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2015 Advanced Lithography :

Enhancing Defect Detection with Zernike Phase Contrast in EUV Multilayer Blank Inspection

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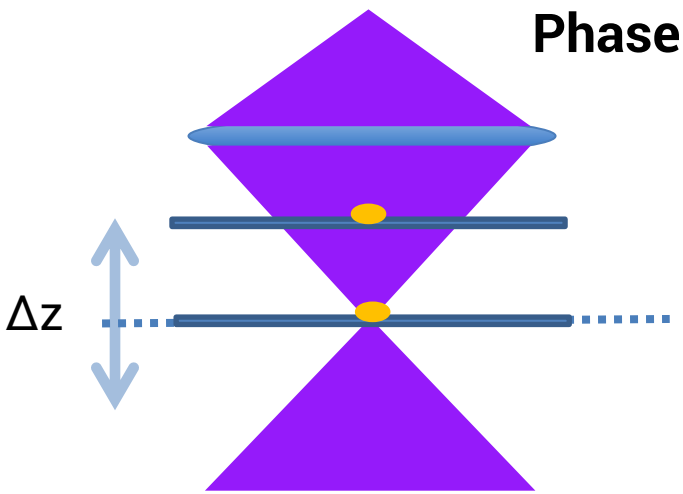
Big picture

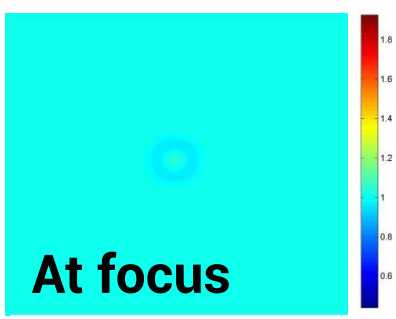
- Experimental result from Intel program defect mask using phase contrast method will be presented:
  - *SNR ~ 8 at focus is demonstrated for a program defect with a height about 0.35 nm.*
  - *The relationship between signal and noise under different apodization conditions will be discussed.*
  - *Comparison between bright field, dark field, and Zernike phase contrast microscope will be presented.*

Why Zernike phase contrast for actinic blank inspection? "In-focus inspection with better defect sensitivity"

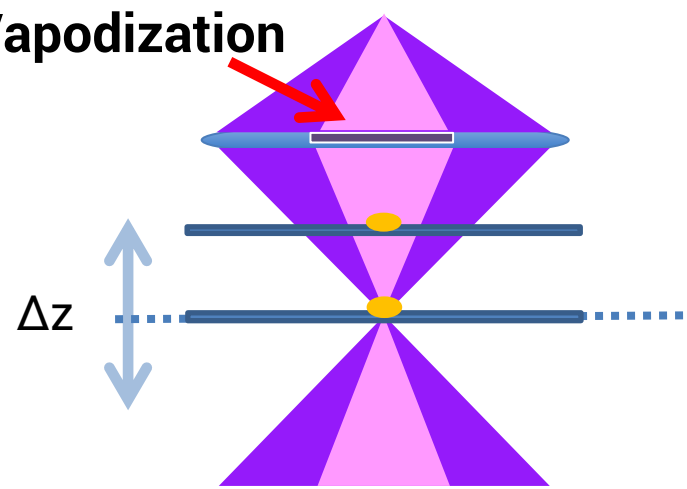
Conventional microscope



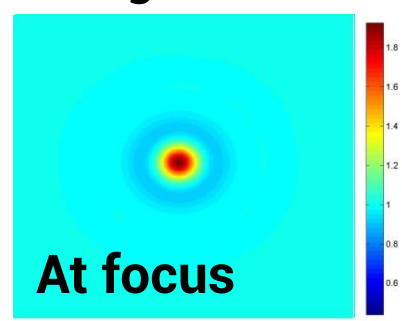
Aerial image of the mask



Zernike phase contrast microscope



Aerial image of the mask

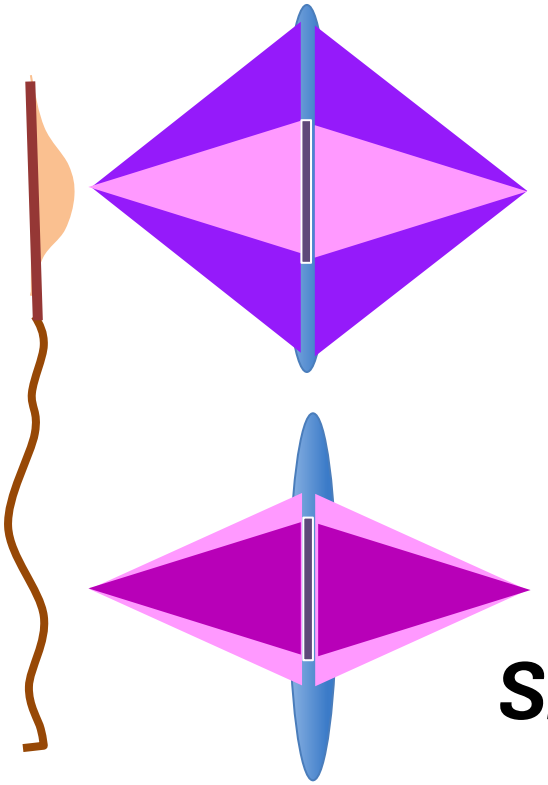


Y.G. Wang, "Zernike phase contrast microscope for EUV mask inspection," SPIE Advanced Lithography (2014).

Better SNR = Higher Capture rate!

Phase Defect
FWHM: 60 nm
H: 1 nm

Rough Surface
Correlation
length: 90 nm



DC is phase-shifted and attenuated.

Better contrast!

+

Low frequency part is attenuated.

Smaller speckle noise!

||

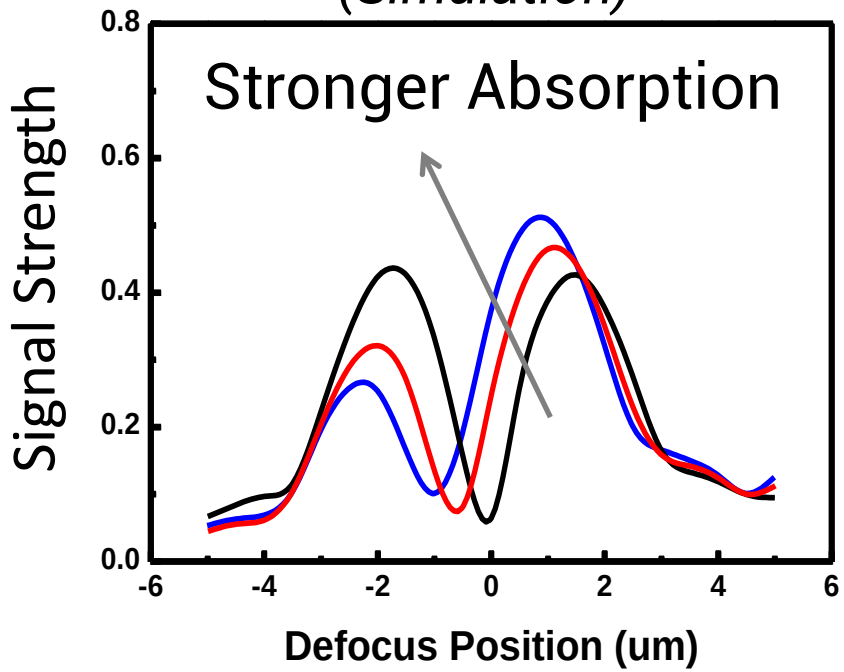
Better Signal-to-Noise Ratio!

Y.G. Wang, "Phase-enhanced defect sensitivity for EUV mask inspection," SPIE Photomask technology (2014).

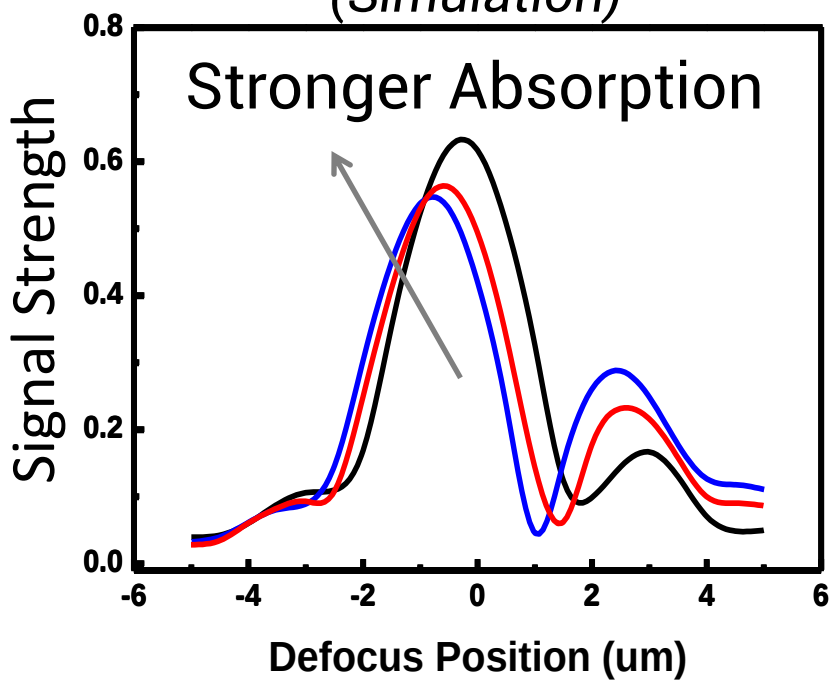
"Pure Phase" defect → *"Phase + Amplitude"* defect

Phase w./ 0% abs. Phase w./ 50% abs. Phase w./ 75% abs.

Conventional
(Simulation)



Zernike Phase Contrast
(Simulation)



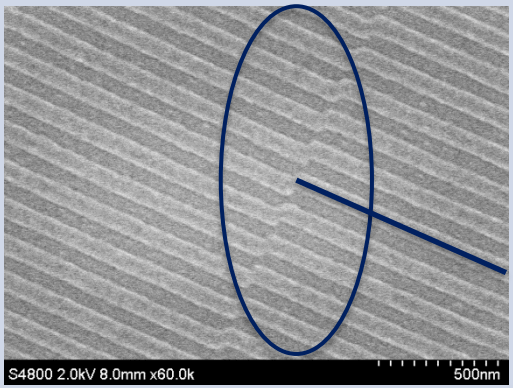
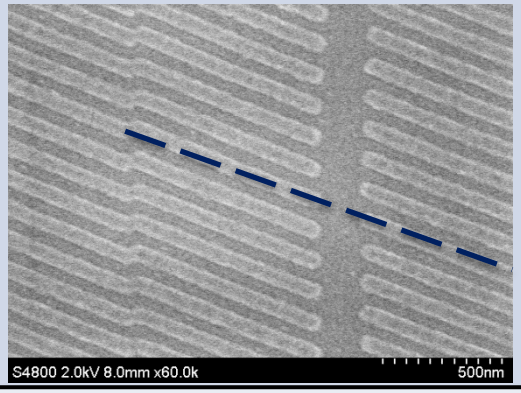
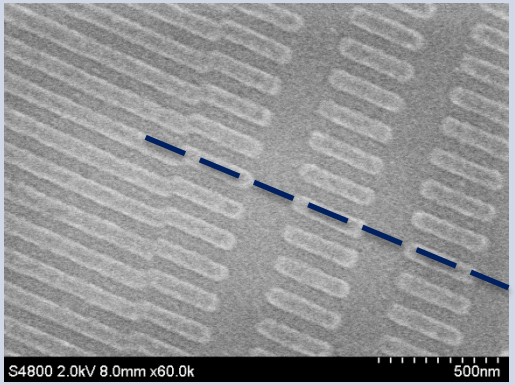
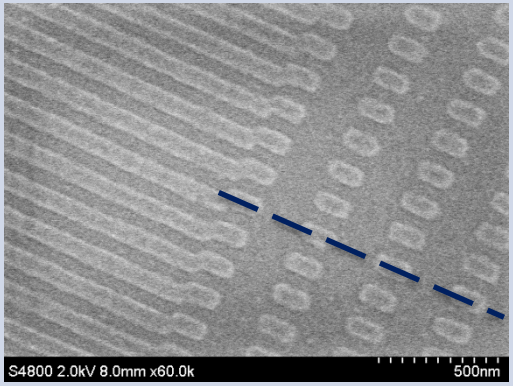
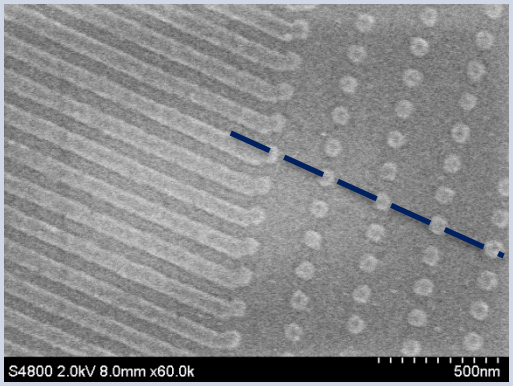
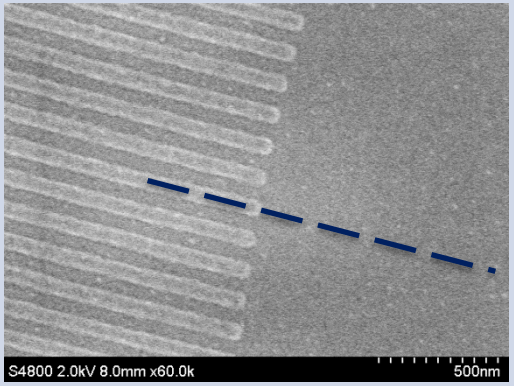
- Defect Type: *Bump. Height = 1nm. FWHM = 60nm.*
- Illumination: *4xNA= 0.33, Sigma: 0.3.*

SEMATECH zoneplate mask inspection microscope

- Source: Synchrotron
- Optics: Zoneplate-lenses
- 4xNA: 0.25 – 0.625
- Sigma: Programmable

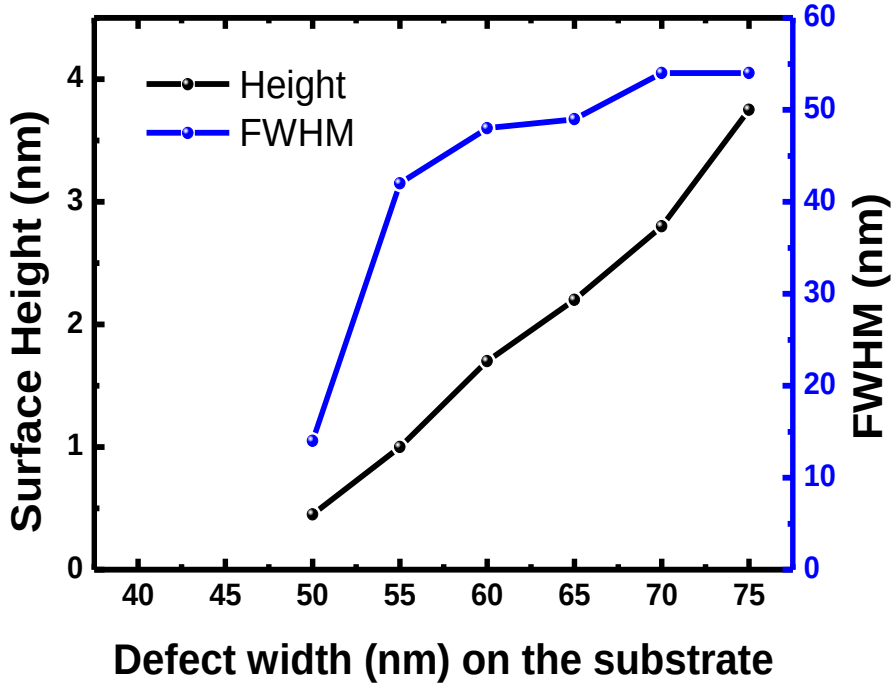
Customize design features (Phase shift/Apodization) on zoneplates!

Customize features on SHARP zoneplates

90°/ 100%	90°/ 69%	90°/ 41%
		
90°/ 20%	**90°/ 8%**	**Dark field**
		

Program defect information by AFM

Measured size of ML phase bumps

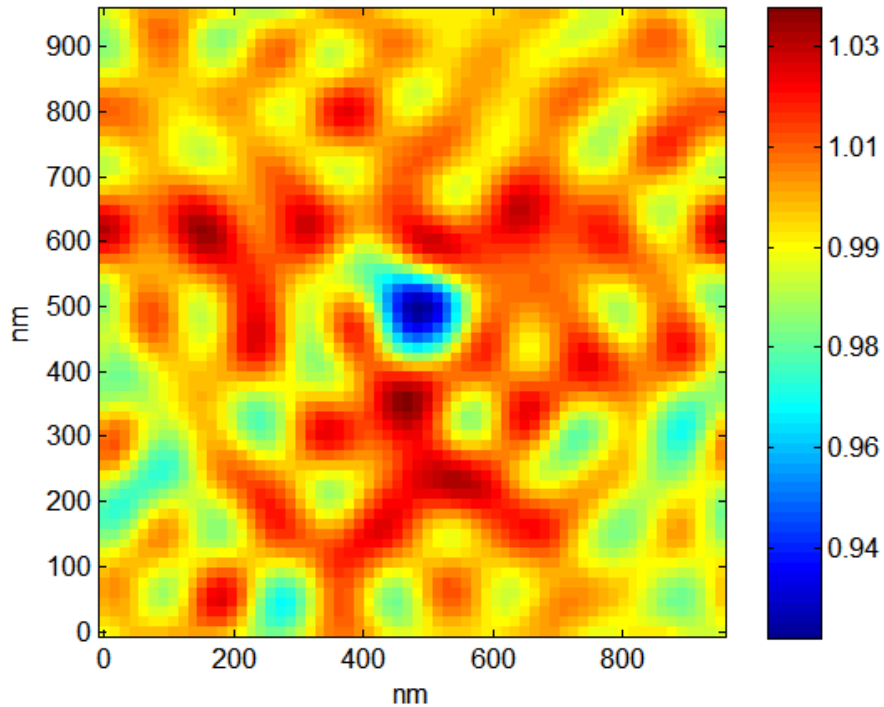


- Shape: point defect.
- Width: 40 – 75 nm on the substrate.

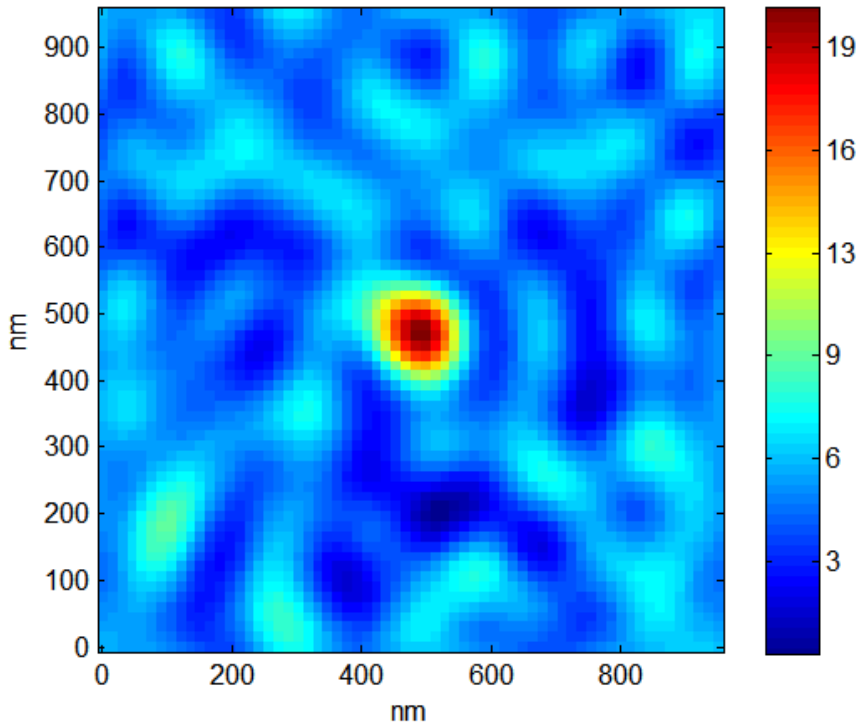
T. Liang, "Growth and Printability of Multilayer Phase Defects on EUV Mask Blanks," JVSTB (2007).

Smallest defect (H: 0.35 nm) identified on the mask

Amplitude (E-field)



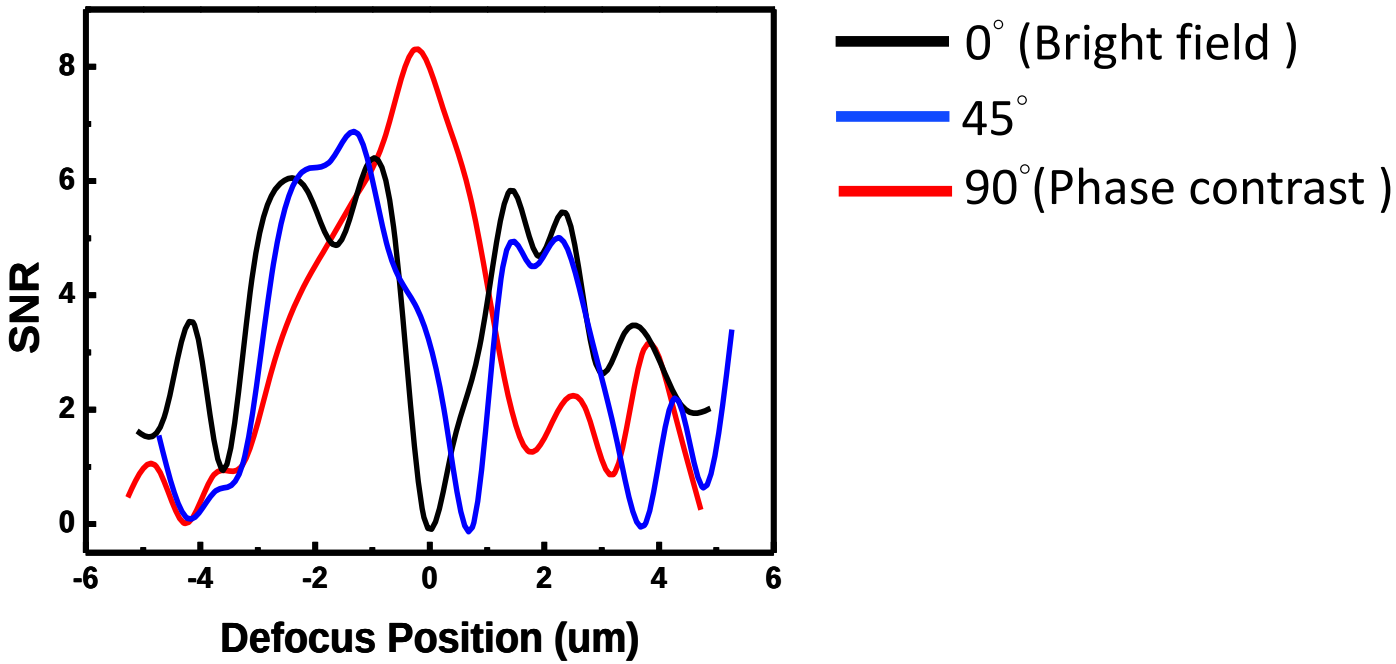
Phase (degree)



- Amplitude: 0.94
- Effective height: 0.35nm

R. Claus, "Phase measurements of EUV mask defects," SPIE Advanced Lithography (2015).

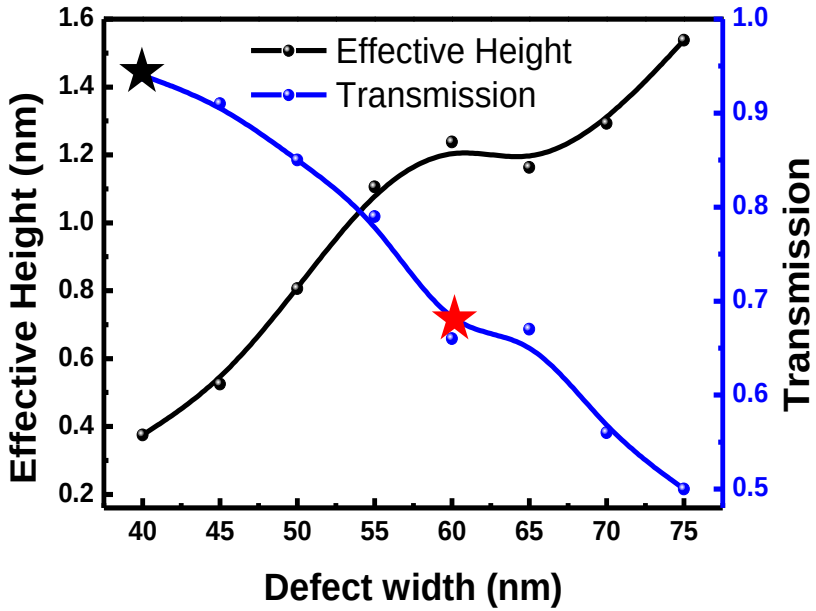
High SNR (~8) at focus by Zernike phase contrast



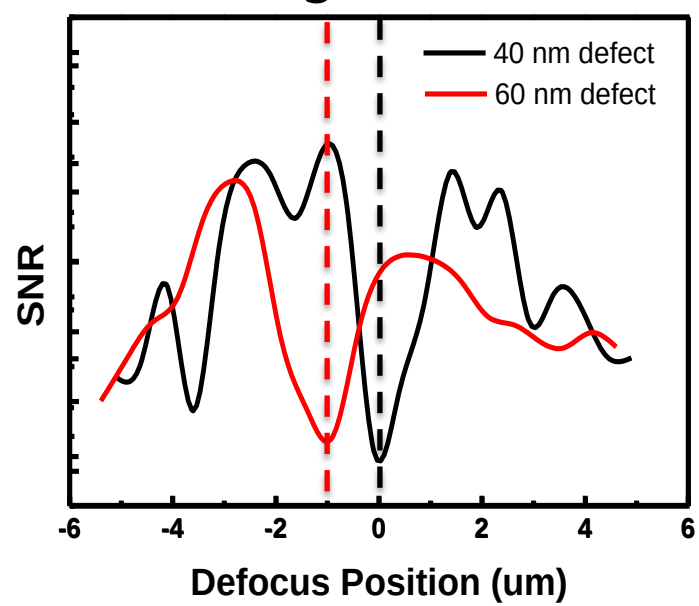
- Shift of the minimum SNR and the asymmetric of the peak value on each side indicate the phase shifts.

- Illumination: *4xNA= 0.33, Sigma: 0.3.*

Larger defect has more absorption



Bright field



Phase → Phase+ amplitude

- The absorption component of the phase defect changes its through-focus behavior.

- Illumination: *4xNA= 0.33, Sigma: 0.3.*

Zernike phase contrast works for both types of defect

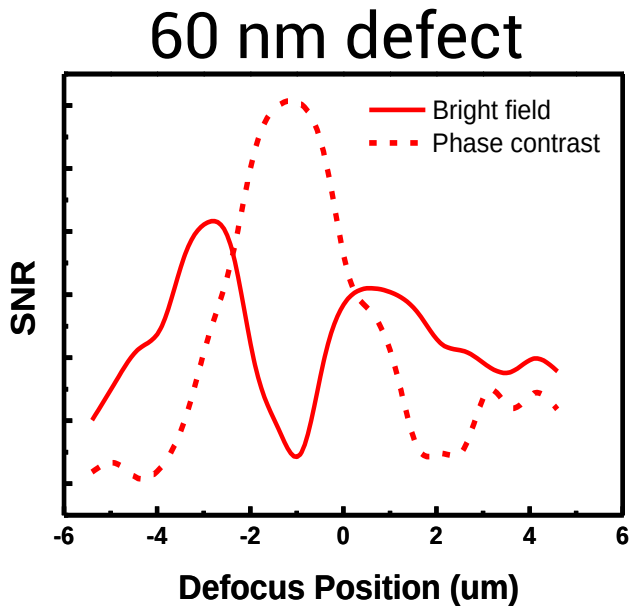
SNR at focus				
Method \ Defect	40 nm (H: 0.35 nm)	50 nm (H: 0.77 nm)	60 nm (H: 1.24 nm)	70 nm (H: 1.29 nm)
Bright field	0.70	3.60	12.35	17.12
Phase contrast	7.80	11.60	21.35	20.13
Enhancement	x11.14	x3.22	x1.72	x1.11

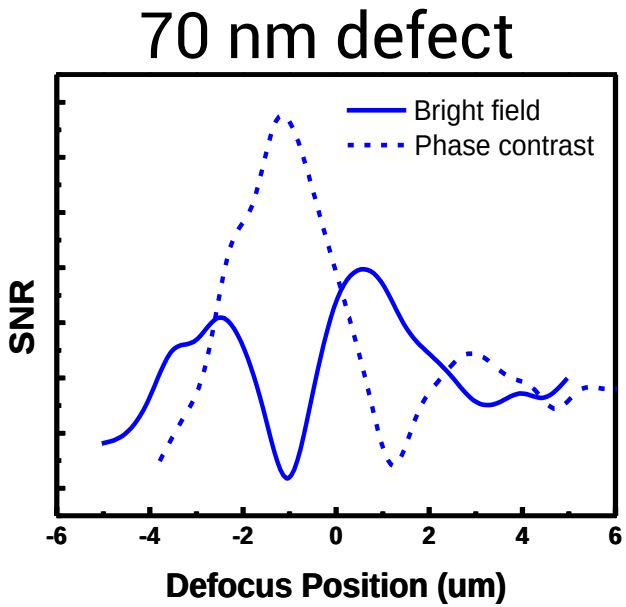
Pure phase → Phase+ amplitude

- Stronger enhancement for "phase dominated" defect by Zernike phase contrast method.

- Illumination: *4xNA= 0.33, Sigma: 0.3.*

Stronger SNR enhancement at optimum defocus

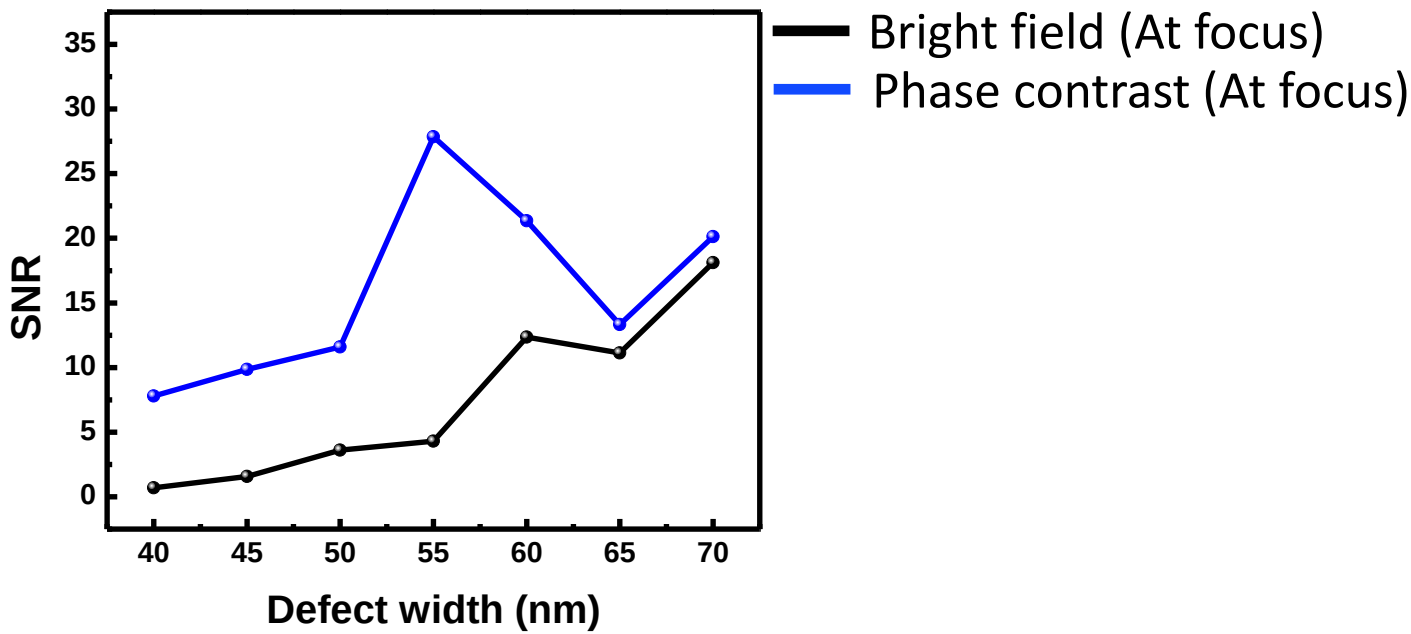




Method \ Defect	60 nm (H: 1.24 nm) At focus	60 nm (H: 1.24 nm) Max.	70 nm (H: 1.29 nm) At focus	70 nm (H: 1.29 nm) Max.
Bright field	12.35	20.7	17.12	19.7
Phase contrast	21.35	30.1	20.13	33.3

- Illumination: *4xNA= 0.33, Sigma: 0.3.*

Height, width, absorption of defects influence SNR

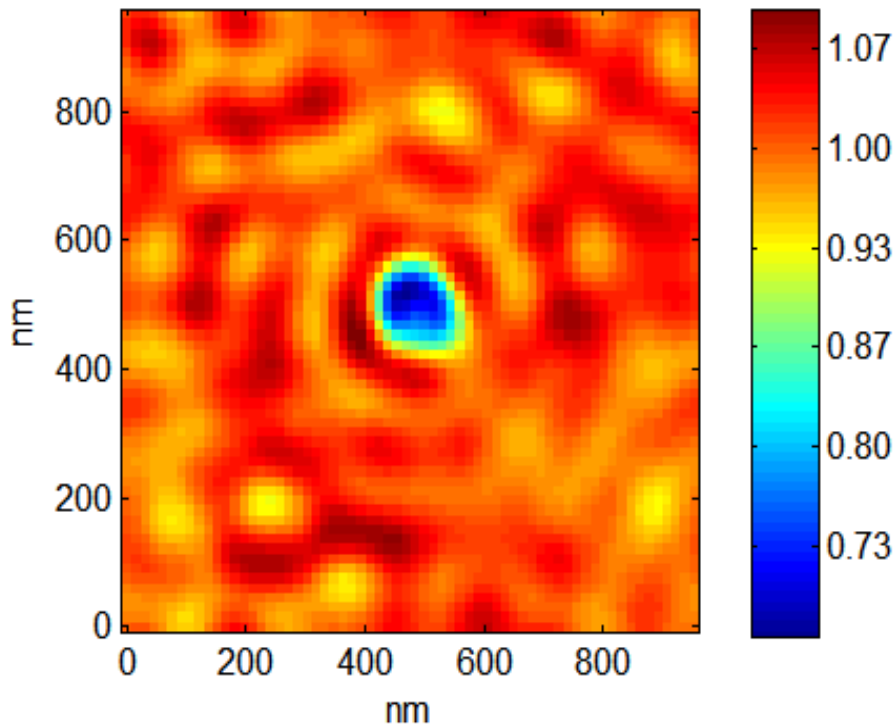


- Height: ***Optical path length.***
- Width: ***Scattering angle vs. NA, Phase-shifted region.***
- Absorption: ***Through-focus behavior.***

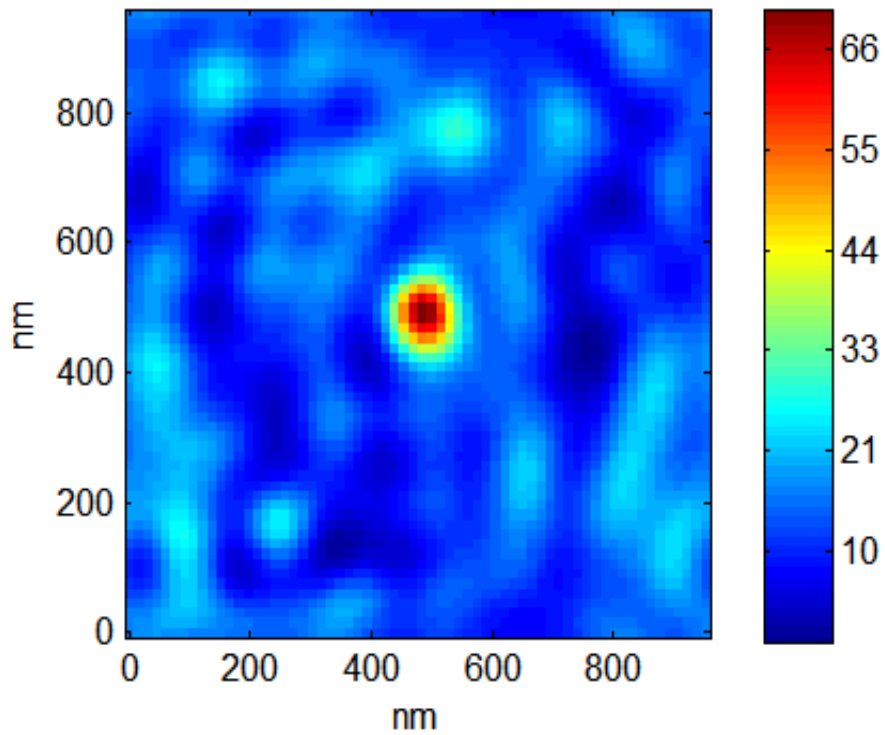
- Illumination: *4xNA= 0.33, Sigma: 0.3.*

Native defect information by algorithm

Amplitude (E-field)



Phase (degree)

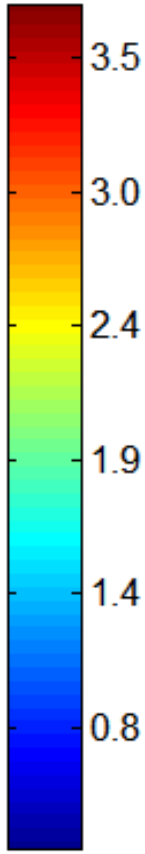


- Amplitude: 0.73
- Effective height: 1.23nm

R. Claus, "Phase measurements of EUV mask defects," SPIE Advanced Lithography, (2015)

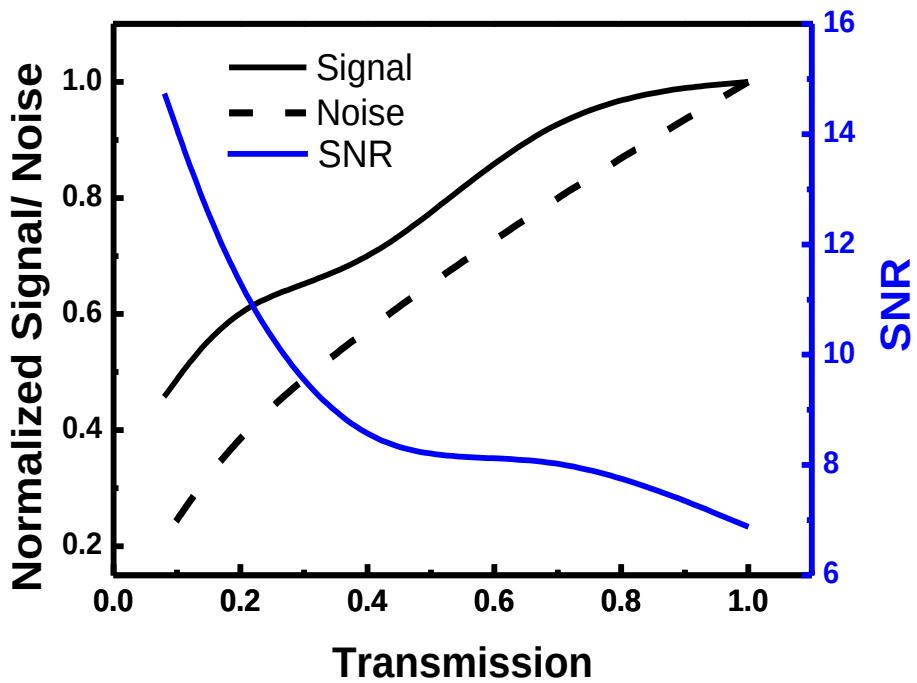
Native defect images by different methods

Method \ Defocus	-4 um	-2 um	0 um	+2 um	+4 um
0°/100%					
90°/100%					
90°/69%					
90°/41%					
90°/20%					
90°/8%					



- Illumination: *4xNA= 0.33, Sigma: 0.5.*

Noise drops faster than signal under apodization

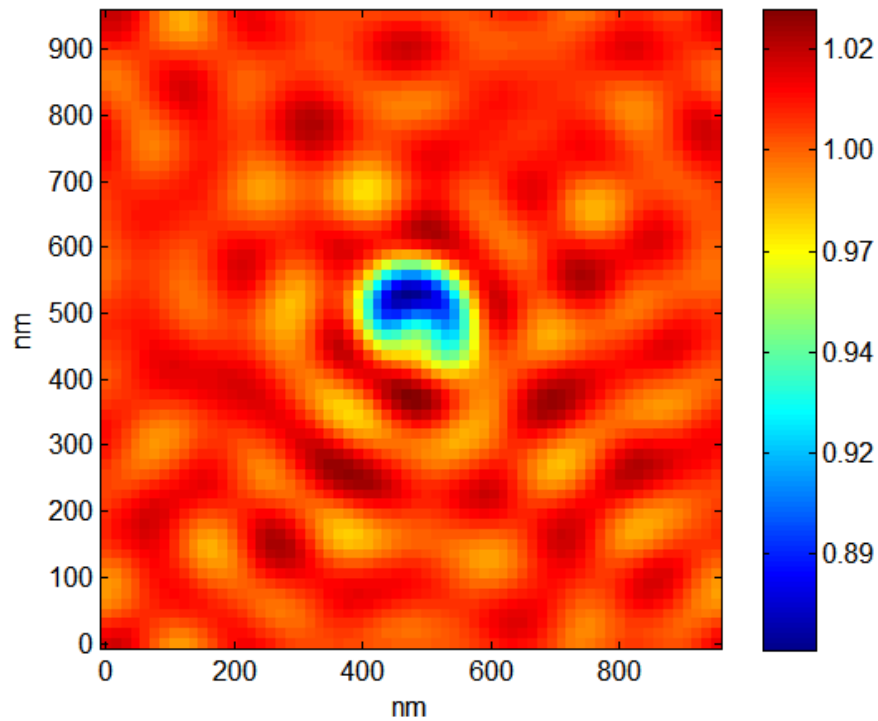


- Noise drops to 20% while signal drops to 45% at 8% intensity transmission.

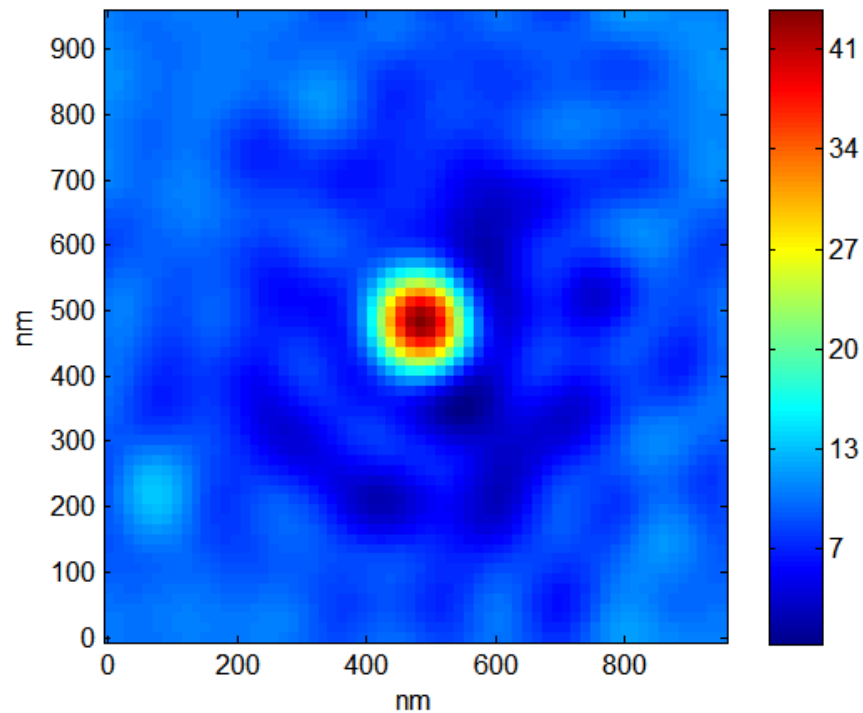
- Illumination: *4xNA= 0.33, Sigma: 0.5.*

50 nm defect information by algorithm

Amplitude (E-field)



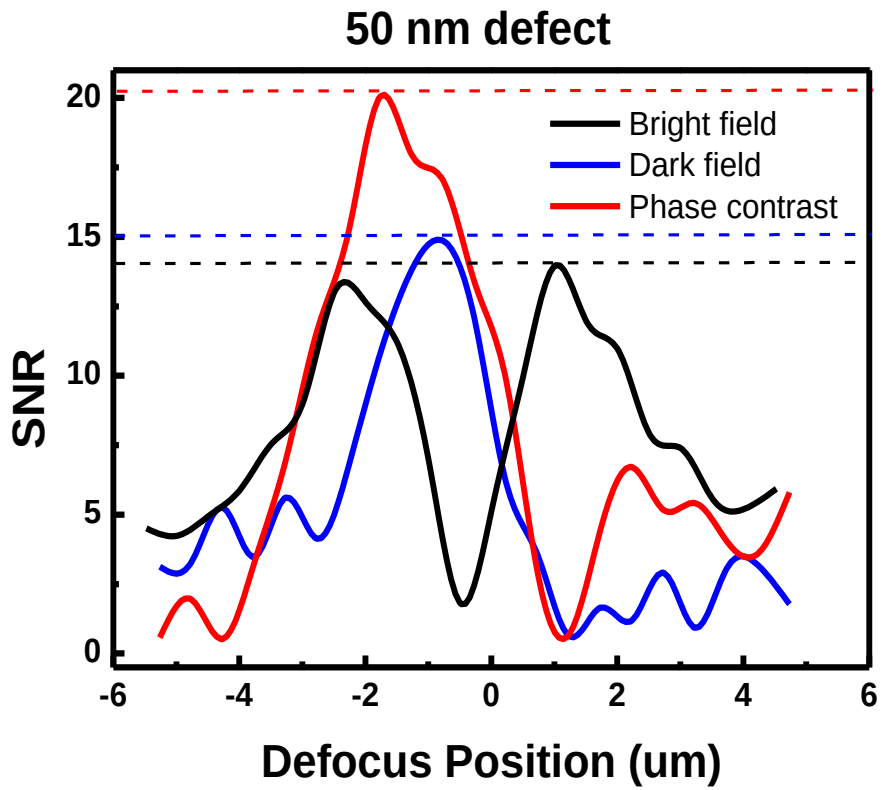
Phase (degree)



- Amplitude: 0.89
- Effective height: 0.77nm

R. Claus, "Phase measurements of EUV mask defects," SPIE Advanced Lithography, (2015)

Bright field vs. Dark field vs. Zernike phase contrast



- 4xNA for dark field is 0.4 while the other two are 0.33.

- Illumination: *4xNA= 0.33 and 0.4, Sigma: 0.3.*

Summary

- High SNR at focus has been demonstrated on multilayer phase bumps by Zernike phase contrast method.
- SNR up to 30 at optimum defocus position for phase defects with absorption is achieved by Zernike phase contrast microscope.
- 80% reduction on speckle noise and 55% reduction on defect signal can achieve a 2-fold enhancement on SNR under 8% intensity transmission.

Acknowledgement

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