An Image Based Method for EUVL Aberration Metrology

Zac Levinson[1], Bruce Smith[1], Sudhar Raghunathan[2], Obert Wood[2], Markus Benk[3], Kenneth Goldberg[3]
1 Nanolithography Research Labs, Microsystems Engineering Program, Rochester Institute of Technology, 168 Lomb Memorial Drive, Rochester, NY 14623
2 GLOBALFOUNDRIES, 400 Stone Break Rd. Extension, Malta, NY, 12020
3 Lawrence Berkeley National Labs, One Cyclotron Road, Berkeley, CA 94720

R·I·T

1 - Introduction

Aberrations in an EUV lithography (EUVL) system can affect CD, depth of focus, and pattern overlay. It is of critical importance to EUVL insertion to characterize and understand these aberrations and their behavior during system operation.

Metrology techniques to estimate wavefront error can be split into two classes,

Interferometric Methods

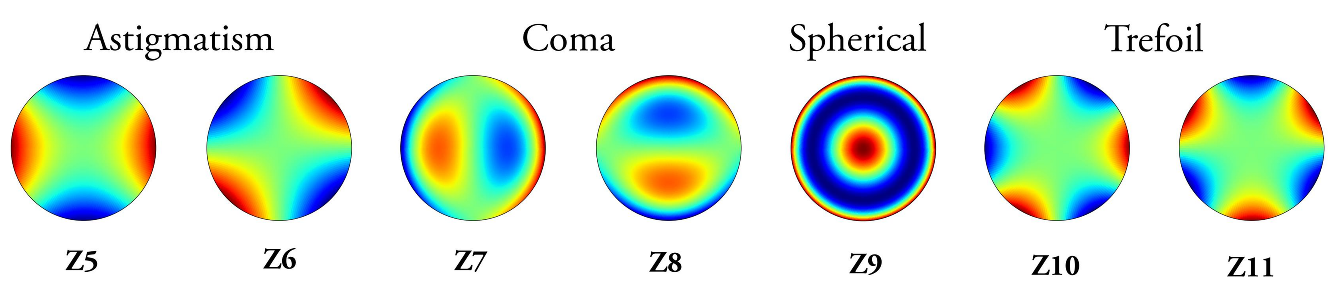
- de facto standard aberration metrology
- potential of sub-nanometer accuracy
- difficult to implement in situ due to the requirement of additional optics

Image-Based Method

- automated wavefront fitting to CD image data
- potential of sub-nanometer accuracy
- large amounts of data and simulations required
- can be implemented in situ during tool use

We present two experimental case studies using an image-based fitting method. Pupil phase variation is extracted using a single algorithm from: 1) an ASML NXE:3100 EUVL scanner at IMEC, and 2) the SEMATECH Actinic Reticle Review Project (SHARP) EUV Mask Microscope

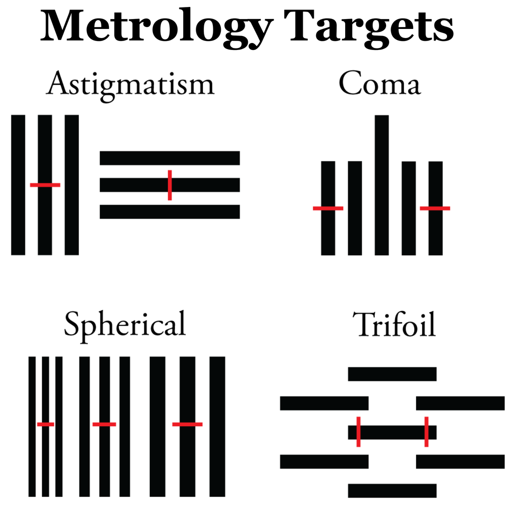
2 – Principles of Image Based Method



$$W(R,\theta)=\sum_{i}^{\infty}\alpha_i Z_i(R,\theta)$$

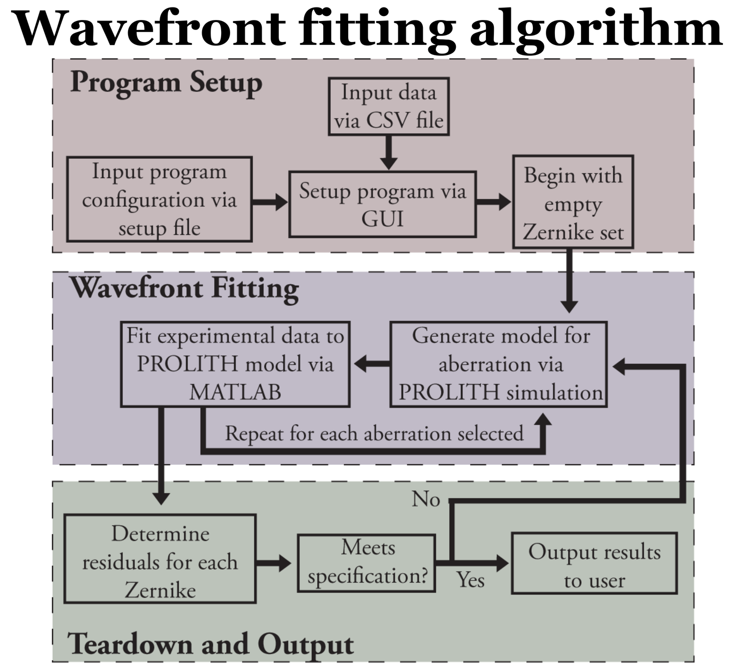
- Pupil phase variation can be described by a Fourier-Zernike series: an infinite sum of weighted polar polynomials
- Aberrations are interrogated via CD data from images of metrology targets
- Pupil phase variation is iteratively fit to difference in CD between features of different orientations through focus or exposure
- Red lines denote measurement locations

Metrology Targets



- Targets chosen to be sensitive to specific aberrations
- Wavefront iteratively fit to CD-SEM data via custom numerical algorithm

Wavefront fitting algorithm



There is an inherent trade-off between the printability and the aberration sensitivity of the target structures

- Smaller structures are more sensitive to aberrations, and the most sensitive structures may not be printable
- Method uses NILS threshold to define printability

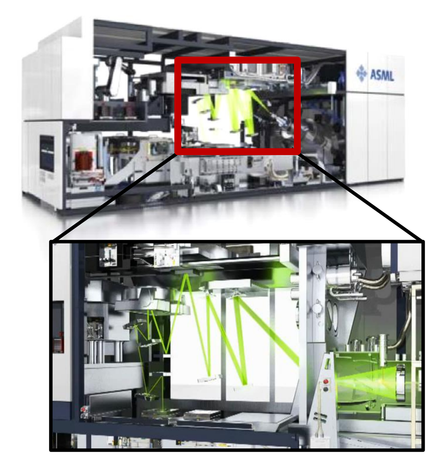
Metrology Target Optimization

1. Chose source shape
2. Determine minimum NILS, maximum focus offset, and desired aberration tolerances
3. Use these as parameters to aerial image simulations
4. Chose best target size by determining the smallest printable pitch for desired conditions

3 – EUV Optical Systems

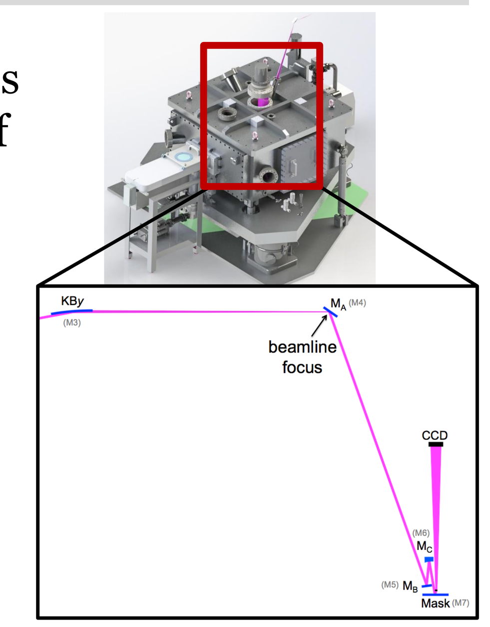
NXE:3300 EUVL Scanner

- 13 element reflective lens
- Fixed set of illuminators at 0.25 NA
- CD collected from SEM micrographs of resist patterns



SEMATECH Actinic Reticle Review Project (SHARP) EUV Mask Microscope

- Zone plate lens
- Wide range of illuminators and NAs available
- CD collected from CCD images



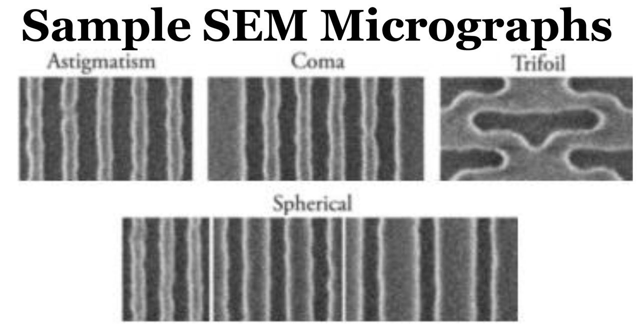
Expected Sources of Pupil Variation

1. Multilayer mirror defectivity
2. Mask defectivity
3. Thermal drift
4. Each of 13 reflections in the catoptric lens

1. Multilayer mirror defectivity
2. Mask defectivity
3. Thermal drift
4. Zone plate lens
5. Beam alignment and setup

4 – NXE:3100 EUVL Scanner Wavefront Extraction

Sample SEM Micrographs



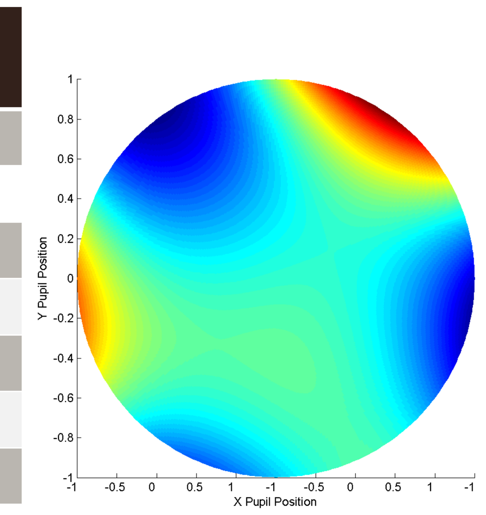
Metrology Target Selection

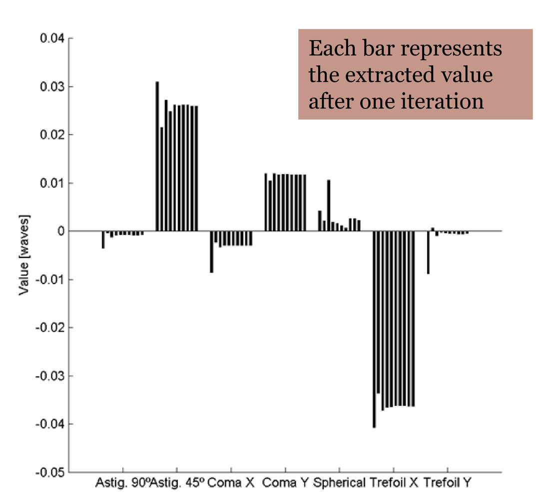
Aberration Name	Target CD [nm]
Astigmatism 90º	32
Astigmatism 45º	32
Coma X	30
Coma Y	30
Spherical	25
Trefoil X	35
Trefoil Y	35

- Annular source (0.5 σ_I /0.8 σ_O @ 0.25 NA) chosen by testing sources with synthetic wavefronts to minimize RMS error
- 2.0 NILS threshold to define printability
- Aberration tolerance set to mean aberration levels from ASML EUV ADT
- Five wafers were exposed: 1 FEM, and 1 production wafer for process window centering; 1 FEM, and 2 focus meander wafers for wavefront extraction
- Extraction completed for all third order aberrations in 10 iterations—13.4mλ RMS
- Mean square error (MSE) of models is consistent with past experiments

Wavefront Extraction

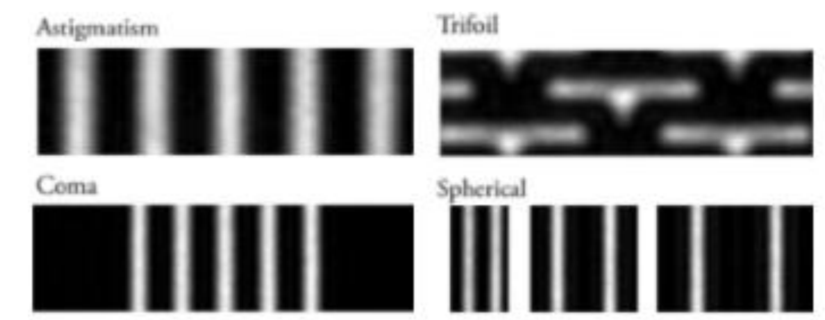
Aberration Name	Extracted Value [mλ]	ΔCD MSE [nm²]
Astigmatism 90º	-0.82	0.136
Astigmatism 45º	+26.58	0.184
Coma X	-2.92	0.038
Coma Y	+12.00	0.043
Spherical	+0.15	N/A
Trefoil X	-36.09	1.032
Trefoil Y	+1.27	0.590





5– SHARP EUV Mask Microscope Wavefront Extraction

Sample SHARP Micrographs

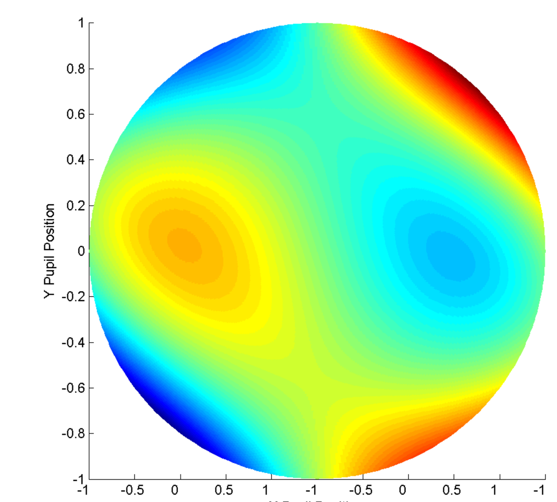


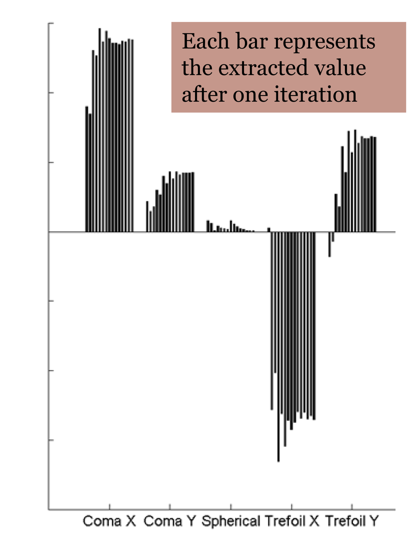
Metrology Target Selection

Aberration Name	Target CD [nm]
Astigmatism 90º	30
Astigmatism 45º	30
Coma X	50
Coma Y	50
Spherical	30
Trefoil X	35
Trefoil Y	35

Wavefront Extraction

Aberration Name	ΔCD MSE MSE [nm²]
Astigmatism 90º	NA
Astigmatism 45º	NA
Coma X	0.281
Coma Y	0.065
Spherical	N/A
Trefoil X	1.197
Trefoil Y	0.066





- Used conventional source 0.1σ @ 0.25 4xNA chosen to introduce a small amount of pupil averaging
- Modulation is not as important on SHARP because the CCD records gray levels—targets optimized by calculating the pitch required to sample the desired locations
- Collected data on eight zone plates ranging from 0.25 to 0.33 4xNA over four days (with replicates)
- Odd third-order aberrations and spherical aberration extracted for one 0.25 4xNA zone plate—62.6mλ RMS
- MSE of models for those aberrations is consistent with past experiments
- Normalized terms reported – to be confirmed with next experimental dataset

6 - Conclusions

- Image-based method is being developed to provide an in situ pupil monitoring solution for EUV systems
- Extraction of pupil phase wavefront carried out with IMEC NXE:3100 and SHARP EUV mask microscope with a single algorithm
- Full third-order phase wavefront was extracted from the IMEC NXE:3100 with low MSE
- Unable to extract all third order aberrations from SHARP
- Characterization of pupil amplitude variation is likely needed for a more complete system description
- Future work will focus on describing and characterizing pupil amplitude variation and impact on results

Acknowledgements

- Erik Verduijn[1], Antoine Wojdyla[2], Pawitter Mangat[1], Vicky Philipsen[3], Eric Hendrickx[3]
- Semiconductor Research Corporation (SRC) / Global Research Collaboration (GRC) through Research Task 2126.001
- KLA Tencor for use of the PROLITH lithography simulator

1 GLOBALFOUNDRIES, 400 Stone Break Rd. Extension, Malta, NY, 12020
2 Lawrence Berkeley National Labs, One Cyclotron Road, Berkeley, CA 94720
3 IMEC, Kapeldreef 75, 3001 Heverlee, Belgium