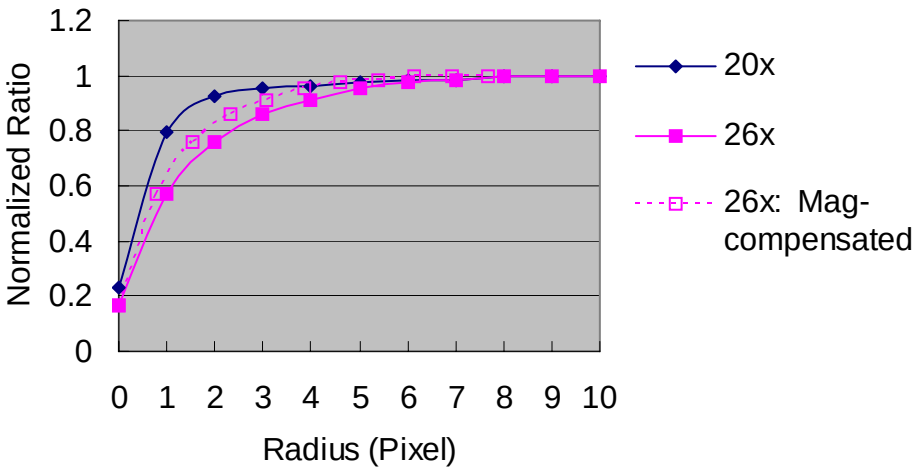
26x optics



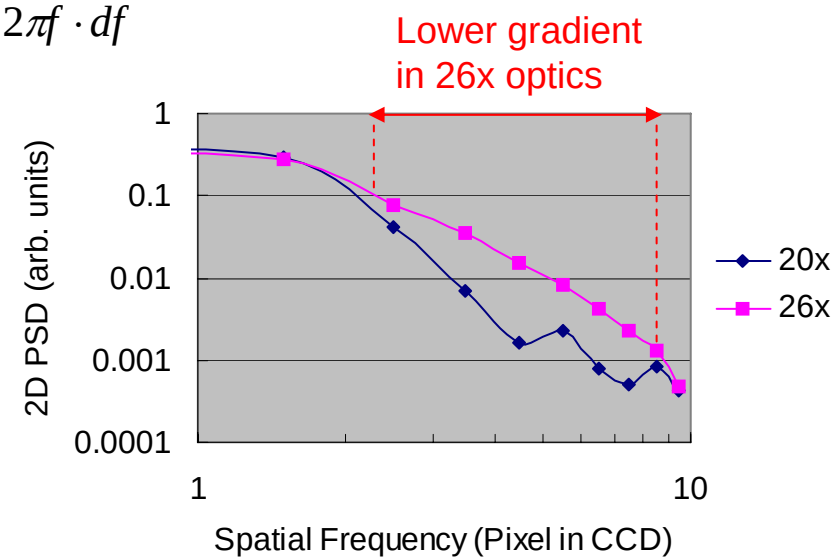
Translation to PSD

Comparison of Average Integrated PSF

$$I(P) = \int_0^P PSD(f)2\pi f \cdot df$$



Translated PSD Curves



Lower gradient in 2~8 pixels

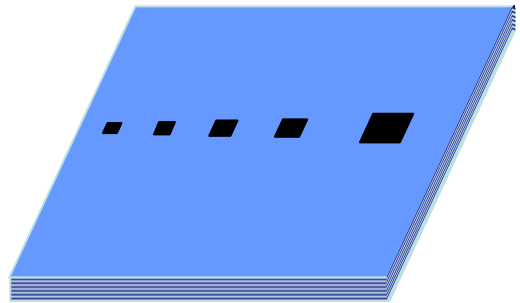
⇩

Roughness in spatial frequency of :
700um~2.9mm in M1(concave) and/or
150um~600um in M2 (convex) can be worse in 26x optics

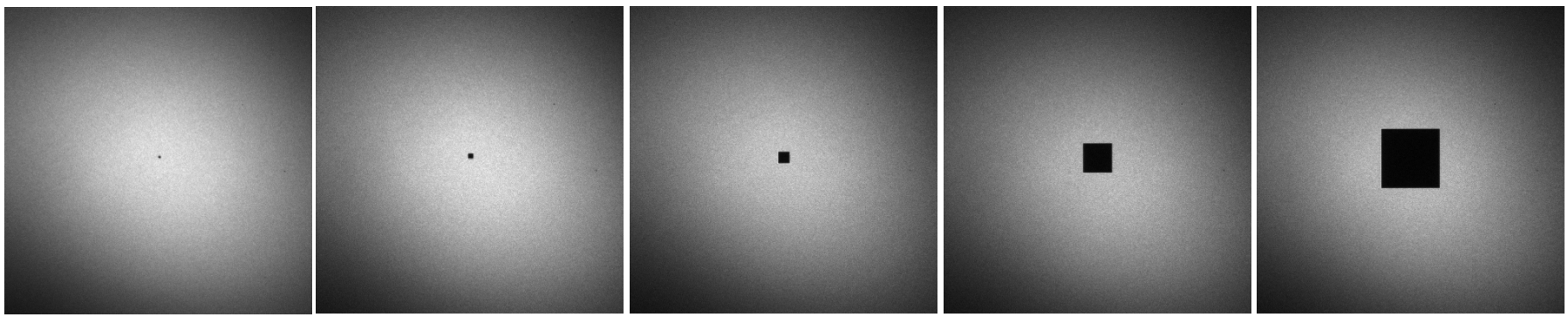
Quality of 26x optics worse than 20x.

Evaluation of shorter MSFR

- Test mask:
  - Clear filed mask with various sizes of absorber pads
- Evaluation procedure
  - Get darkfield image and measure “flare” from surrounding background intensity at pad center

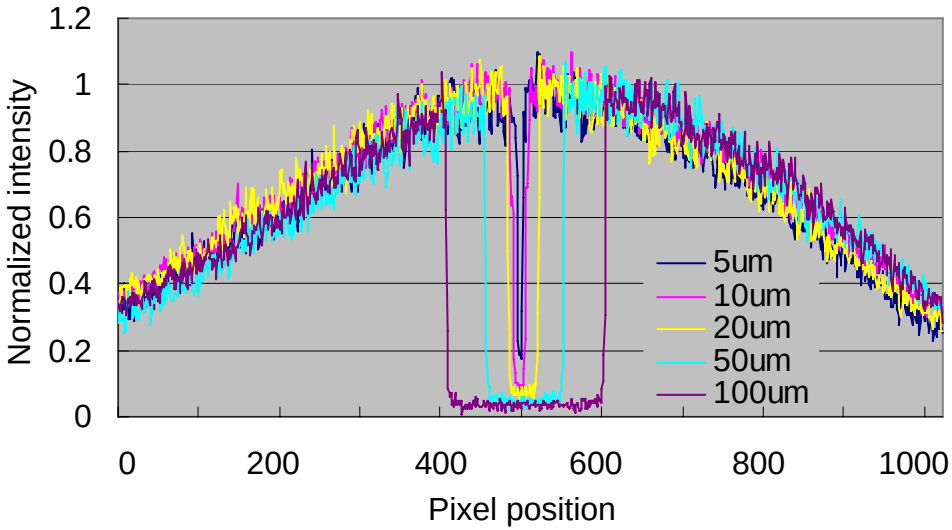


Pad: 5um 10um 20um 50um 100um



← 500um →

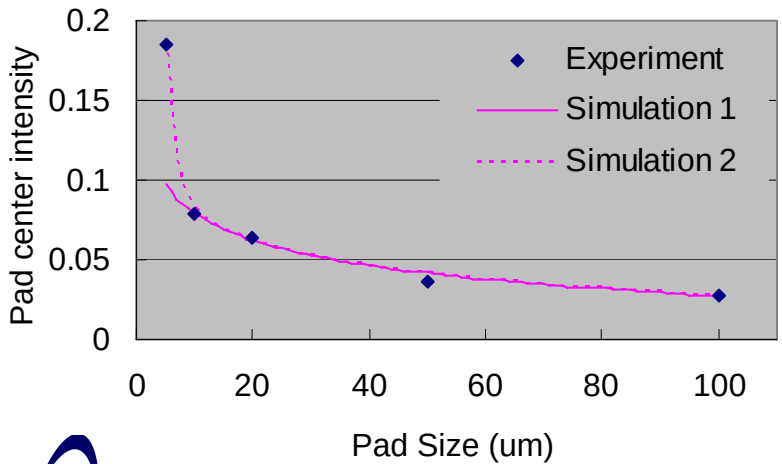
Comparison with model PSD



$$F_{center}(R_{PAD}) = \int_{R_{PAD}}^{\infty} I(r) \cdot PSF(r) \cdot 2\pi r dr$$

$$I(r) = \exp(-\frac{r^2}{R_{ill}^2}) \quad : \text{Illumination distribution}$$

$$PSF(r) = \frac{16\pi^2}{\lambda^4 \cdot \rho_2^2} \cdot \left(PSD_2(\frac{r}{\lambda \cdot \rho_2}) + \alpha^2 \cdot PSD_1(\frac{\alpha \cdot r}{\lambda \cdot \rho_2}) \right)$$



Simulation 1:

both PSD ~ $1/f^{2.1}$,
(M1: 60um~1.2mm, M2:12~240um),
MSFR=0.29nm

Simulation 2:

PSD1(M1) ~ $1/f^5$ for 400um~1.2mm
Others are same with Sim 1

Consistent with PSF characterization

Discussion

- Supplier data turn out to corroborate worse MSFR in 26x optics

MSFR (nm RMS: 1um~1mm)

	20x	26x
M1(convex)	0.36	0.41
M2(concave)	0.26	0.57

- Image data analysis suggests the worse area is in longer spatial period range in MSFR range and beyond into figure error range.
- Preferably compared with each PSD if available

- Less-than-anticipated improvement in sensitivity well explained by worse optics quality.
  - Not a counterproof of sensitivity improvement path by magnification.
  - Rather, more-than-predicted improvement possible as 20x optics was still below state-of-the-art quality.
- Target spec for 26x optics are:
  - Assuming >90% within radius of 1 pixel (13um)

$$\left(\frac{4\pi}{\lambda}\right)^2 \cdot \int_{f_{\min}}^{f_{\max}} PSD(f) \cdot 2\pi f \cdot df = \left(\frac{4\pi\sigma}{\lambda}\right)^2 < 0.05$$

$$\therefore \sigma < 0.24\text{nm}$$

for roughness period integration range of:
7um ~ **7mm** in M1 and 1.4um ~ **1.4mm** in M2

Summary

- Upgrade of projection optics from 20x to 26x implemented.
- Less-than-anticipated improvement in sensitivity attributed to worse MSFR to short range figure errors of mirrors by image data analysis.
- More improvement in sensitivity than previous prediction expected by using state-of-the-art quality mirrors.

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