Recent Advances of the Visible-Light PDI for EUVL Aspheric Mirrors

K. Otaki, M. Ishii, T. Yamamoto, S. Nakayama, J. Saito, A. Suzuki and K. Murakami
Extreme Ultraviolet Lithography System Development Association (EUVA), EUV Metrology Laboratory

Outline of this study

Topic 1 - Theory -

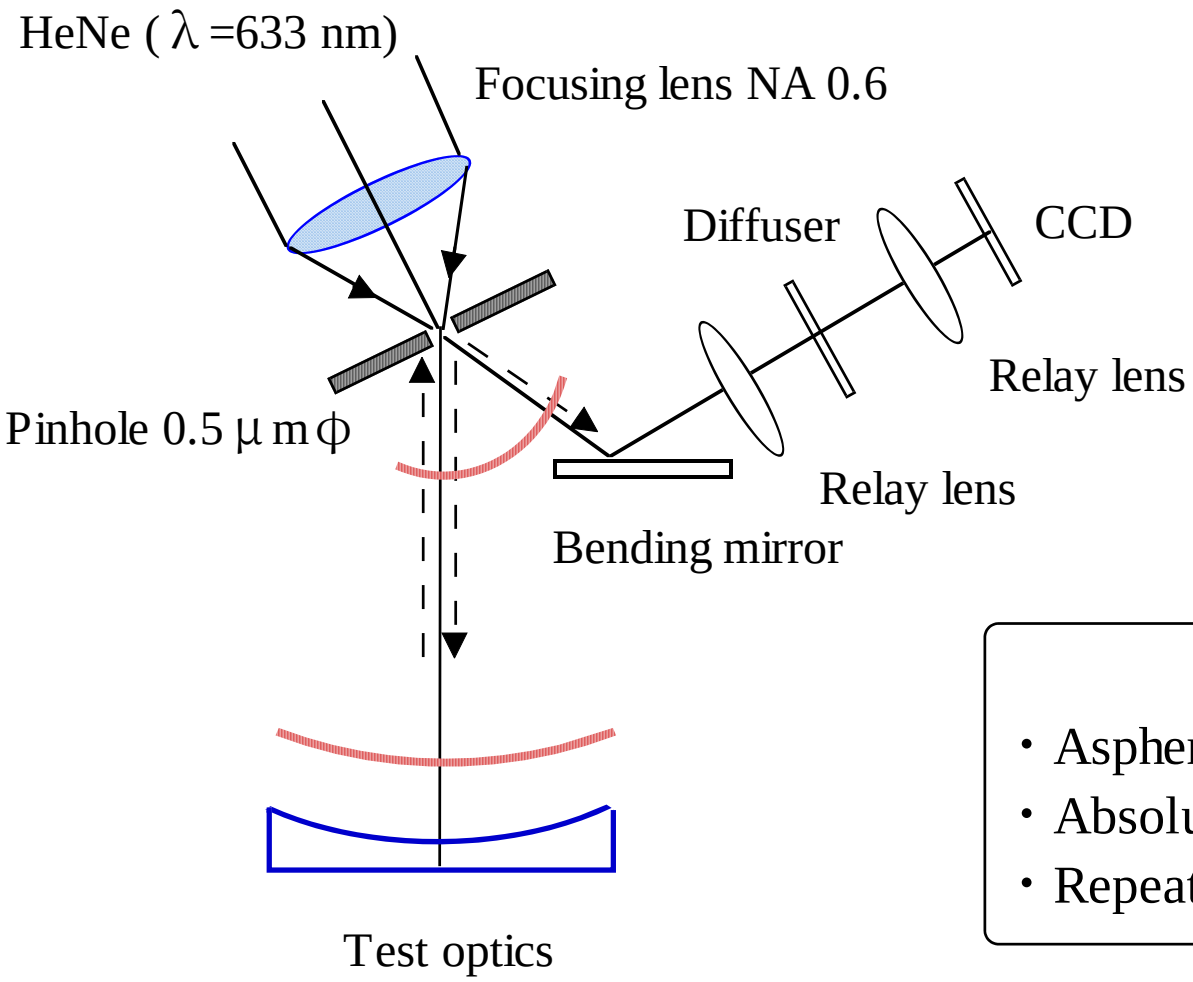
Show the difficulty of EM simulation for the absolute accuracy estimation in Visible-light PDI and find simulation conditions for significant results.

Topic 2 - Experiment -

Show the accuracy improving by

- **replacing the higher accurate pinhole**
- **correcting the distortion induced pixel position error caused by the tilted relay-lens**

Principle of visible-light PDI



Target

- Aspheric sag = several um
- Absolute accuracy 0.1-0.2 nm rms
- Repeatability < 0.05 nm rms

Topic 1 - Theory -

Difficulty of simulation

Simulation of accuracy of the visible-light PDI has some difficulties.

1: **Very high accuracy is required to simulate**

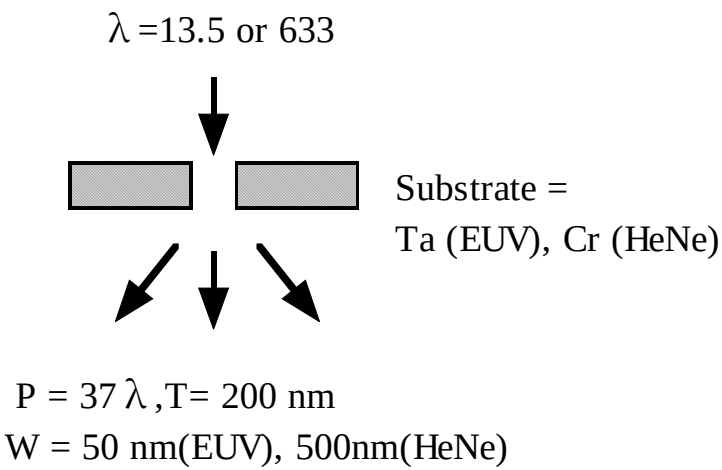
	@λ-PDI	Visible-light PDI	Visible-light PDI	
wavelength	13.5 nm	532 nm rms	632.8 nm	
Target	Wavefront	Wavefront	Aspheric figure	
Target of measurement	0.675 nm rms *	0.675 nm reds	0.276 nm rms **	
Accuracy of measurement	0.338 nm rms	0.338 nm rms	0.138 nm rms	(50% of target)
Accuracy of simulation	0.068 nm rms	0.068 nm rms	0.028 nm rms	(10% of target)
	= λ /200	= λ /7500	**= λ /23000 !**	

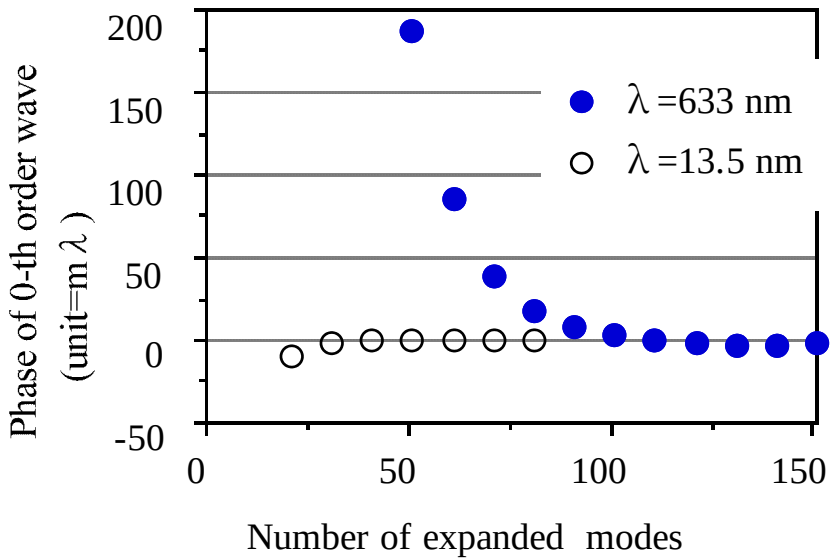
* Wavefront error of P.O. = 0.05 λ rms =0.675 nm rms.

** Figure error is converted to the wavefront error.

2 : Long CPU-time is required because of slow convergence

	@λ-PDI	Visible-light PDI	Visible-light PDI
wavelength	13.5 nm	532 nm rms	632.8 nm
Index of material	Low index (1)	High index (metal)	High index (metal)
Convergence	Fast	Slow	Slow
CPU time	Short	Long	Long





Results

1. Scattered EM Field

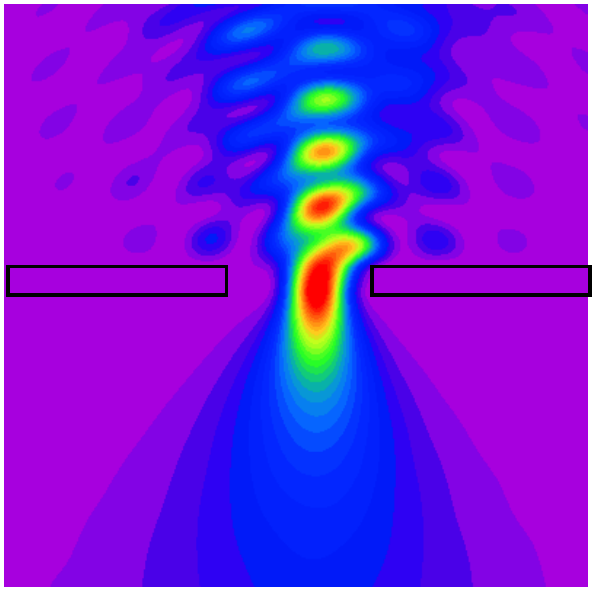
NA 0.6, TE-mode, λ =0.633um
W=1.0 um, T=0.2 um
Beamspot displacement = 0.2 um

Procedure

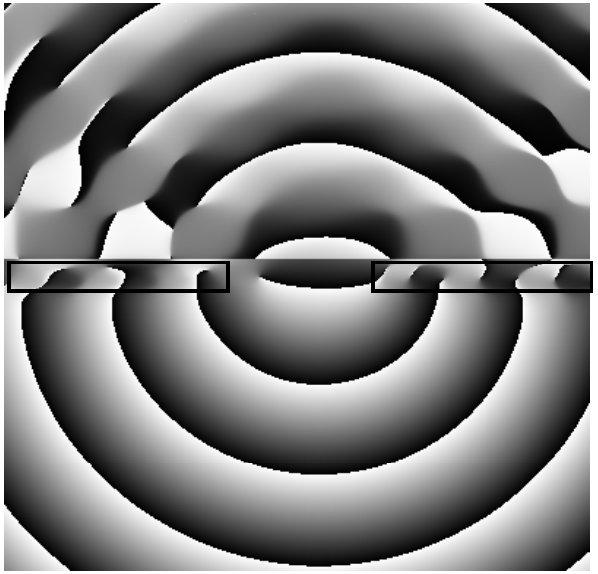
Diffraction Amplitudes by RCW
↓ Superposing plane waves
Near Field
↓ Fourier Transform
Far Field

4 um

4 um



Intensity



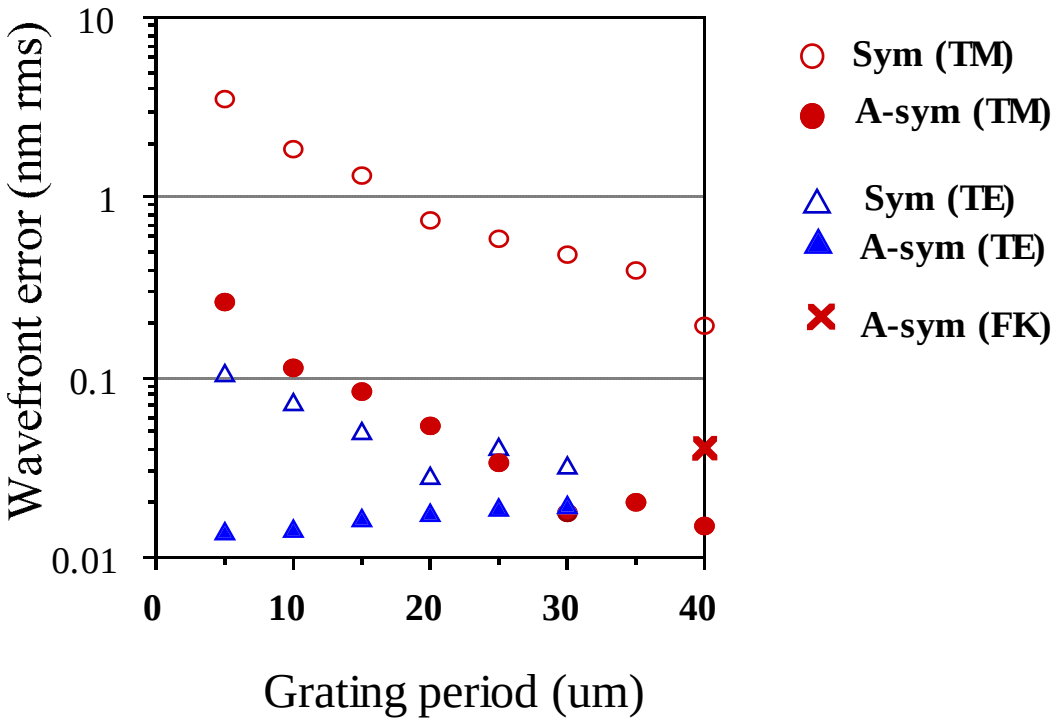
Inc. + Refl.

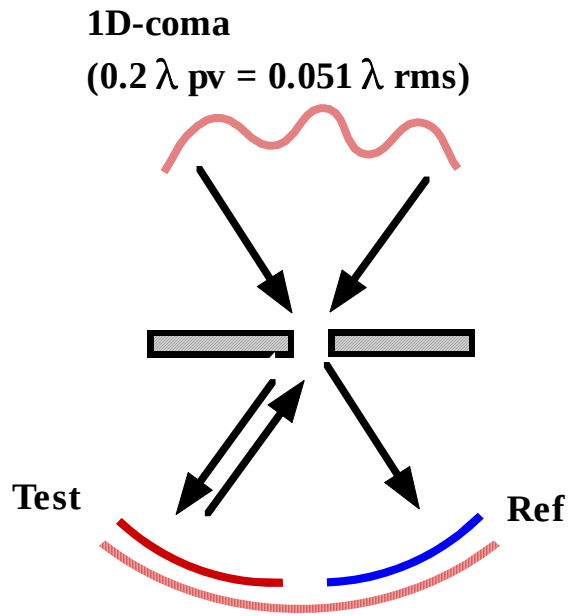
Trans.

Phase

Near completely spherical
(Error < 0.1 nm rms)

2. Convergence - Wavefront vs Grating period -





$$WF_{Sym} = \frac{\phi(\alpha)+\phi(-\alpha)}{2} \Rightarrow \text{No error}$$

$$WF_{A\text{-}sym} = \frac{\phi(\alpha)-\phi(-\alpha)}{2} \Rightarrow \text{Error}$$

➡ Anti-symmetric wavefront error converges when p ≧10 um (TE-mode), p ≧30 um (TM-mode)

- Conclusion of Topic 1 -

1. **Difficulties in numerical simulation of accuracy in visible-light PDI have been shown.**

2. **2-D EM wavefront simulation have been executed under periodic conditions using RCW.**

3. **Convergence condition has been studied and it was shown that anti-symmetric wavefront error can be obtained with enough accuracy when period > 30um.**

In visible region, it's so difficult to simulate wavefront error with high accuracy !

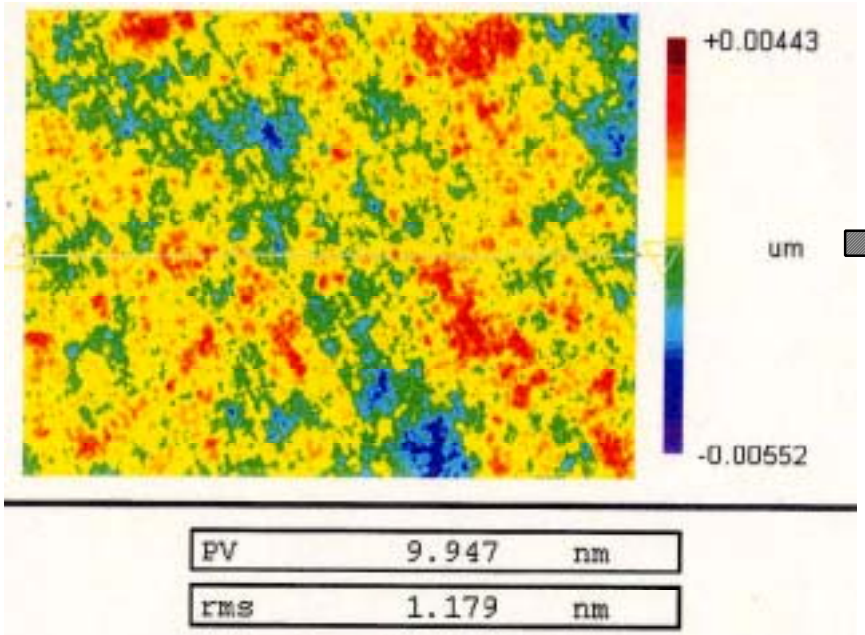
Topic 2 - Experiment -

Improving roughness of the pinhole substrate

Zygo NewView 50×
Size 0.71×0.53 mm

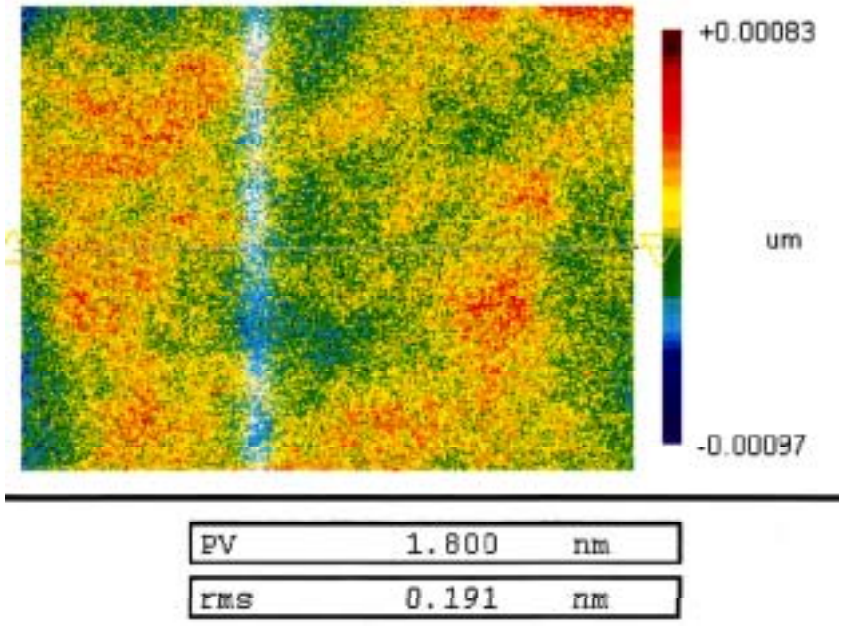
Former pinhole

1.179 nm rms



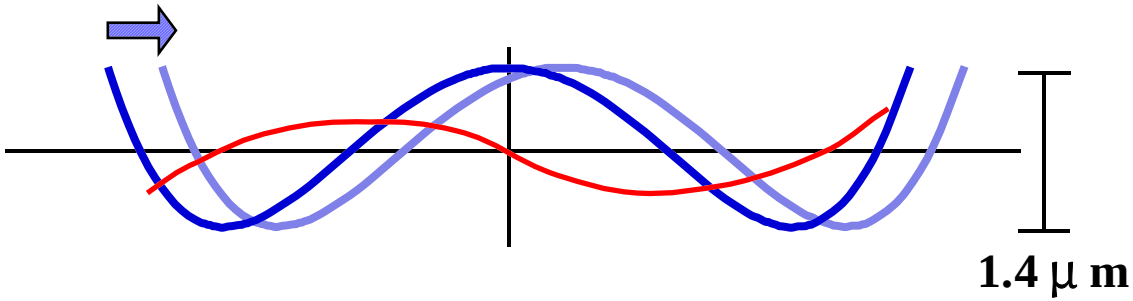
New accurate pinhole

0.191 nm rms



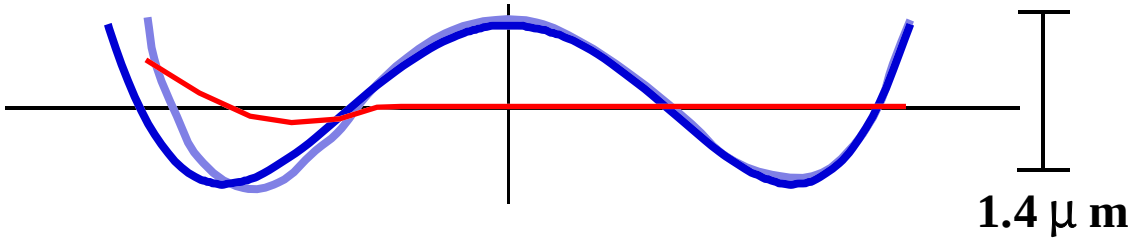
Difficulty of aspheric mirror measurement

Displacement sensitive



1/200 pixel displaced → Error =0.1 nm rms

Distortion sensitive

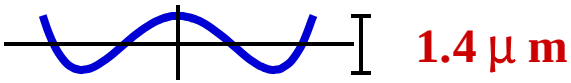


1/100 pixel distorted → Error =0.1 nm rms

*** 1pixel= 0.91 mm on mirror, 40 um on CCD**

Measurement conditions

NA 0.15



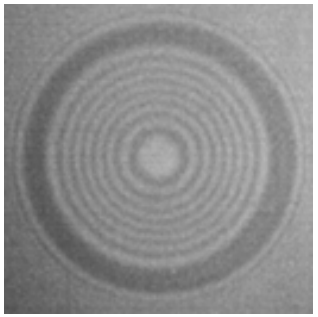
1.4 μ m

PDI

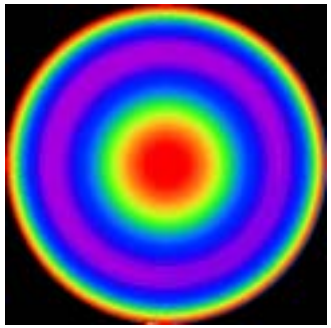
Source	HeNe (λ =633 nm)
Pinhole	0.5 μ m φ
Atomospher	He-gas (>80%)

Mirror

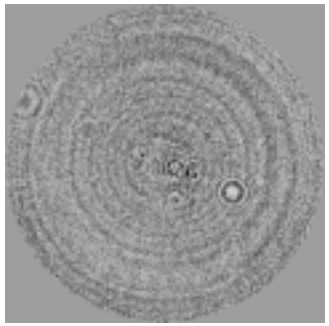
Curvature	R= 673.0 - 671.3 mm
Diameter	200 mm φ
NA	0.15
Sag	1.4 μ m



Interferogram



Measured data



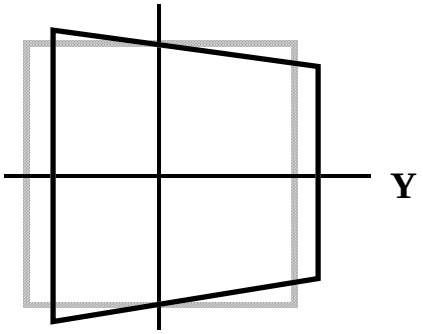
Precision 0.09 nm rms

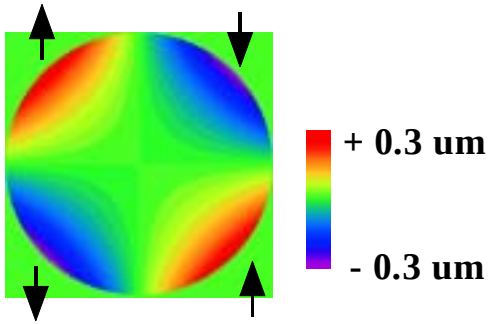
Distortion induced systematic error

Tilt of relay-lens = 0.1 deg, Pixel size=40 μ m

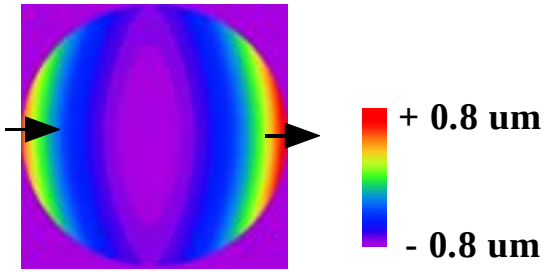
Max-distortion = 0.75um = pixel / 50

Induced systematic error = 0.24 nm rms !

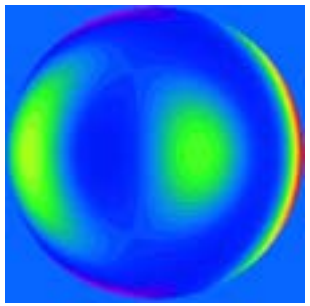




Dist-X



Dist-Y



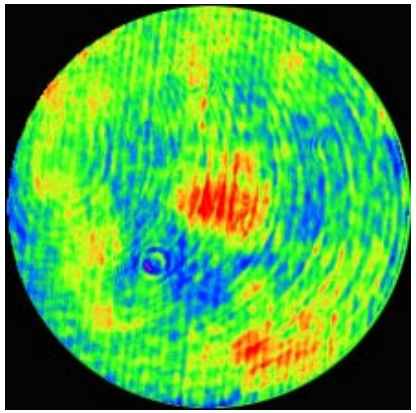
Total	0.24 nm rms
Z5	0.15 nm rms
Z15	0.18 nm rms

Induced systematic error

Measured figure

Before / *After* distortion correction (-Z81)

0 deg rotation

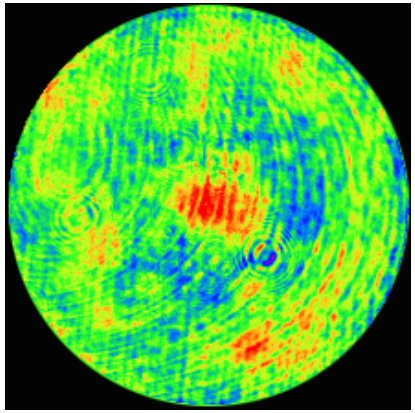


W=1.88 / *1.70* nm rms

(0.91 / *0.62* nm rms)

(0.88 / *0.62* nm rms)

- 90 deg rotation

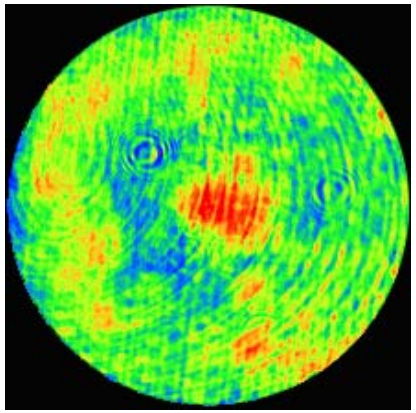


W=1.67 / *1.68* nm rms

(Deviation)

(1.13 / *0.77* nm rms)

+ 90 deg rotation

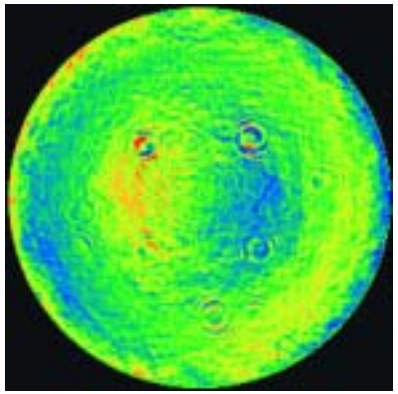


W=1.84 / *1.78* nm rms

Analyzed systematic error (Rotationally asym.)

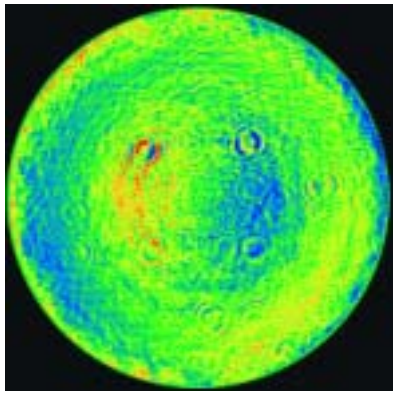
Before / After distortion correction (-Z81)

Analyzed from
ϕ =0 deg and 90 deg



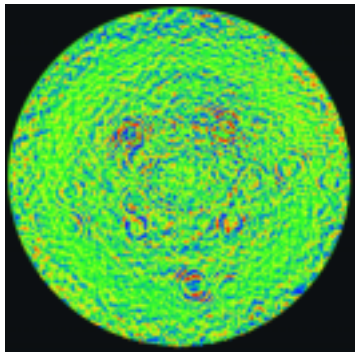
Total 0.60 / 0.42 nm rms
Z15 0.52 / 0.34 nm rms
(5th coma)

Analyzed from
ϕ =0 deg and -90 deg



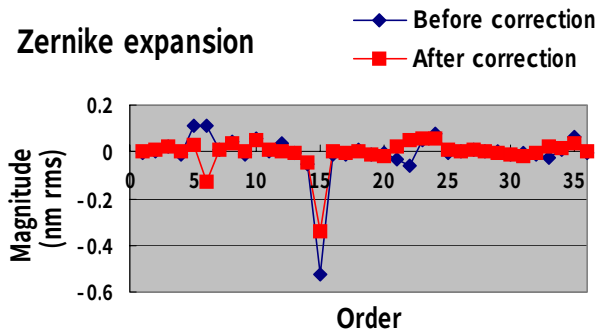
Total 0.62 / 0.42 nm rms
Z15 0.51 / 0.34 nm rms

Deviation



0.10 / 0.08 nm rms

Good agreement !



- Conclusion of Topic 2 -

1. **Accuracy improving has been confirmed by replacing the higher accurate pinhole and by correcting distortion induced pixel position error.**

2. **Systematic error of 0.34 nm rms has been obtained with high repeatability (<0.10 nm rms).**

3. **Dominant component of the systematic error is the 5-th coma (=15-th Zernike).**

4. **Origin of the residual systematic error will be non-common path error induced by the bending mirror and the relay-lens.**

→ Next step

References

K. Otaki, T. Yamamoto, Y. Fukuda, K. Ota, I. Nishiyama and S. Okazaki, J. Vac. Sci. Technol. B, vol. 20 (2002) 295-300

K. Otaki, K. Ota, I. Nishiyama, T. Yamamoto, Y. Fukuda and S. Okazaki, J. Vac. Sci. Technol. B, vol. 20 (2002) 2449-2458

K. Ota, M. Ishii, E. Sawaya, T. Yamamoto, H. Ichikawa, S. Nakayama, K. Otaki and T. Gemma, Technical Digest of the 1st Int. Symposium on EUV Lithography, Dallas, Oct. 2002

Acknowledgement This study was supported by NEDO.