High-Precision Wavefront Metrology Using Low Brightness EUV Source

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Outline

- Introduction
- Concept
  - Principle of the Metrology
- Experiment
  - Instruments
  - Data Analysis & Calibrations
  - Repeatability
- Summary

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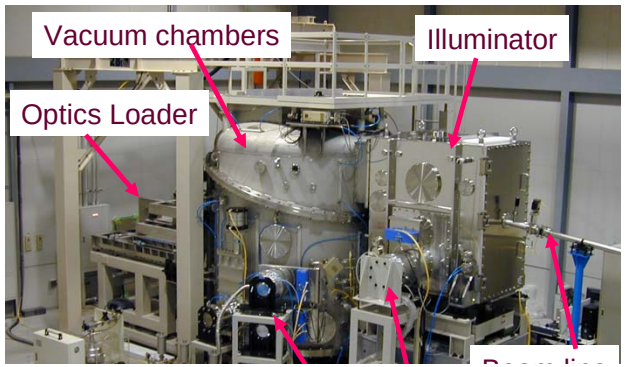
Introduction

Former EUV interferometers we have developed need a high-brightness light source, such as undulator of synchrotron.

However, the former interferometry is not applicable to wavefront measurement on practical exposure tools, due to insufficient brightness of their light sources (LPP or DPP).

We developed a novel interferometry system suitable for low-brightness sources in exposure tools.



EUV interferometer
at NewSUBARU (undulator)

source	brightness [photons/mm^2/mrad^2/0.1%BW]
undulator	**~10^{17}**
DPP	**~10^{11}**

~10^6

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Principle of multi-incoherent source Talbot interferometer (MISTI)

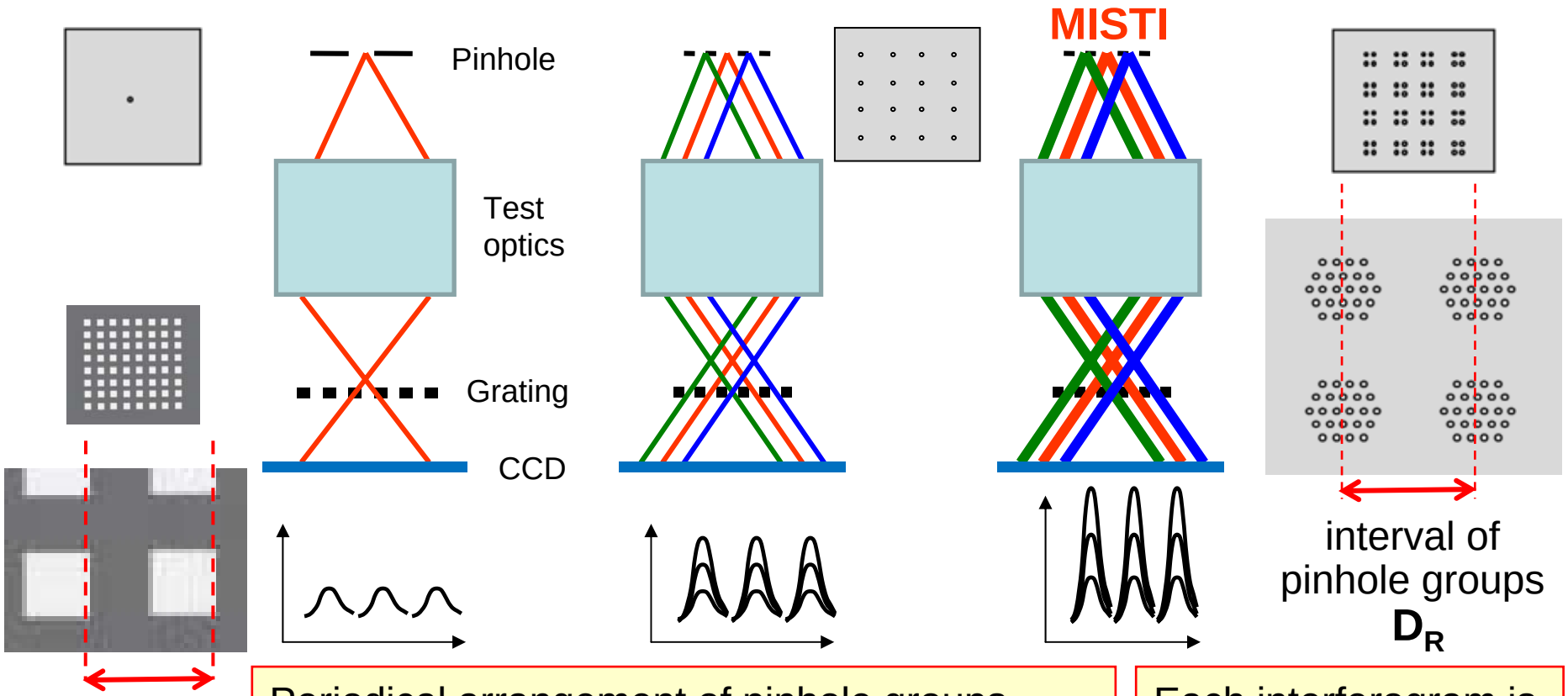
(1)Single pinhole
# of pinhole : 1

→

(2) Multi pinhole
# of pinhole : 1000

→

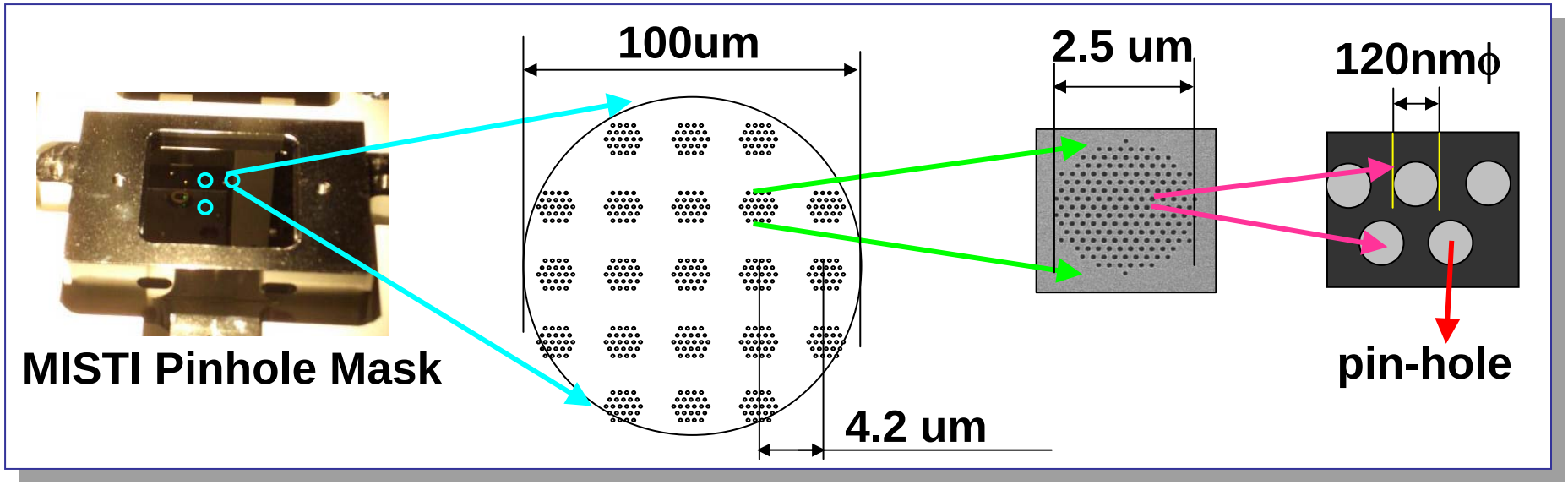
(3) Multi pinhole group
# of pinhole : 10^6



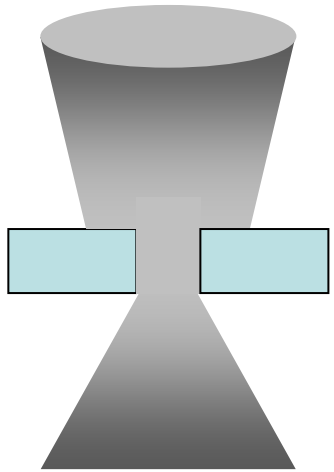
Periodical arrangement of pinhole groups makes fringe intensity **10^6 times brighter** than that in a single pinhole interferometer.

Each interferogram is superimposed when **$D_G = M \times D_R$**

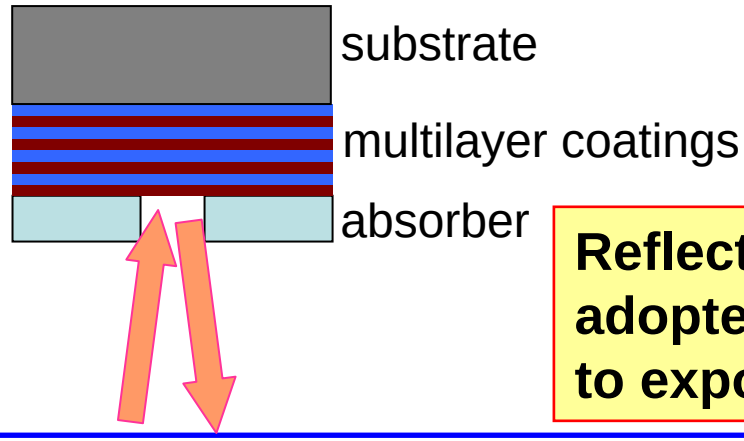
MISTI pinhole mask



Transmissive pinhole



Reflective pinhole (pin mirror)



Reflective type was adopted for compatibility to exposure tools

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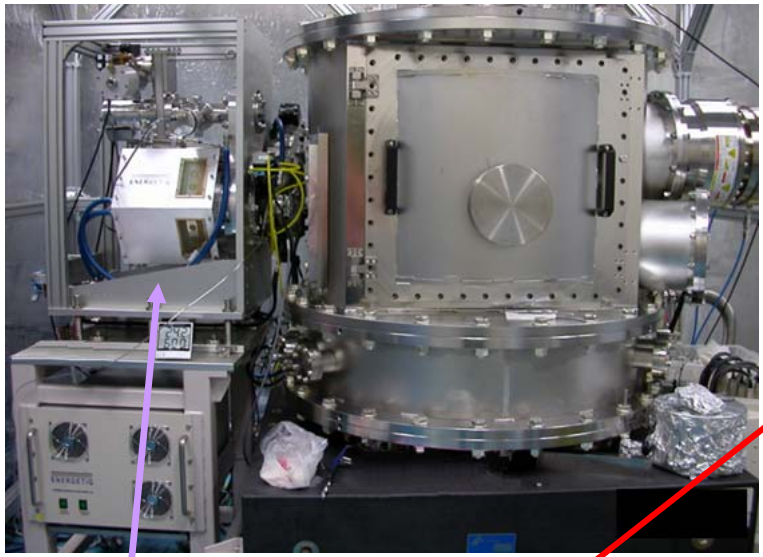
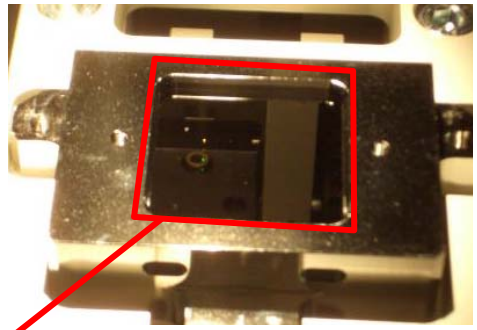
MISTI experimental setup





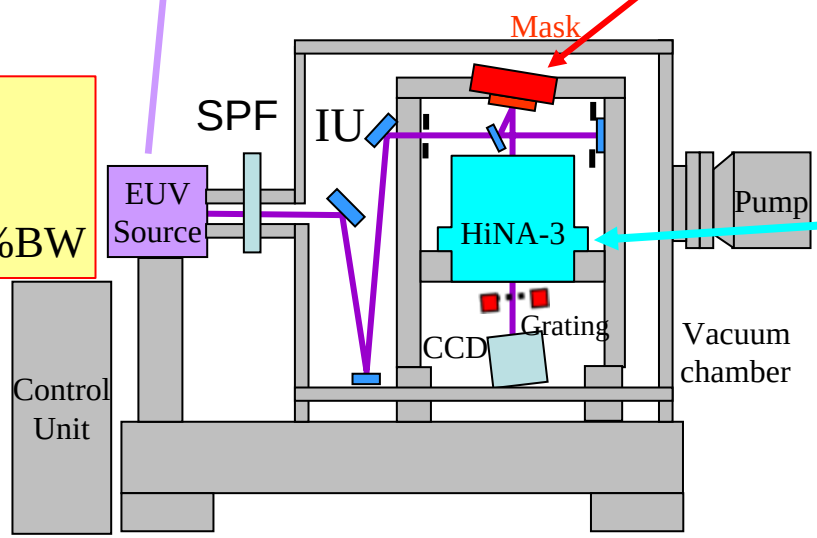
Pinhole mask
(MISTI mask)

EUV source
(Energetiq)

Brightness

$10\mathrm{W}/2\pi/\pm1\%\mathrm{BW}$

$\cong 10^{11}$ photon/mm^2/mrad^2/0.1%BW

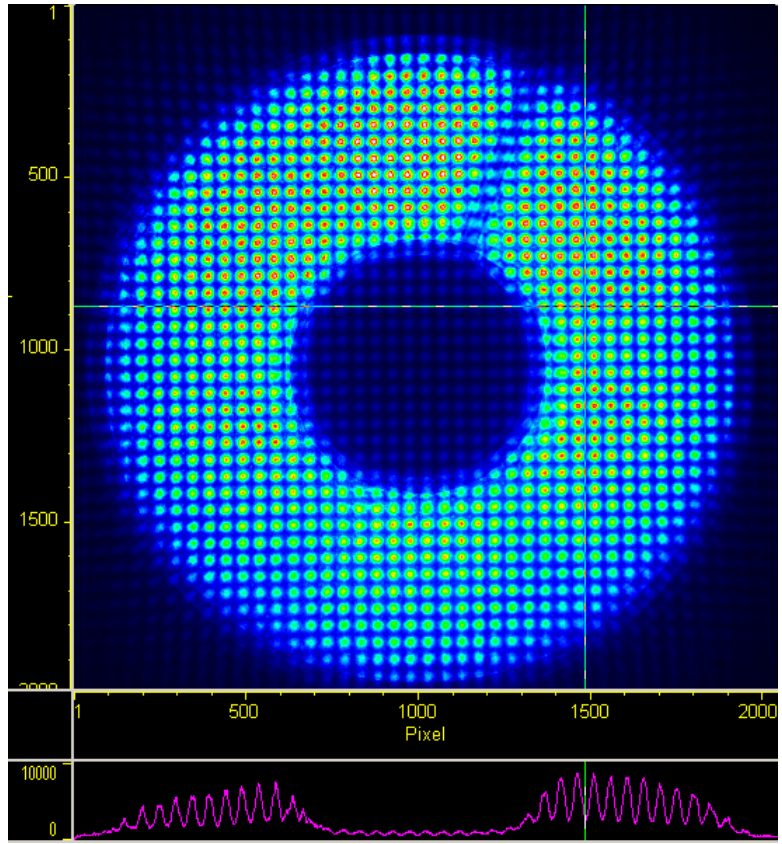


Test optics (HiNA-3)
NA 0.3
mag. 1/5

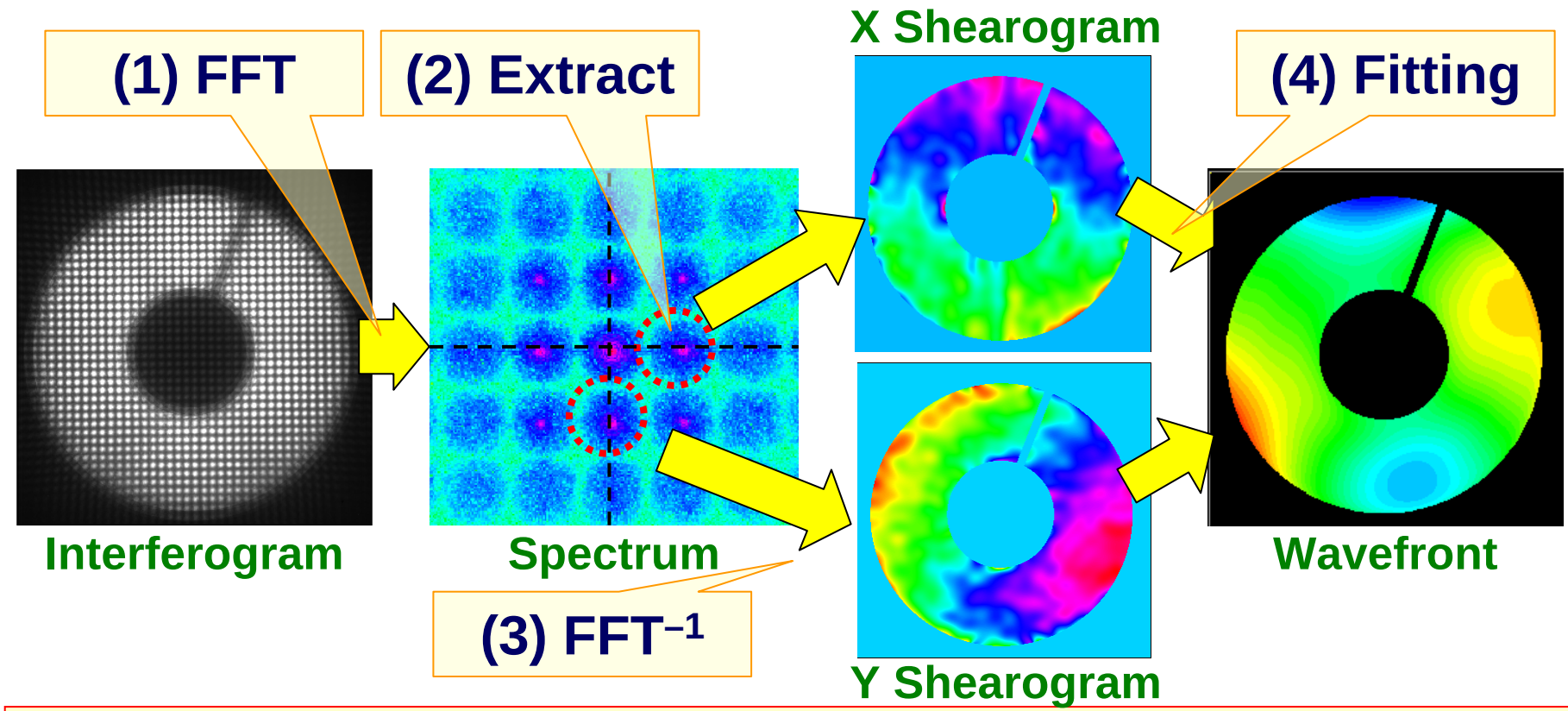
MISTI interferogram

Sufficient intensity of interferogram was obtained to evaluate aberration of test optics.

CCD Exposure	20 sec.
Fringe Intensity	~ 7000 counts
CCD Dark level	~ 200 counts



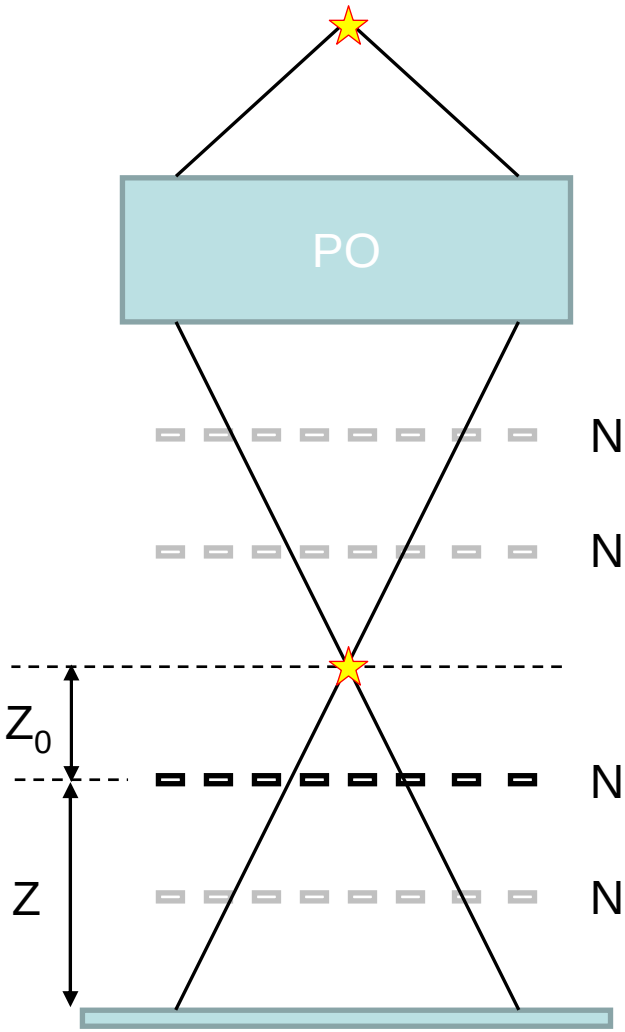
Reconstruction of wavefront



(1) **FFT** of interferogram
(2) **Extract** spectra of 1st orders (X- and Y-directions)
(3) **Inverse FFT** of X- and Y-components ("shearograms")
(4) Reconstruct by fitting with **difference Zernike polynomials**

Measured wavefronts

The systematic errors vary according to the Talbot number.



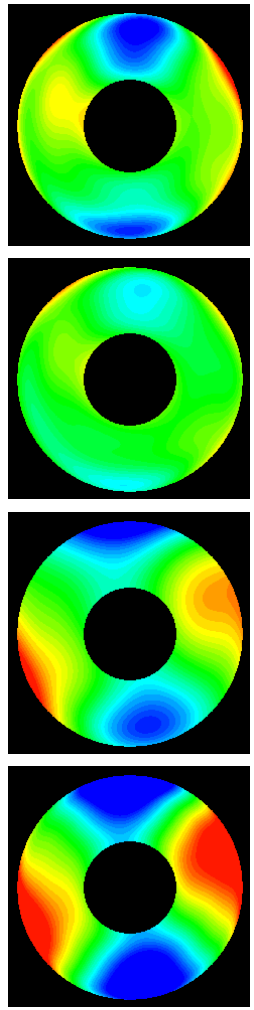
$$\frac{1}{Z_0}+\frac{1}{Z}=\frac{\lambda}{2Nd^2}$$

N = –1.0

N = –0.5

N = +0.5

N = +1.0



N = –1.0
2.95nmRMS

N = –0.5
1.51nmRMS

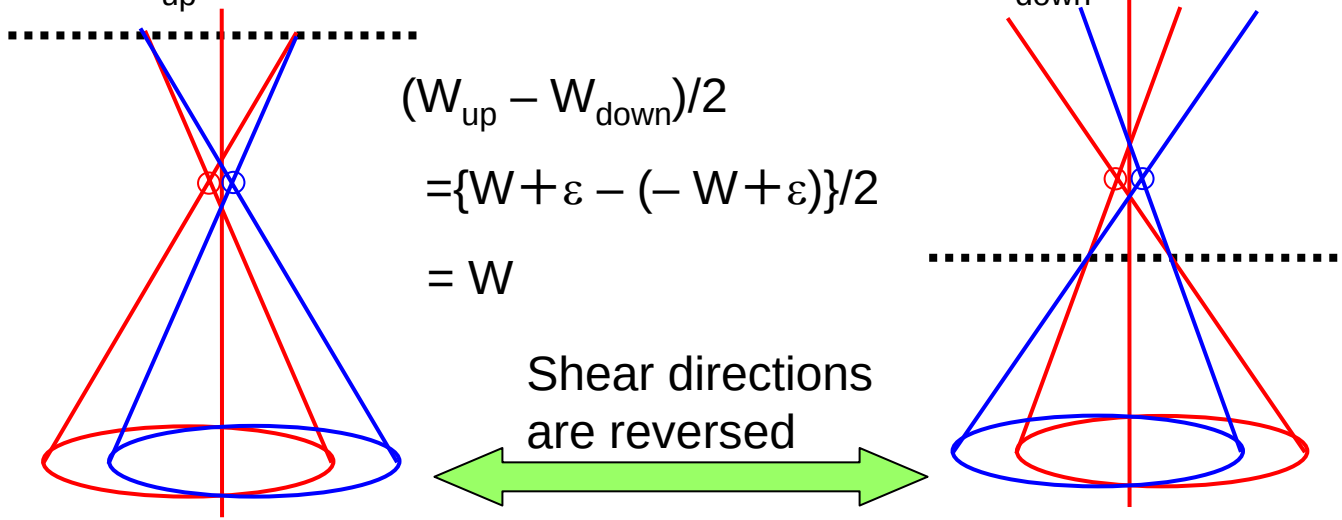
N = +0.5
3.53nmRMS

N = +1.0
5.37nmRMS

Calibration 1: grating up-down method

$W_{up} = W + \varepsilon$

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



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

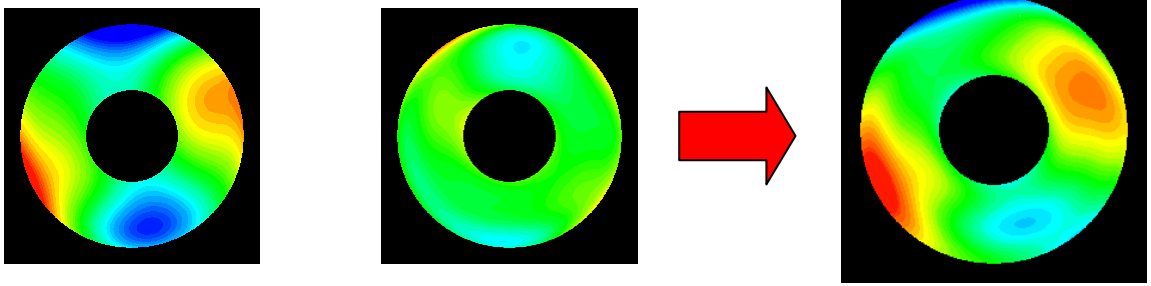
$= \{W + \varepsilon - (-W + \varepsilon)\}/2$

$= W$

Shear directions are reversed

Talbot number
N = +0.5
3.53nmRMS

Talbot number
N = –0.5
1.51nmRMS

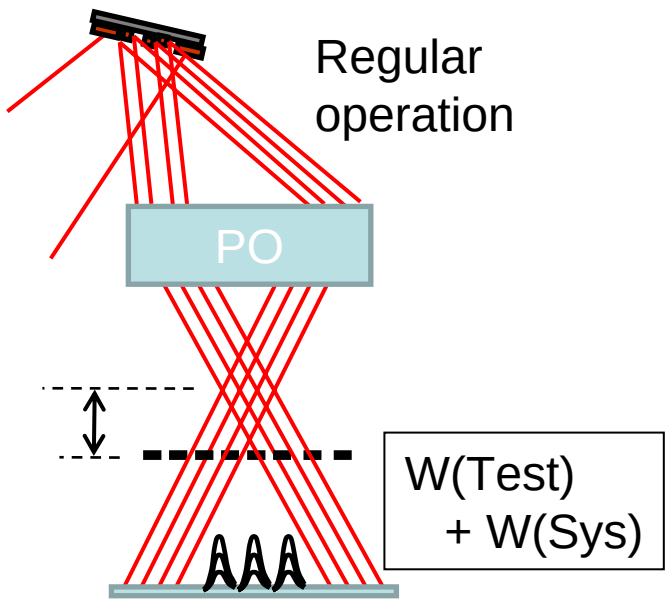


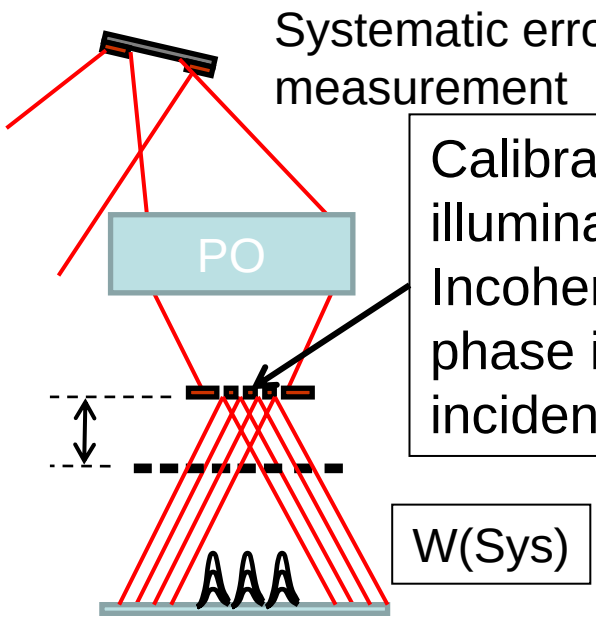
The test wavefront (1.79nmRMS)

calibrated by grating up-down method

Aberration of the test optics was derived from the measurement at N=+/–0.5.

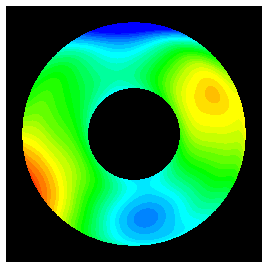
Calibration 2: calibration mask



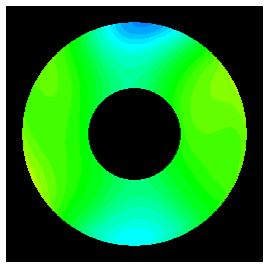


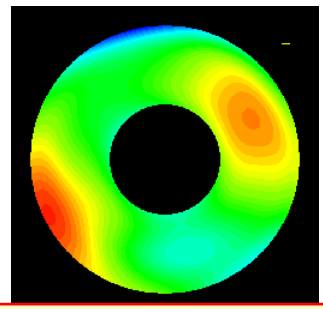
Calibration mask was illuminated **incoherently**. Incoherency removes phase information from incidence wavefront.

Regular operation
2.93nmRMS



Systematic error
1.59nmRMS



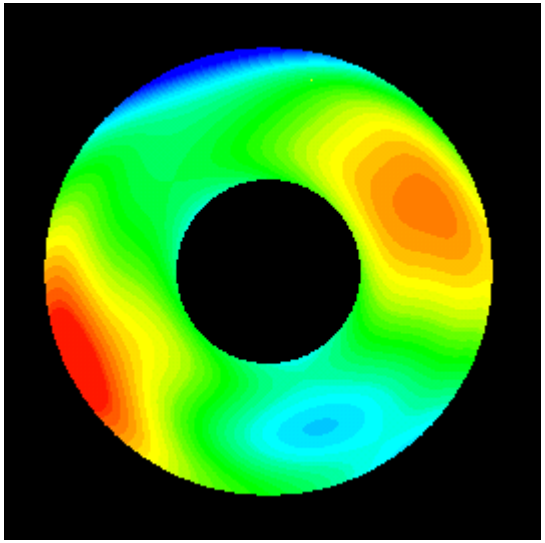


The test wavefront (1.69nmRMS)

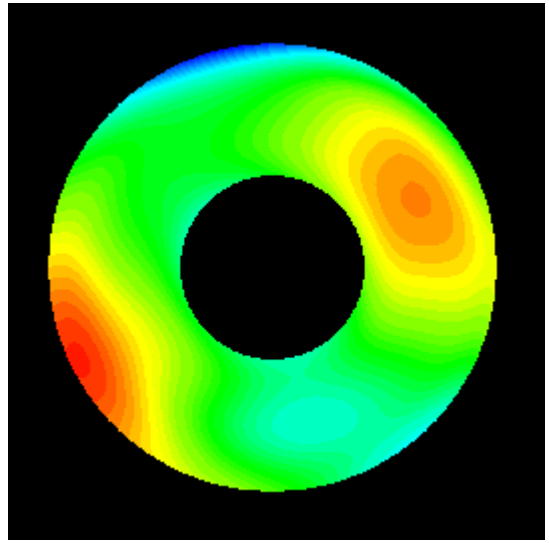
calibrated by mask method

Systematic errors can be acquired directly using a calibration mask.
We calibrated measured wavefront of the test optics using this data.

Comparison of two calibration methods



Grating up-down method
W(Test) = 1.79nmRMS

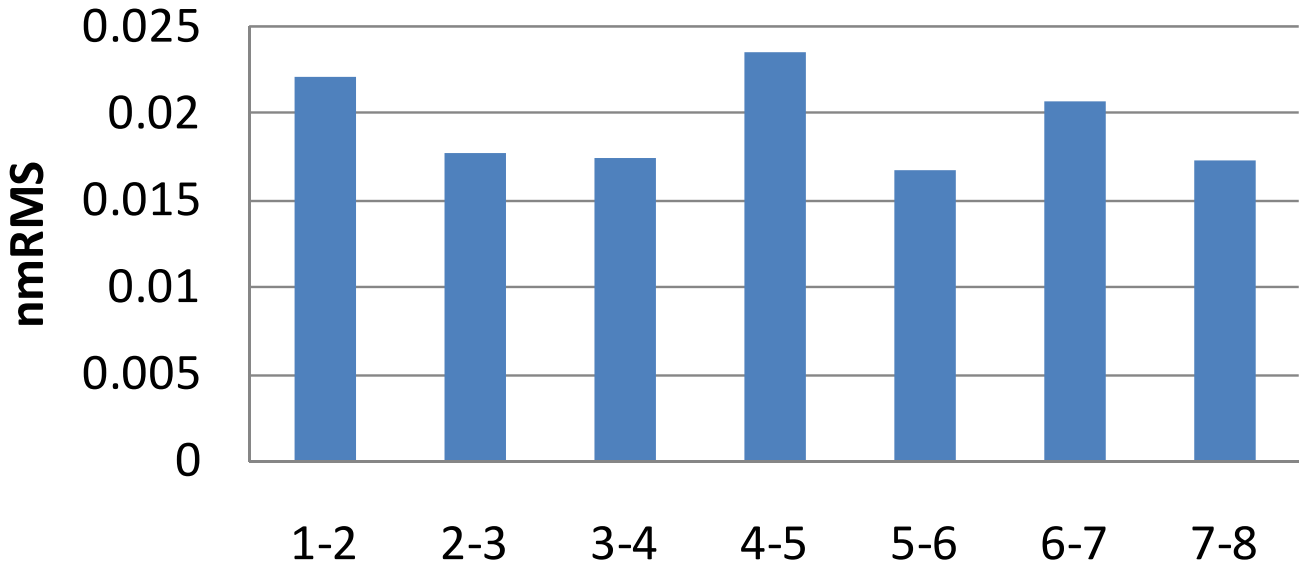


Calibration mask method
W(Test) = 1.69nmRMS

ΔW(Test) = 0.25nmRMS

Aberration of the test optics calibrated by two different methods agreed well.

Repeatability



Repeatability (8 times measurements)

Mean ： 0.019nmRMS

Short term repeatability is very small.

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- We have developed wavefront metrology using low brightness EUV source.
- Repeatability: 0.02nmRMS,

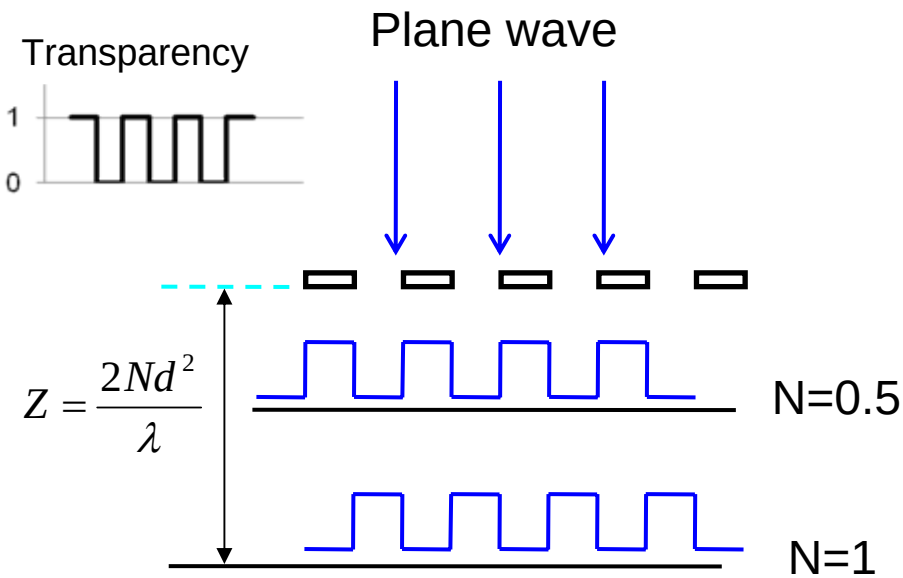
  Absolute accuracy: 0.25nmRMS
- MISTI could achieve interferogram intensity equivalent to conventional EUV interferometer using synchrotron undulator.

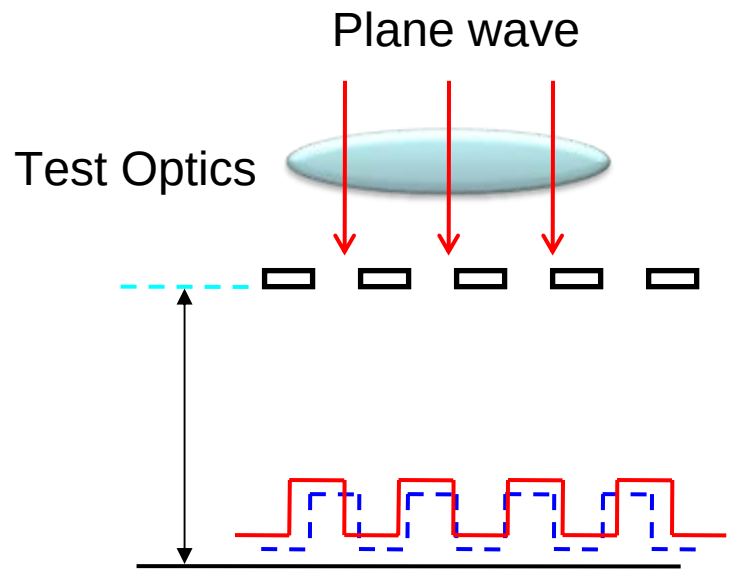
Acknowledgement

We appreciate for Mr. Hayashi, Mr. Abe and Ms. Fujii at Dai-Nippon Printing Co.,Ltd. for manufacturing pinhole masks.

Talbot image and wavefront metrology

When a periodic grating is illuminated by plane wave, same image appears behind grating, which has same distribution to its transparency. It is called “Talbot Image”.



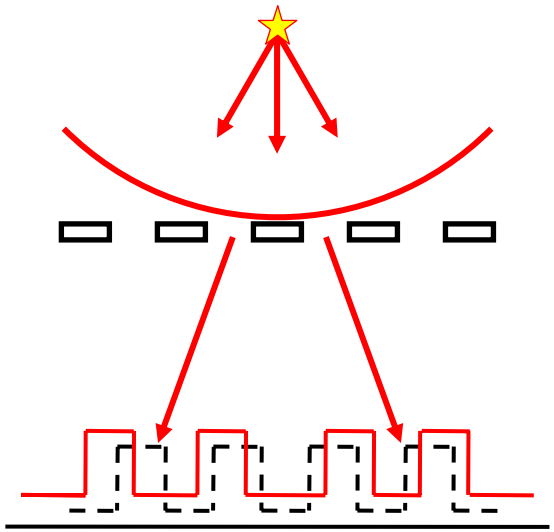


High contrast interferogram appears at the position of $Z = 2Nd^2/\lambda$ from the grating. (N: Talbot number)

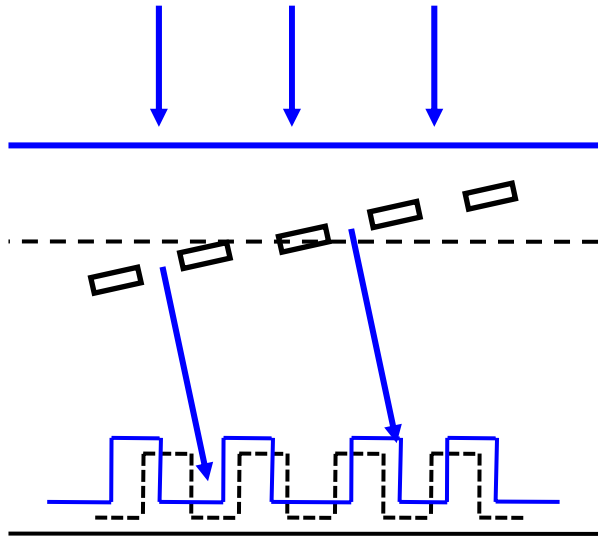
Interferogram is distorted by aberration of test optics.

Systematic errors

Point source



Plane wave



●Systematic Error 1

Grating is Illuminated by spherical wave. Divergent ray causes distortion of Talbot image.

●Systematic Error 2

Tilt of grating and CCD causes distortion of Talbot image.

Wavefront measurement always includes systematic errors. Calibration is very important to eliminate these errors from measurement.