Wavefront Evaluation for 6-mirror Projection Optic with EUV Wavefront Metrology System

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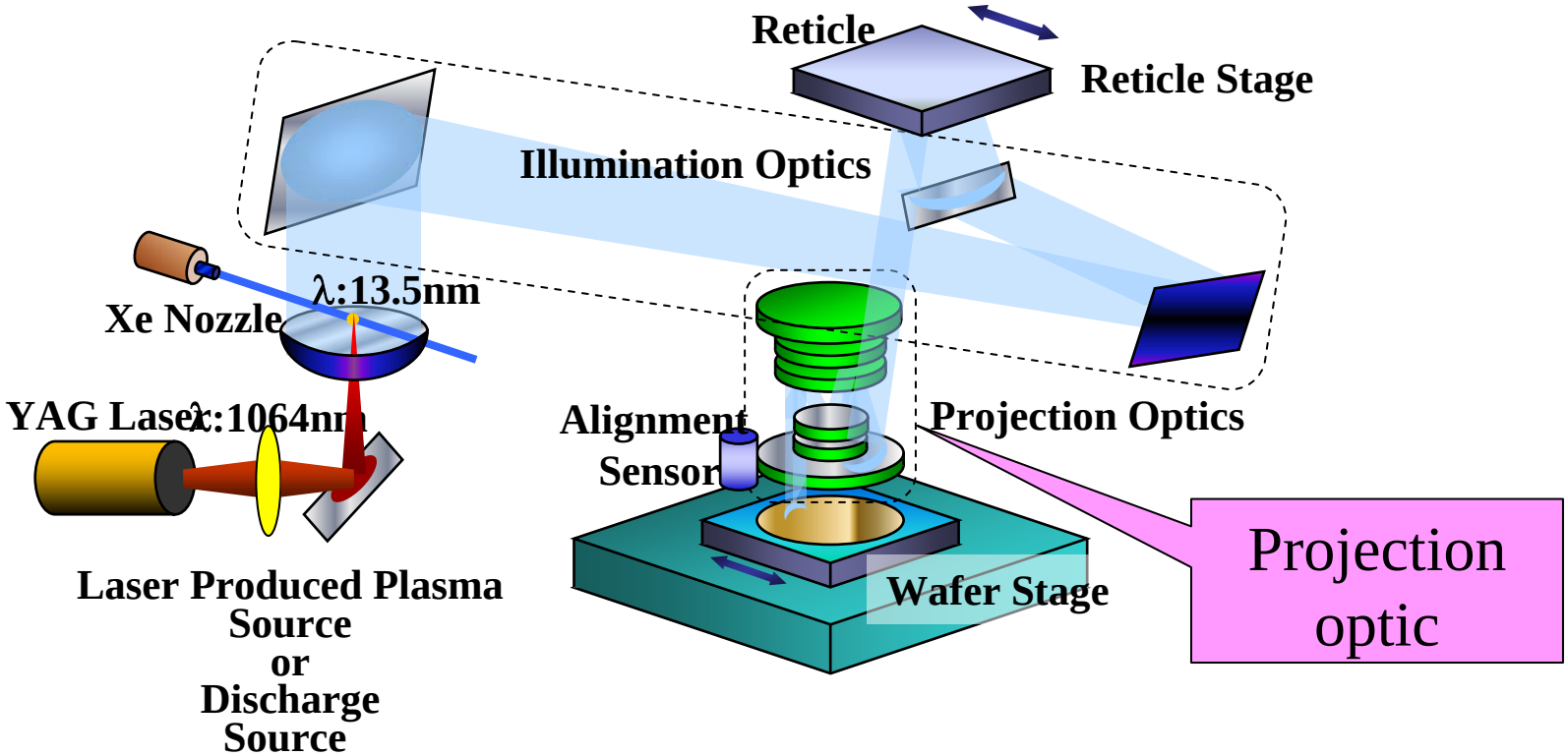
Introduction

We had been developing the at-wavelength wavefront metrology using a prototype projection optic (the first optic). The first optic was used as a test optic for developing the digital Talbot interferometry (DTI). [1] To advance the development, we have introduced the second projection optic with low aberration of about 1.5 nm RMS. The wavefront aberration of the second optic was low enough for applying a point diffraction interferometry (PDI) that is more accurate. [2]

To verify the accuracy of the EUV wavefront metrologies, we compared the measured results with the shearing interferometry and the PDI.

[1] K. Sugisaki, et. al., Proc. SPIE, 6921, 69212U (2008).
[2] K. Sugisaki, et. al., Proc. SPIE, 5921, 81 (2005).

EUV Scanner for lithography

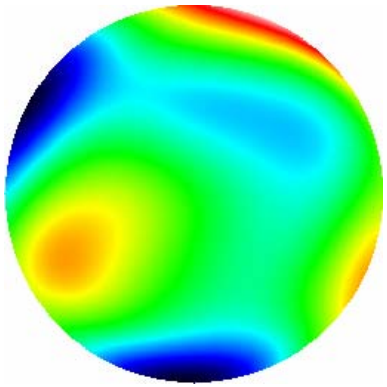
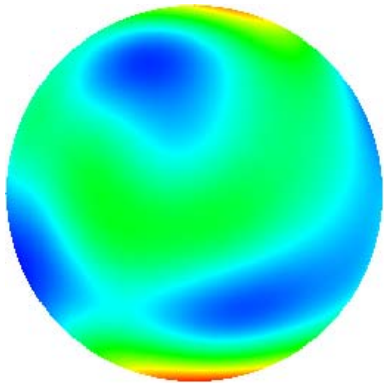


Wave front error of EUVL optics: < 0.45 nm RMS (λ/30 RMS)

Target accuracy of wave front metrology: < **0.1 nm RMS**

Test Optics

- Objective of the second optic introduction
  - Closs check of the metrologies of shearing and the PDI.
  - Improvement of the calibration method.

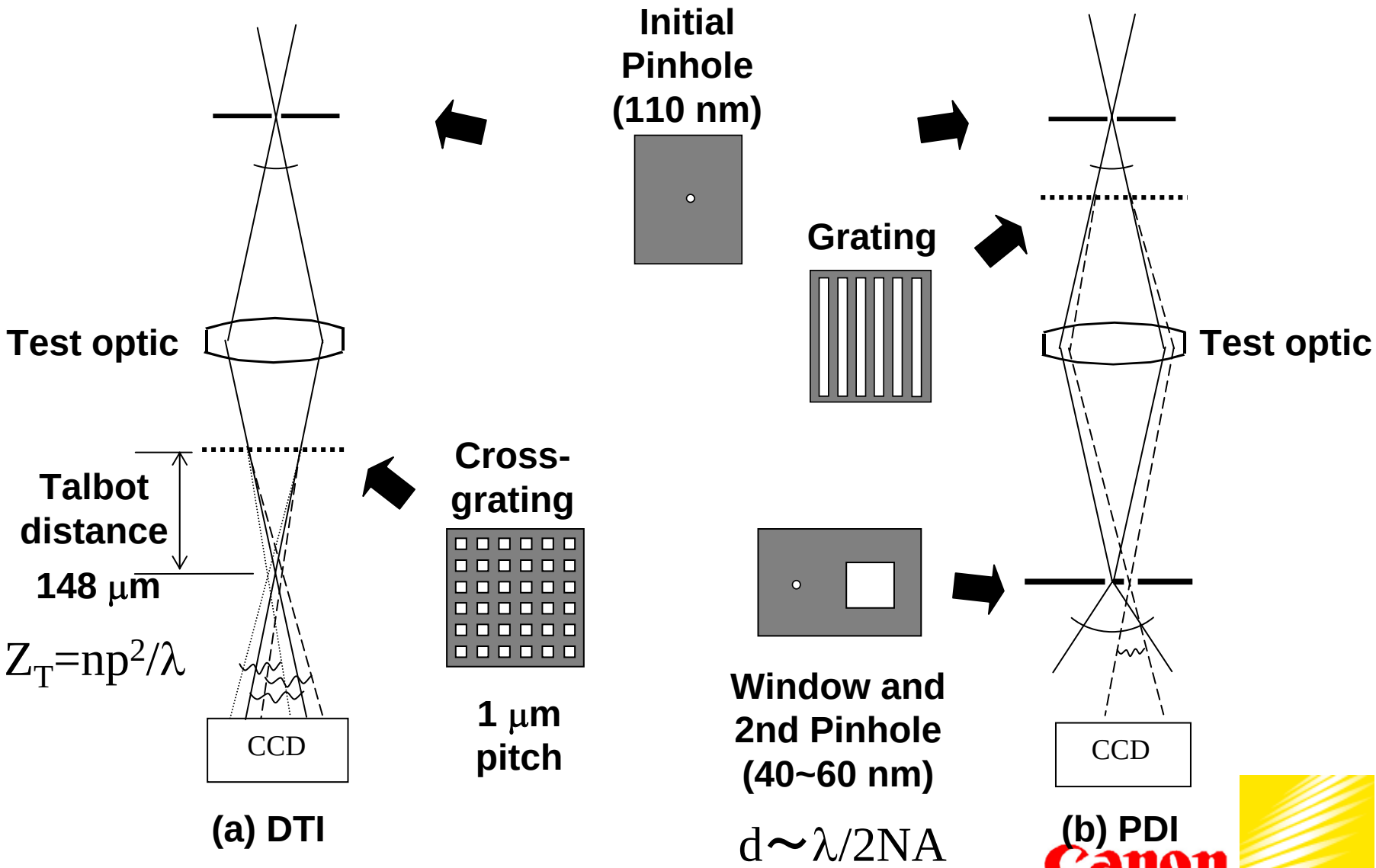
	The first optic	**The second Optic**
NA	0.25	**0.25**
Mirror	6	**6**
Magnification	1/4	**1/4**
Wavefront aberration	 ~10 nm RMS	 **~1.5 nm RMS**

Measuring methods

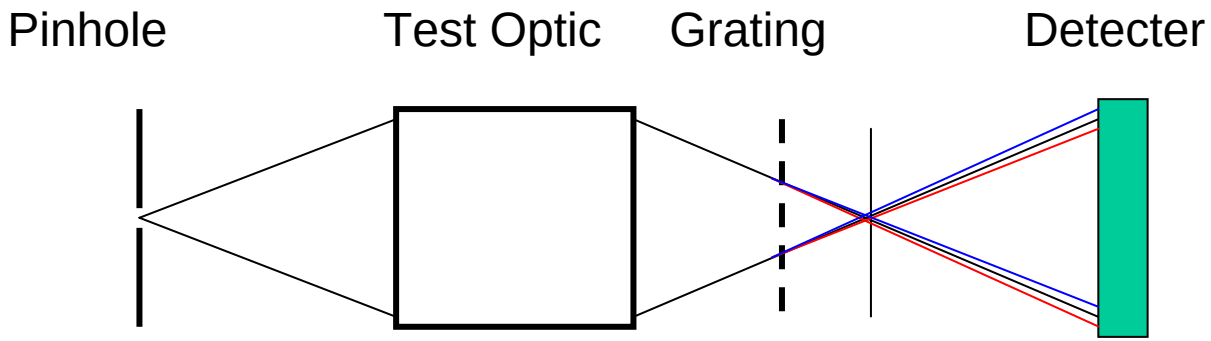
- Digital Talbot interferometer (DTI)
  - Simple and easy operation
  - Wide dynamic range
  - Introducing new calibration method

- Point diffraction interferometer (PDI)
  - Highly accurate
  - Low dynamic range
  - Precise alignment is required.

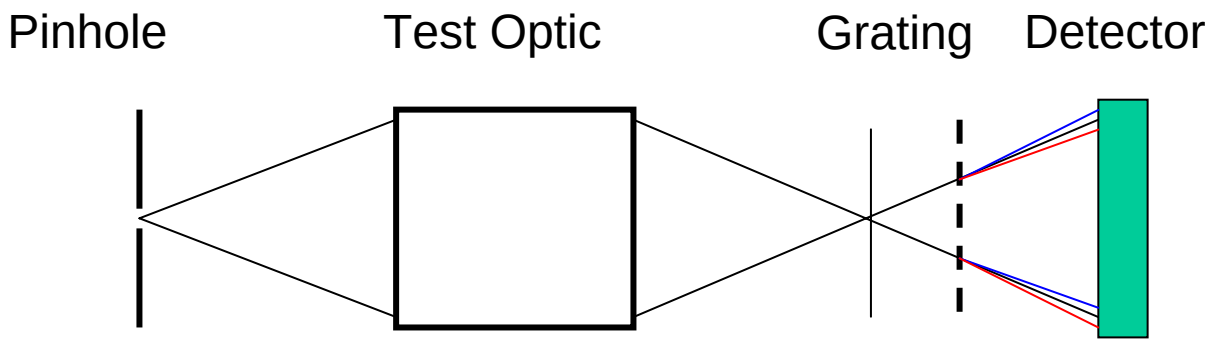
Principles of interferometers



New calibration method for the DTI



(a) Grating before image plane



(b) Grating after image plane

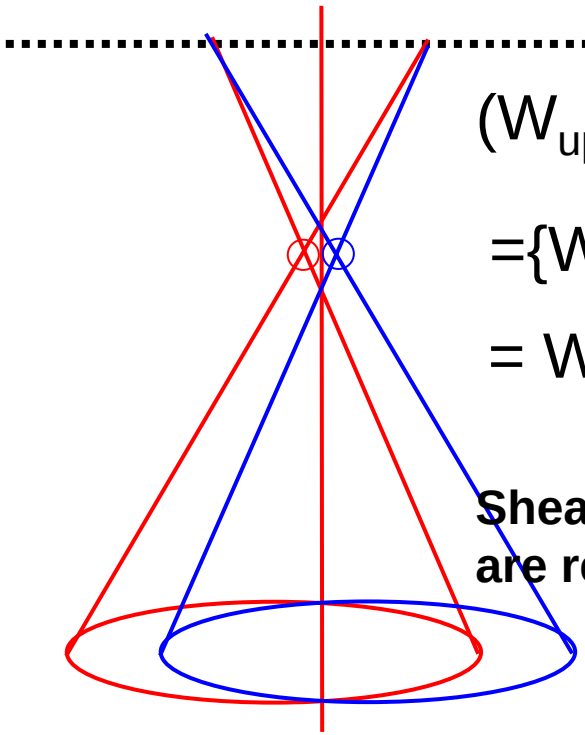
Two arrangements of the grating can be possible in the Talbot Interferometer. To average these two measured results, errors symmetric for the image plane are calibrated.

Principle of the calibration method

The wavefront measured with the grating placed before the image plane is reverse to the wavefront measured with the grating placed after the image plane. On the other hand, intrinsic error of the Talbot interferometer and errors induced by the tilt of the detector/grating are the same for both the grating arrangements.

$W_{up}=W+\varepsilon$

$W_{down}=-W+\varepsilon$

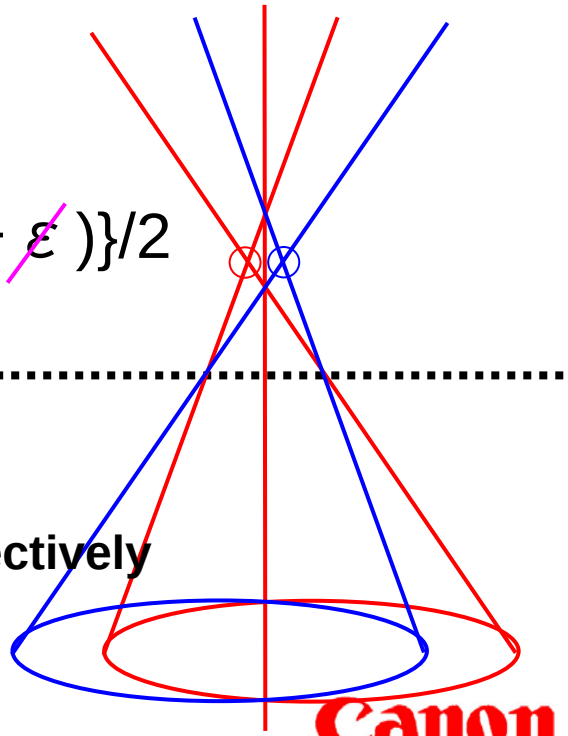


$(W_{up}-W_{down})/2$

$=\{W+\cancel{\varepsilon}-(-W+\cancel{\varepsilon})\}/2$

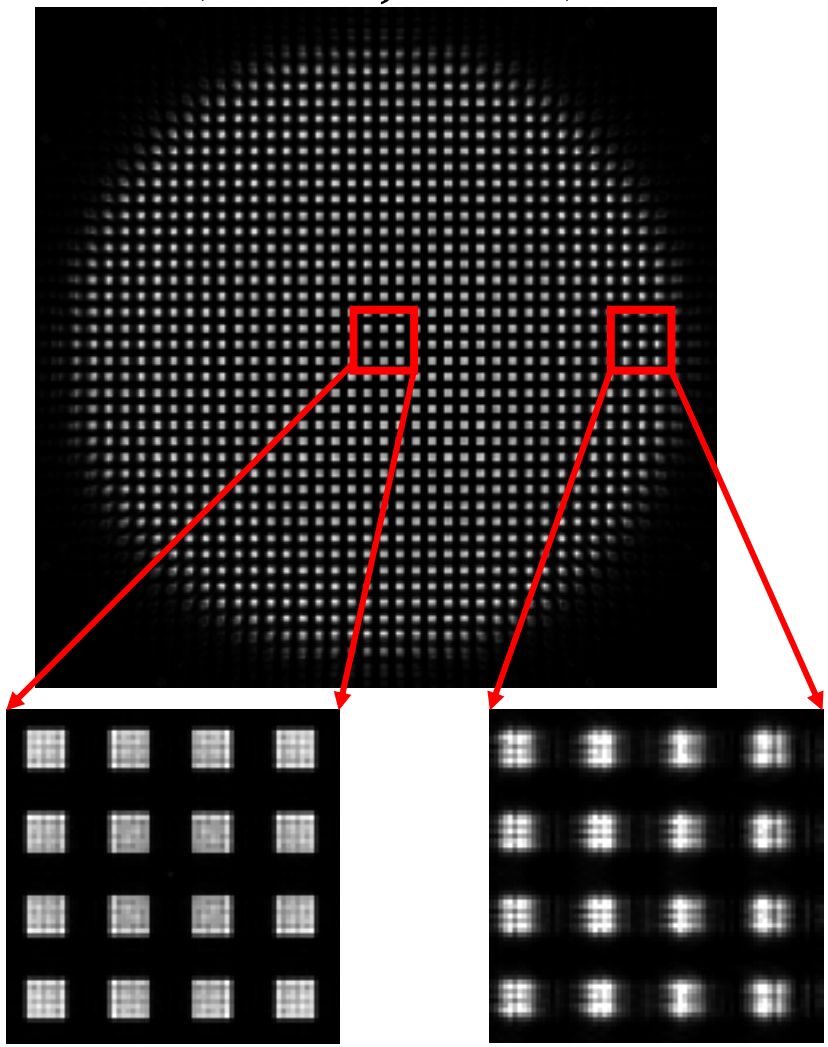
$=W$

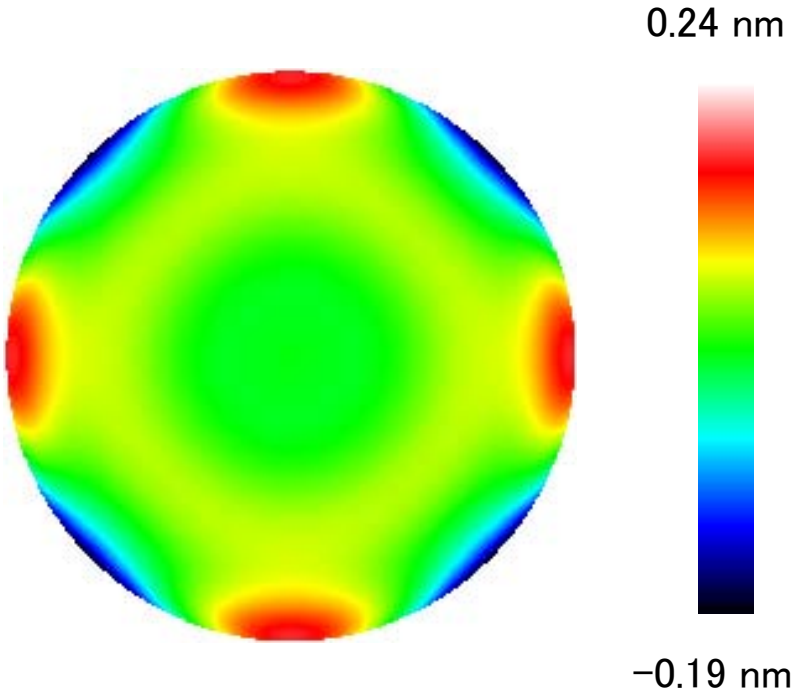
Shear directions are reversed, respectively



Intrinsic error of the Talbot interferometer

Simulated Interferogram
（NA0.25, N=-0.5）

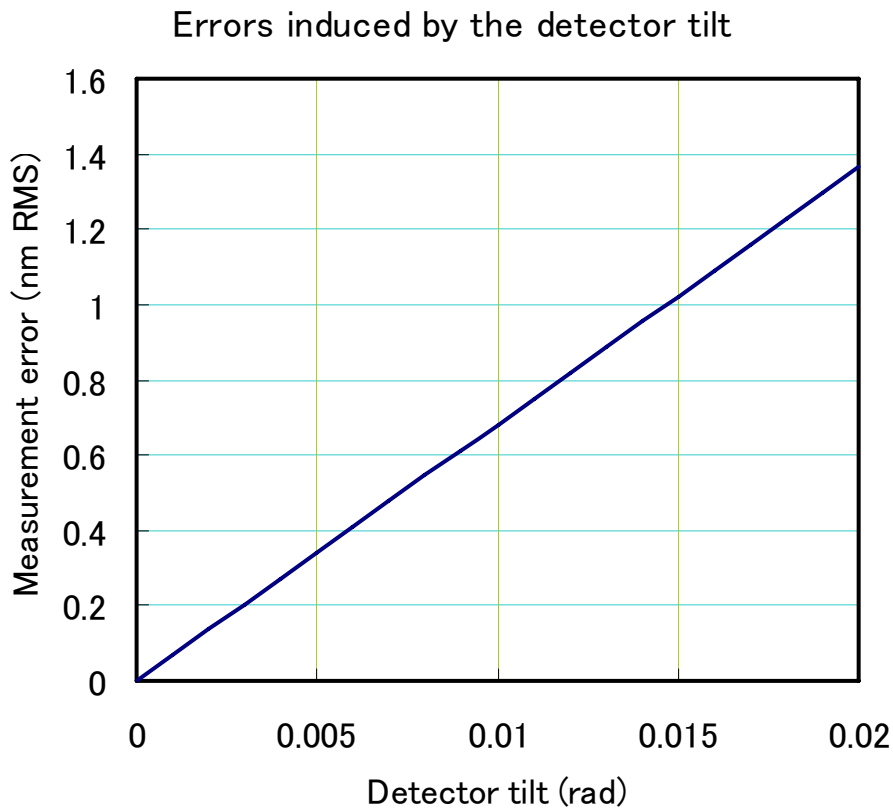




Measurement error
~0.10 nm RMS

Errors induced by the tilt of the detector and the grating

The tilts of the detector and the grating induce errors in the measured results.

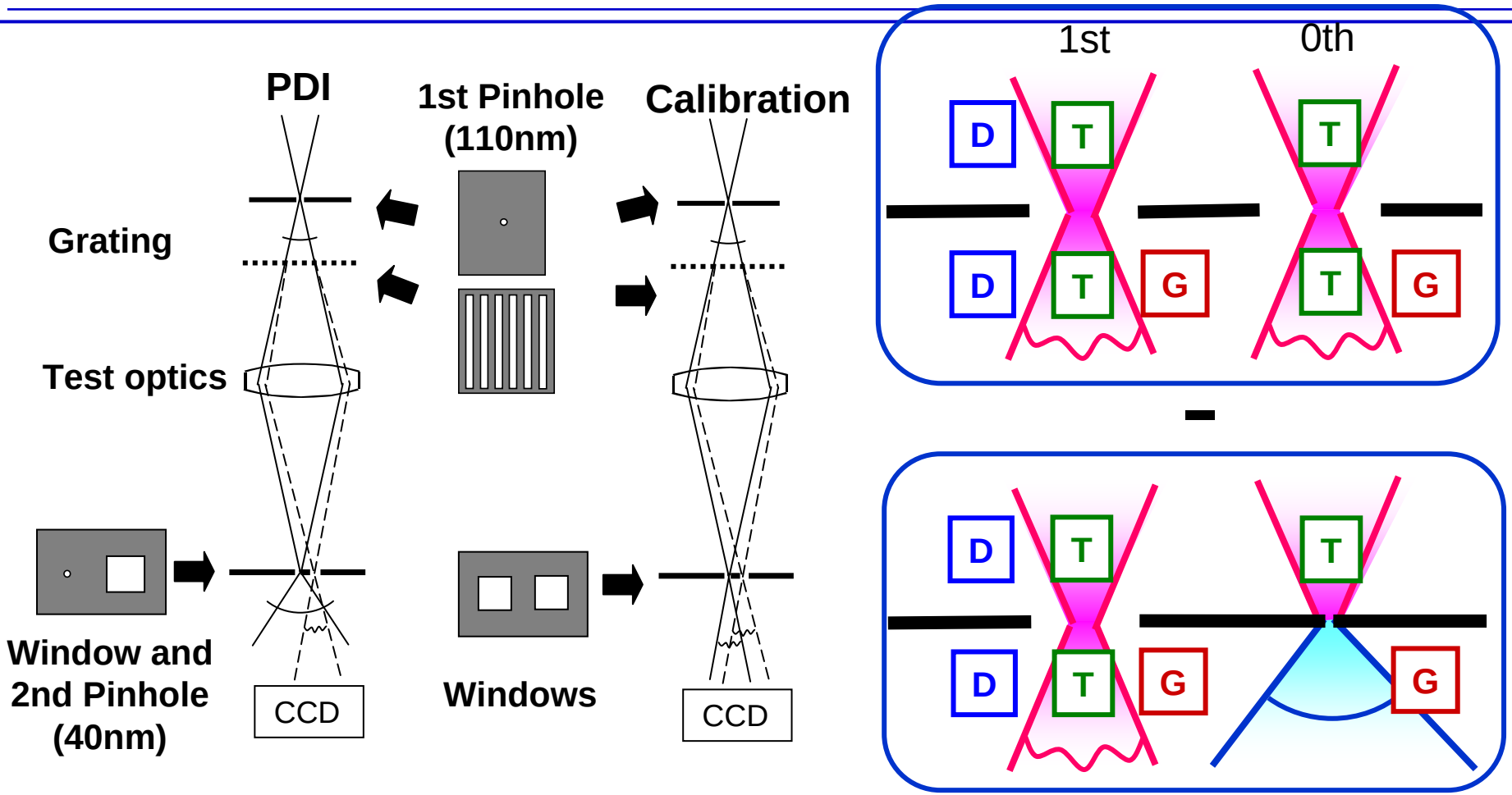


$$\varepsilon_{RMS} \cong \frac{1}{48\sqrt{2}s}\frac{\lambda}{p}Z_T\alpha \cdot NA^2$$

α: Tilt of the detector
s: Shear ratio
λ: Wavelength
Z_T: Talbot distance
p: Pitch of the grating
NA: Numerical aperture

※λ=13.5nm, NA0.25, p=1μm, Z_T=148μm

Absolute PDI



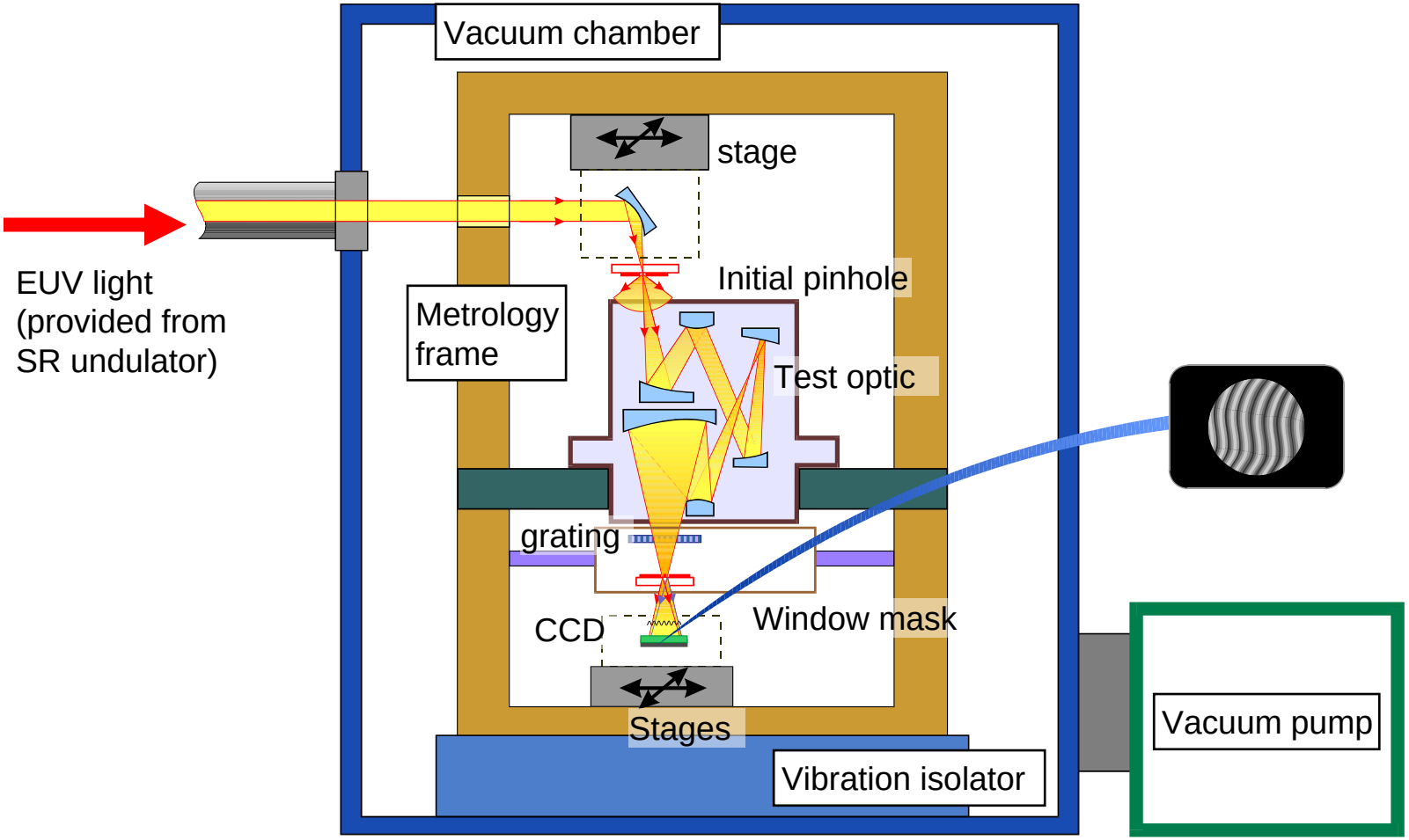
Y. Zhu, et. al, Proc. SPIE, **5752**, 1192 (2005).

The measurement using a window-window mask calibrate errors due to the geometrical arrengement and diffraction effect.

Experimental

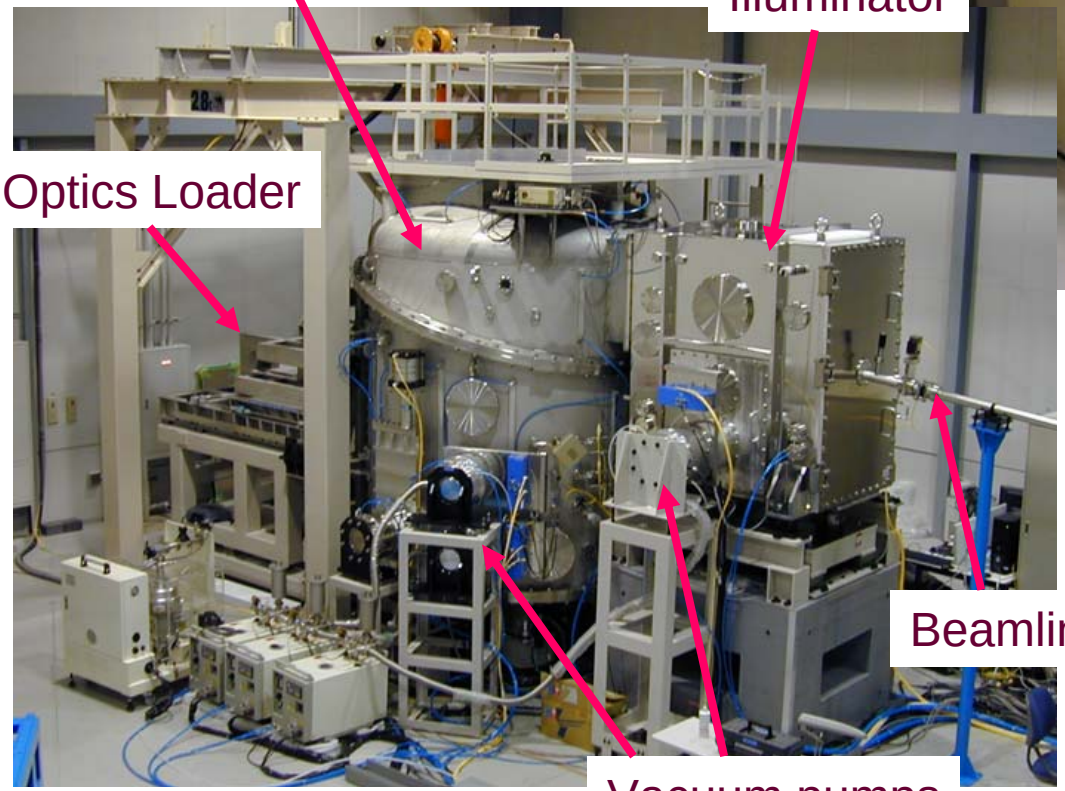
- EUV Source：Undulator（λ=13.5nm）in the NewSUBARU SR facility
- Test optic: EUV projection optic of NA0.25 (the second optic)
- DTI
  - Grating pitch: 1μm
  - Talbot order N: ±1
  - Talbot distance Z_T: 148μm
  - Calibration method: averaging two results measured with up and down grating position
- The PDI：
  - pinhole diameter: 40nm
  - Calibration method: Absolute PDI

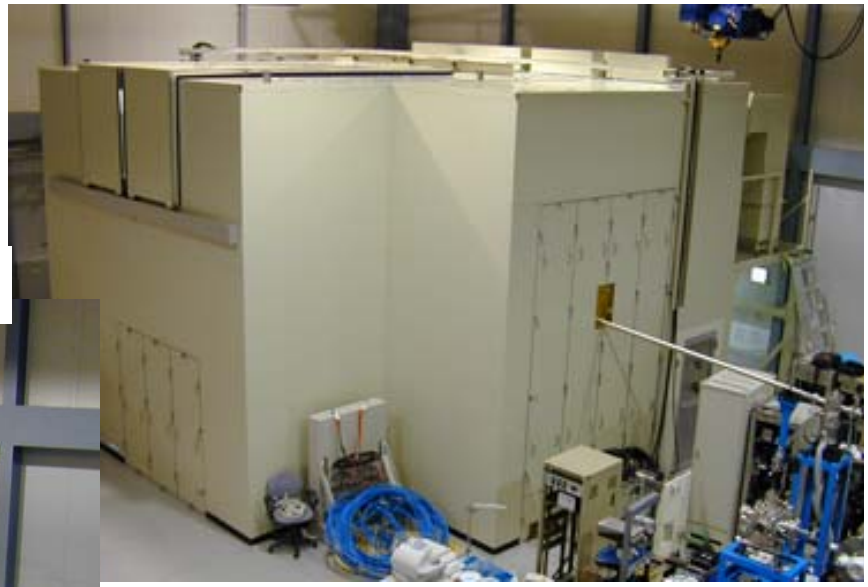
EUV Wavefront Metrology System (EWMS)



The EWMS was designed to measure practical EUV projection optic, which consists of six-mirror and has NA 0.25 and Large exposure field.

EUV Wavefront Metrology System (EWMS)

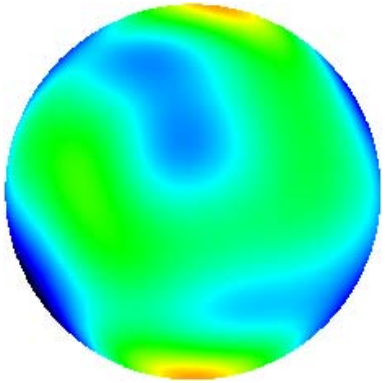




The EWMS is covered with the thermal clean chamber

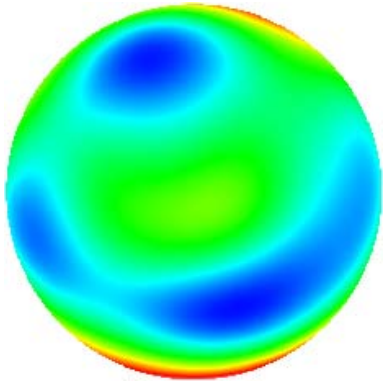
Result of the new calibration for the DTI

DTI with up grating (N=-1.0)



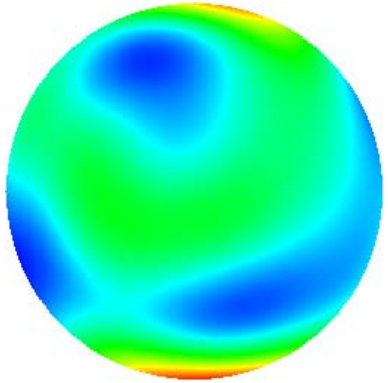
1.32 nm RMS

DTI with down grating (N=+1.0)

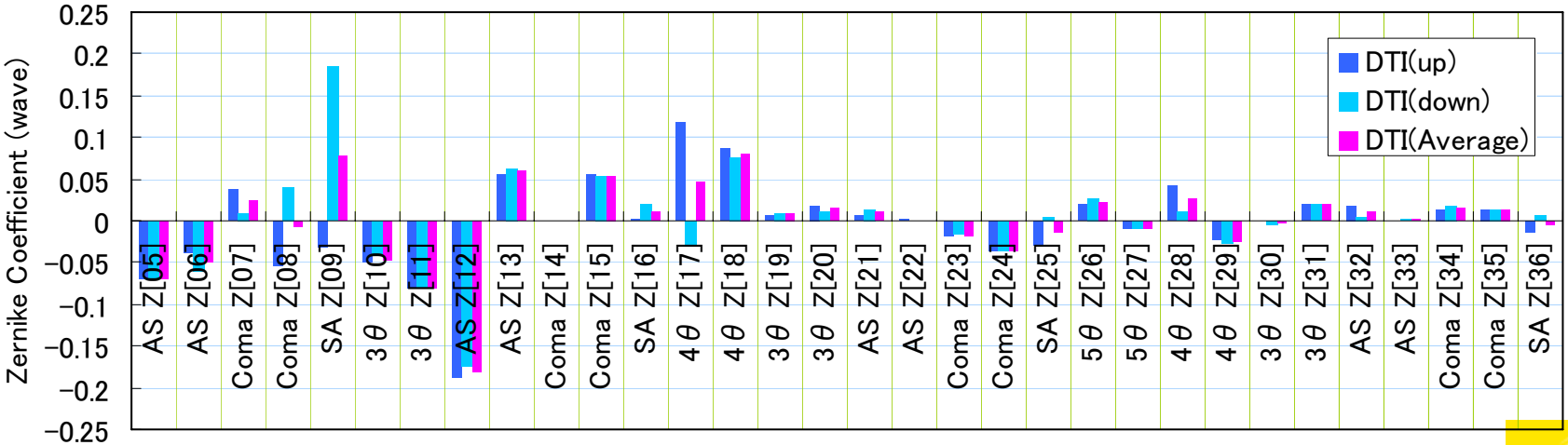


1.61 nm RMS

Averaged (calibrated)



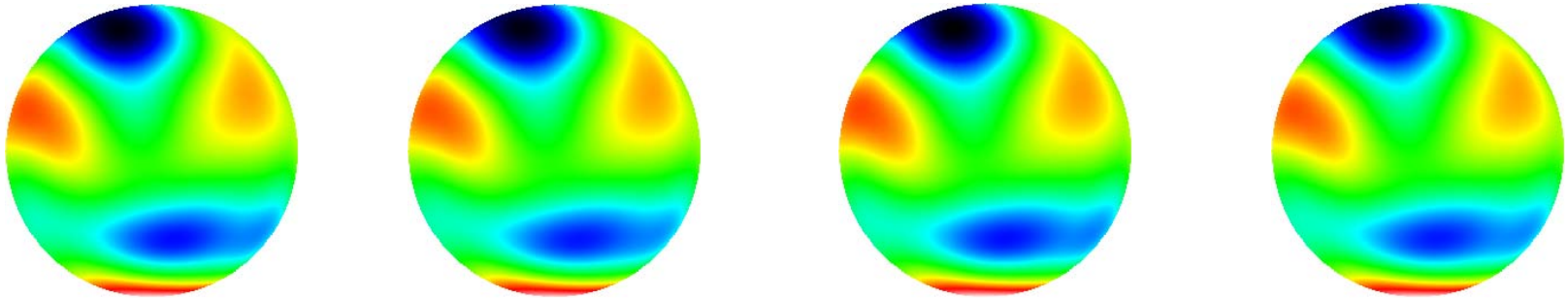
1.32 nm RMS



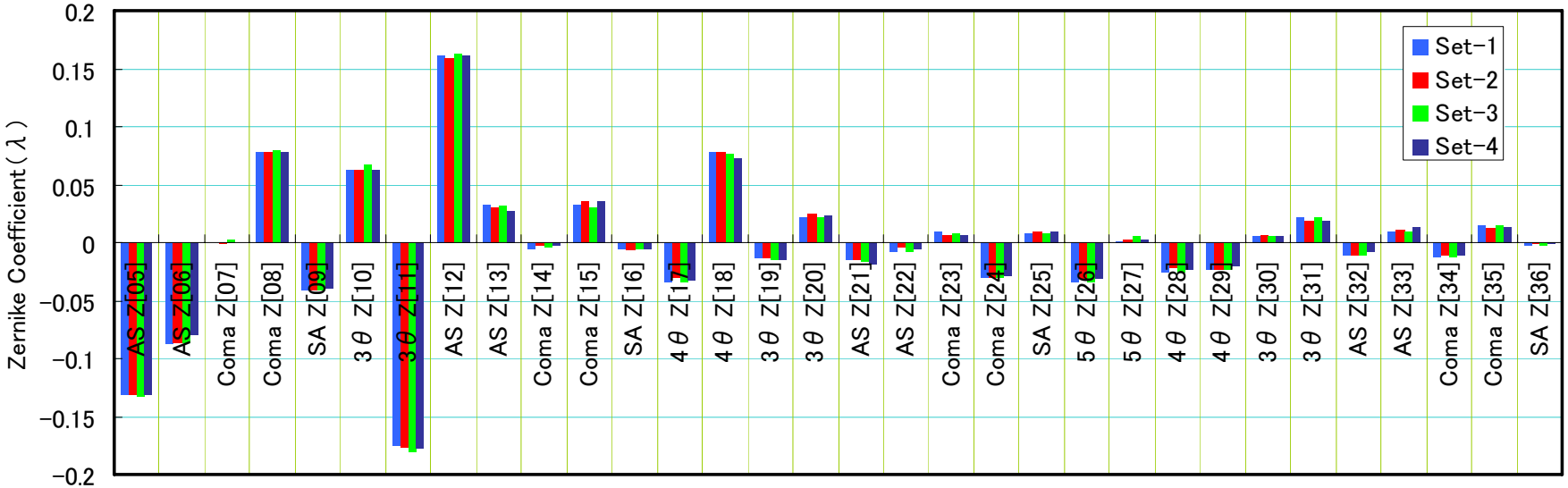
Spherical aberration (Z9), 4θ (Z17), Coma (Z7, Z8) were calibrated.

DTI repeatability

Set-1 Set-2 Set-3 Set-4



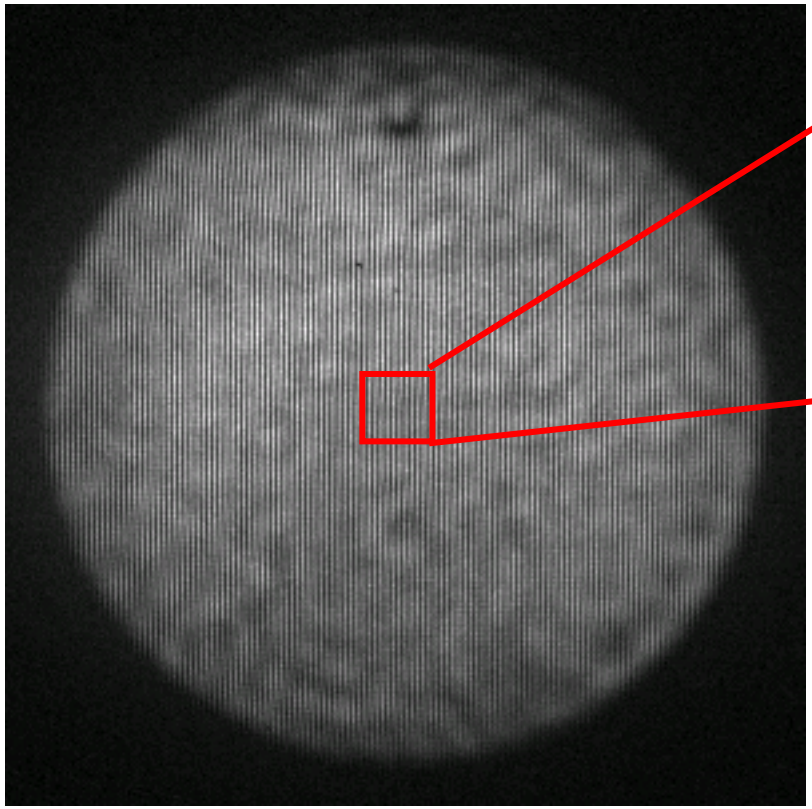
1.572 nm RMS 1.565 nm RMS 1.593 nm RMS 1.554 nm RMS

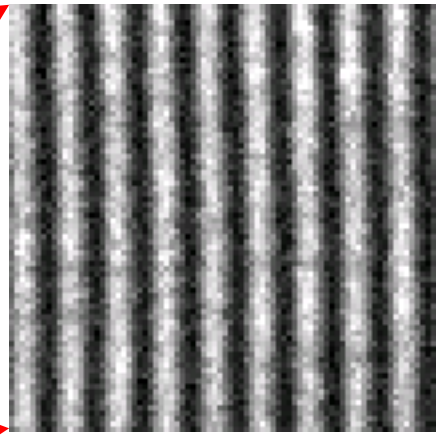


Repeatability of the four measurementts was 0.039 nm RMS.

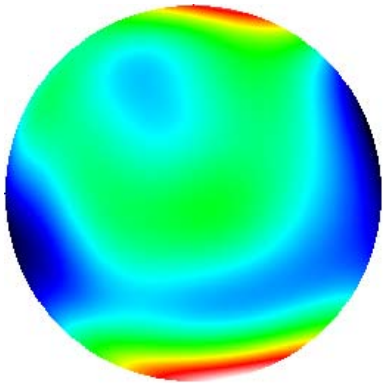
PDI result using 40nm pinhole

Interferogram



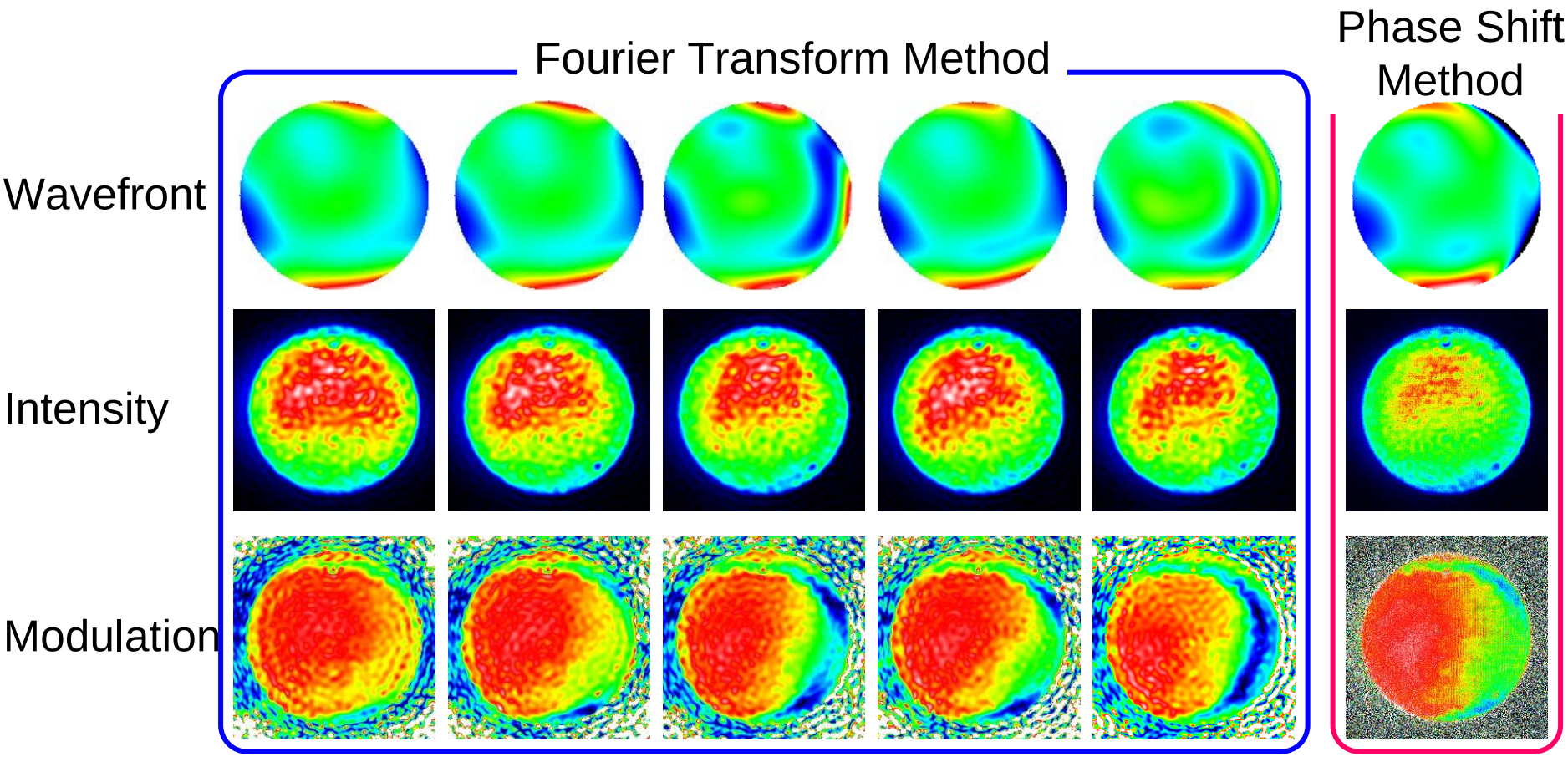


Fourier Transform Method



1.79 nm RMS

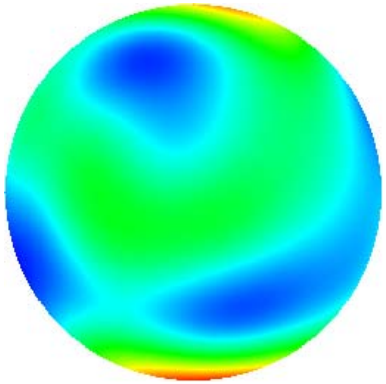
PDI repeatability



PDI measurements were unstable due to fluctuations of the alignment. The fourier transform method was more suitable for such unstable data than the phase shift method because one can adopt appropriate results and exclude of the failed data by the quality check.

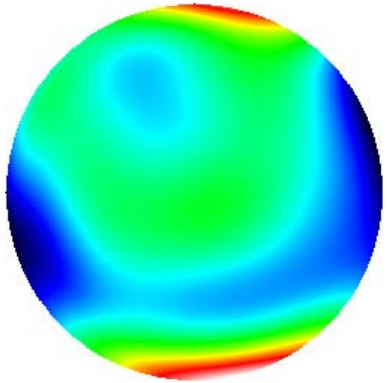
Comparison between the DTI and the PDI

DTI

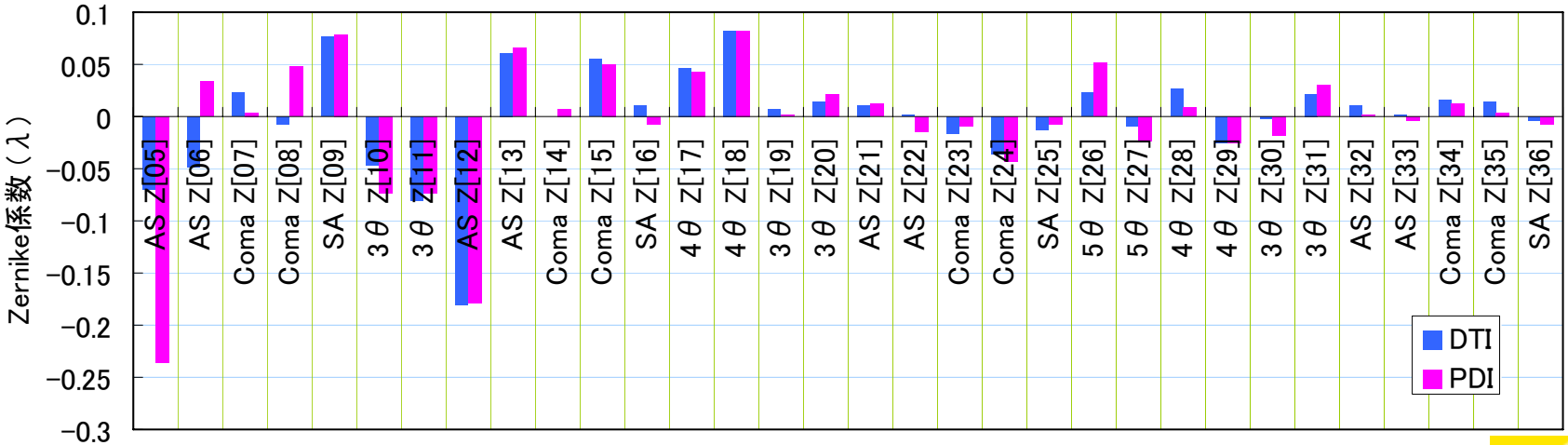


1.32 nm RMS

PDI



1.79 nm RMS



Difference：1.08 nm RMS (Z5～Z36)
0.37 nm RMS (Z7～Z36)

Conclusion

- To advance our development, the second optic has been introduced. The second optic has low aberration enough for the PDI.
- New calibration method for the DTI was proposed. The effect of the calibration was confirmed using the second optic.
- Repeatability of 0.039 nm RMS was achieved by the DTI. The PDI measurements was unstable due to the fluctuation of the alignment. The fourier transform method was useful for such unstable data.
- Both the DTI and the PDI were verified by the comparison the measured results. The difference was 1.08 nm RMS. The difference excluding the astigmatism was 0.37 nm RMS.

Acknowledgements

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Thank you.