Extreme ultraviolet mask substrate phase surface roughness effects on lithographic patterning

Simi A. George, Patrick P. Naulleau, Iacopo Mochi, Farhad Salmassi, Eric M. Gullikson, Kenneth A. Goldberg and Erik H. Anderson

Can indirect top surface phase roughness characterizations be trusted explicitly for predicting scatter related speckle in the image field?

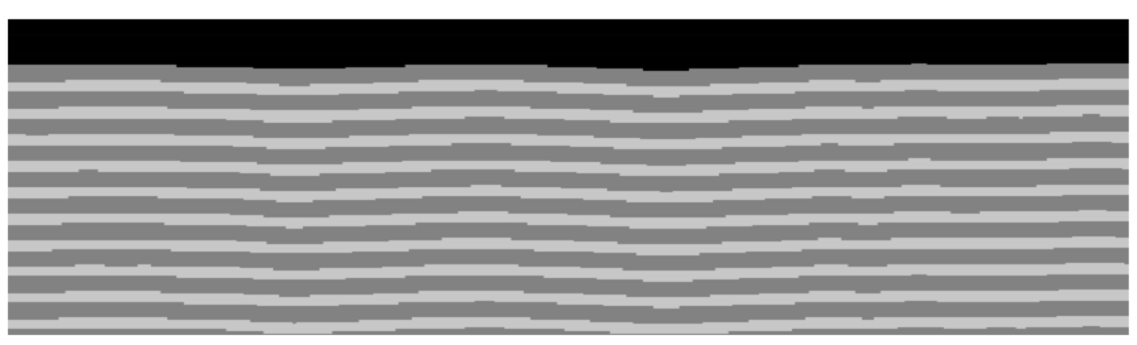
EUV mask contributors to line edge roughness (LER)

EUV lithography pattern line edge roughness (LER) limits below <1.2nm; system level effects from the reflective optics and masks are contributors

Phase roughness of EUV masks

LER from phase coherent mask roughness results from speckle in the aerial image, thus it is necessary to understand the relationships between bottom (substrate) surface roughness, top surface roughness, EUV scattering, and aerial image speckle for developing accurate mask specifications and suitable roughness metrics.

Conformal growth of the mask substrate roughness, the replicated substrate roughness (RSR), to the top multilayer surface may be a significant contributor to pattern LER.



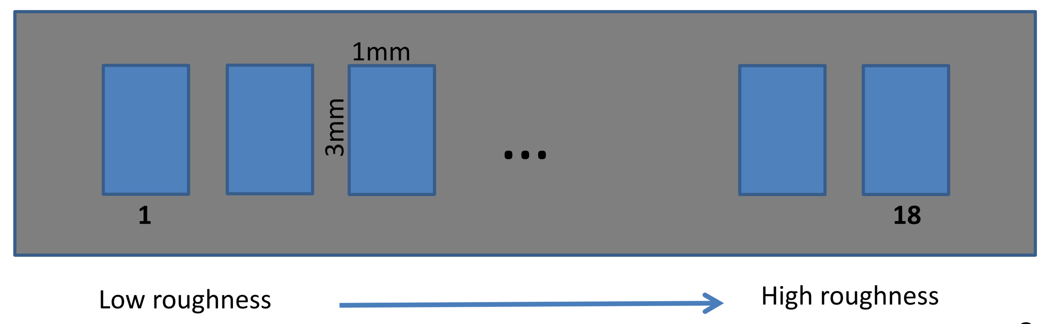
Implications of image plane line-edge roughness requirements on extreme ultraviolet mask specifications
Patrick P. Naulleau and Simi A. George, Proc. SPIE 7379, 73790O (2009)

Multilayer scattering is characterized by interference effects from the roughness of the different material interfaces as well as the conformal growth of the substrate roughness to the top layer surface. These interference effects cause phase modulations in the image field (speckle)

Mask substrate roughness contributing to pattern LER may be significant.

Is 2D topography roughness measured by AFM a good enough metric of mask quality?

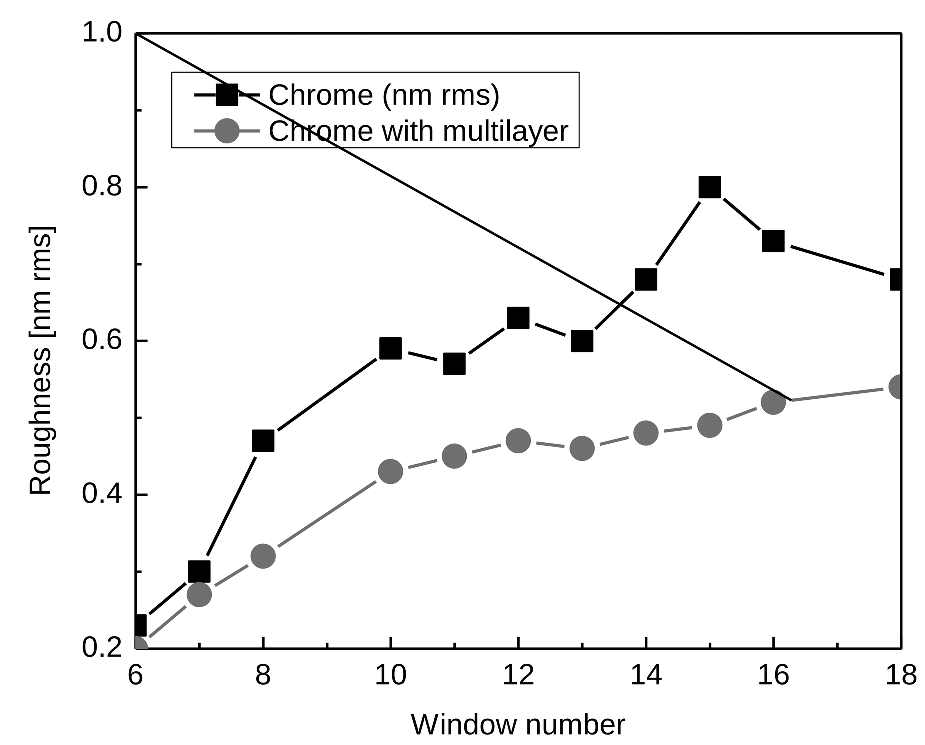
Mask for controlled roughness studies and the surface characterizations



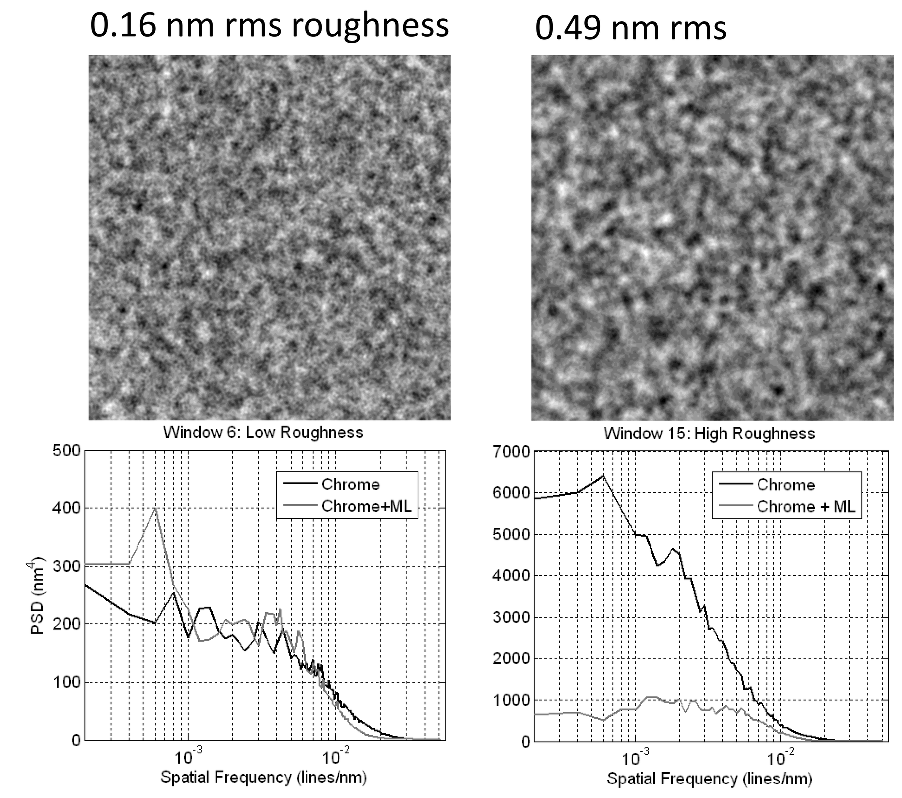
Fabricated by the shadowed deposition of Chromium (Cr) onto a standard 4" Silicon (Si) wafer by DC magnetron sputtering in an Argon gas environment, then multilayer (ML) deposited. AFM scans collected of each surface, before and after ML deposition.

Surface Analysis by Atomic Force Microscopy

Rough mask surface from AFM scans of a 5μm x 5μm area



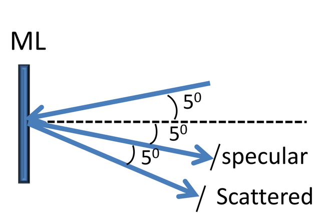
0.16 nm rms roughness — 0.49 nm rms



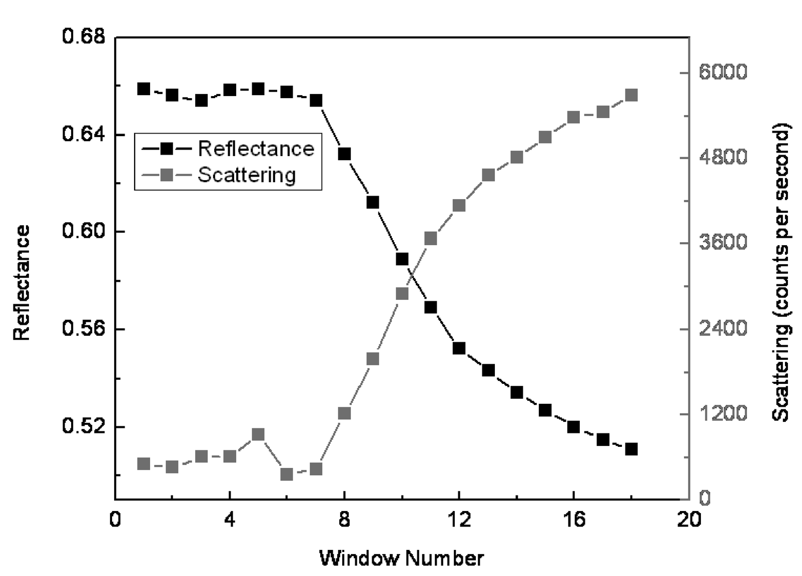
Substrate roughness smoothing from multilayer is less effective once the phase structures are smaller than 200-300 picometers

Soft x-ray reflectometry of multilayers on varying roughness on mask

Roughness from a surface is by using x-ray reflectance and scattering (XRS) measurements at wavelength

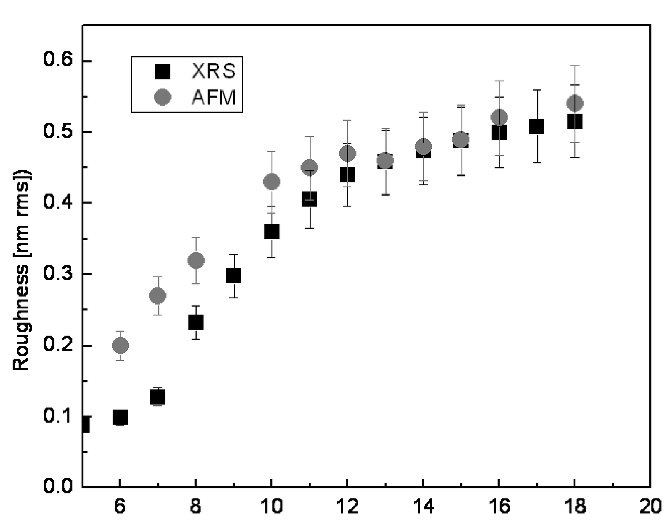


Reflected specular and scattered beam at 13.46nm is measured at a fixed angle with Specular beam divergence is ± 1.2 degrees



Synchrotron based reflectometer located at the advanced light source (ALS) beamline 6.3.2

High spectral purity, a spectral resolving power (eV/ΔeV) of up to 7000, a wavelength accuracy of 10^{-3} nm, and a reflectivity accuracy of 0.1% (absolute)



AFM and XRS measured rms roughness are compared.

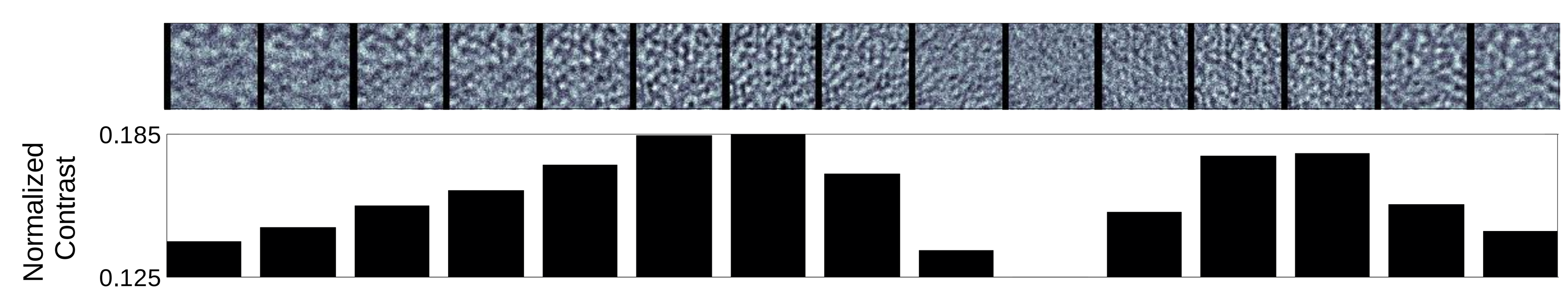
The two sets of data are seen to overlap where the substrate phase roughness heights are large, where the two measurements methods differ by nearly 50% for the low phase roughness mask areas.

Fixed uncertainty at 10% is assumed for both sets of data as coming from the measurement errors

At-wavelength measurements of image plane speckle contrast

The SEMATECH Actinic Inspection Tool (AIT), which is an EUV microscope operating at the wavelength of 13.5nm

Though-focus series of images for four different regions at specific points along the rough gradient were collected with a 0.3NA, 4x stepper equivalent zoneplate. Each image collected in the series is a 16 bit, 2048 x 2048 array corresponding to a 30μm square area on the mask

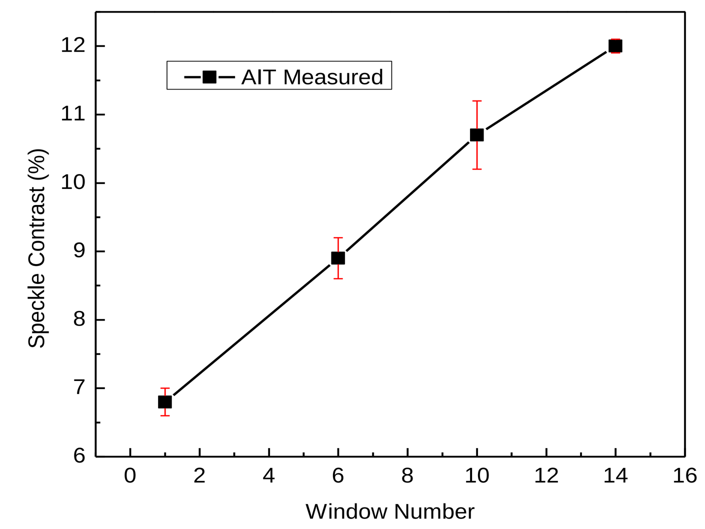


Images through focus of the zoneplate lens, the contrast of the surface granularities is a minimum at the best focus

The best focus image in this series is 6th from the right

Even at the smallest roughness scale, a speckle contrast better than 6% is observed.

Calculated contrast at the best focus of each rough surface measured. The table on the right provides contrast data as well as the corresponding phase roughness by AFM measurements

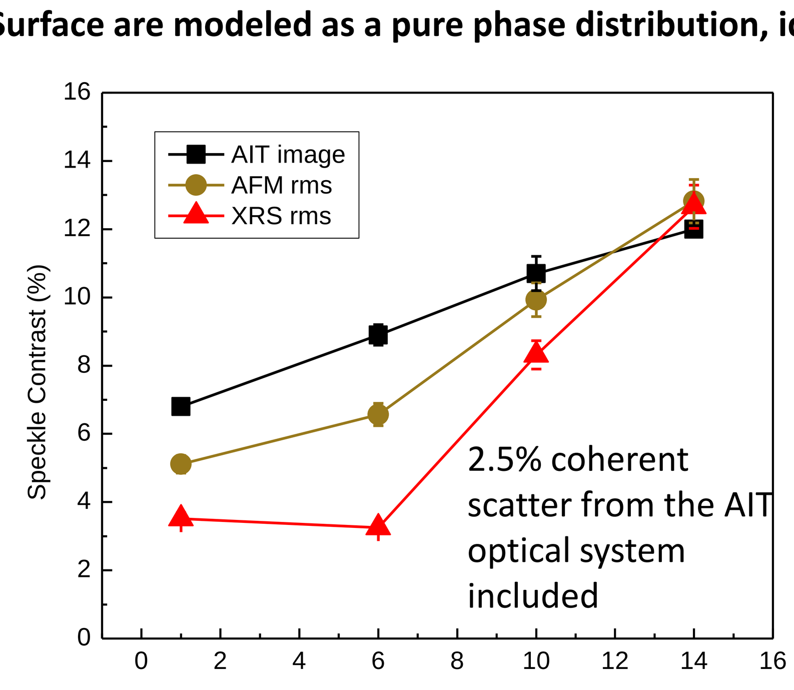


Window	AIT [%]	AFM [nm rms] 10%
1	6.80 0.2	0.16
6	8.90 0.3	0.20
10	10.7 0.5	0.32
14	12.0 0.1	0.46
18	NA	0.54

0.3NA equivalent zone plate, FOV – 1μm

Modeling for speckle contrast comparison to AIT measurements

Surface are modeled as a pure phase distribution, ideal case and with AIT design aberrations for a 1μm FOV



Aberrations	
Piston	0
X Tilt	0
Y Tilt	0
Defocus	-0.019
Astigmatism 90	0.018
Astigmatism 45	-0.017
Coma X	0.005
Coma Y	0.006
Spherical	-0.0002

In the calculated image contrast for AFM and XRS determined phase roughness, the AFM is shown to be a better fit to the measured images. The XRS departure from the AFM measurements may be due to the error that is expected to be in the initial reflectivity chosen for XRS roughness calculations. It is an average of the reflectivities obtained for the first few rough surface regions in the very low roughness region. The second major error comes from ignoring the absorption of the incident beam on sample surface that could lead to the reflectivity loss.

Summary

- Mask substrate roughness induced scatter contributes to LER at the image.
- A programmed roughness mask was used to study correlation between mask roughness metrics and wafer plane aerial image inspection.
- **It was found that roughness measurements by surface topography methods alone do not provide complete information on scatter related speckle, and at-wavelength characterization appears to be necessary.**
- Future work will involve mask patterning on top of the rough areas and imaging with the SEMATECH Berkeley micro-exposure tool on to resist under different illuminations/coherence conditions
- Measurements of total integrated scatter measurements and comparison to AFM, especially in the low roughness regions are completed and to be reported on in the near future.

Contact Information

CXRO scientific and engineering teams, **CXRO.LBL.GOV**
The SEMATECH Berkeley Actinic Inspection Tool (AIT), **AIT.LBL.GOV**
Calibration and standards beamline 6.3.2 at the ALS, **CXRO.LBL.GOV/ALS632**
The CXRO Nanowriter Electron-Beam Lithography Lab, **CXRO.LBL.GOV/NANOFABRICATION**
Center for X-ray Optics, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720

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