EUV Stepper Characterization using Lithography Modeling

Kenny Toh, Paul Davids

Technology CAD,

Intel Corporation

Overview

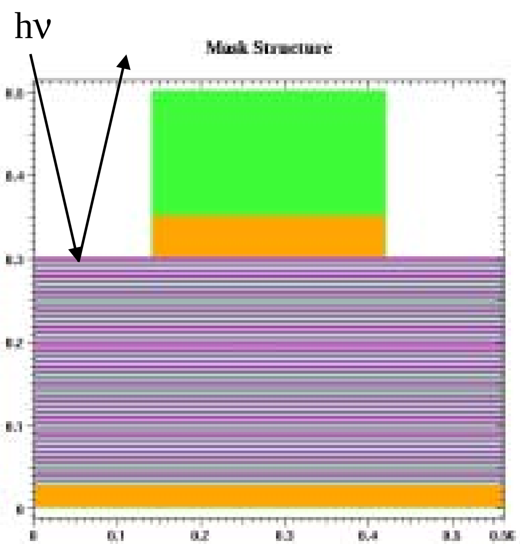
- Modeling Overview
- EUV Mask Height Sensitivity
- Aberration Modeling
- Summary & Future Work

Modeling Overview

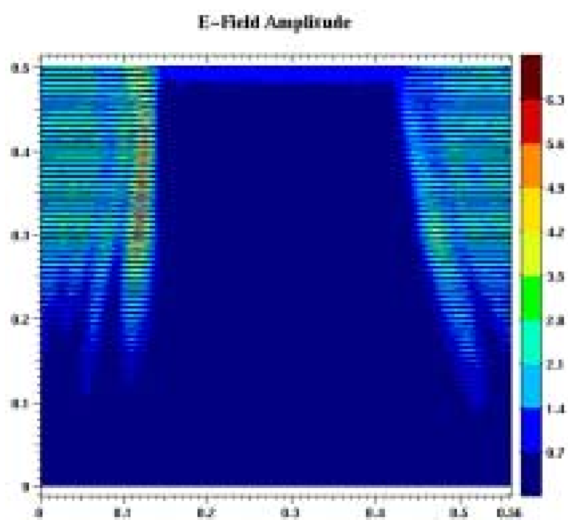
- "LITHOLAND": 2D EUV Mask Simulator
  - Rigorous EM Solver coupled to Lithography Simulator
  - Allows exploration of mask effects, e.g. shadowing, on litho

Simulation Flow

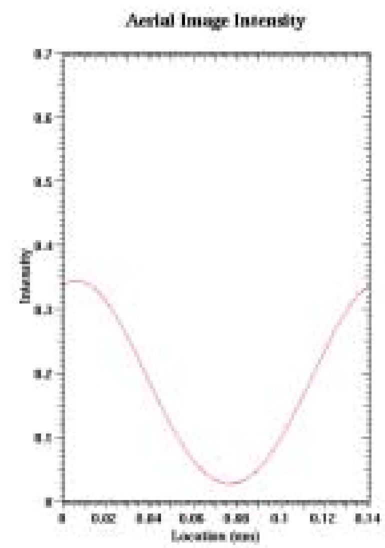
1. Create Mask



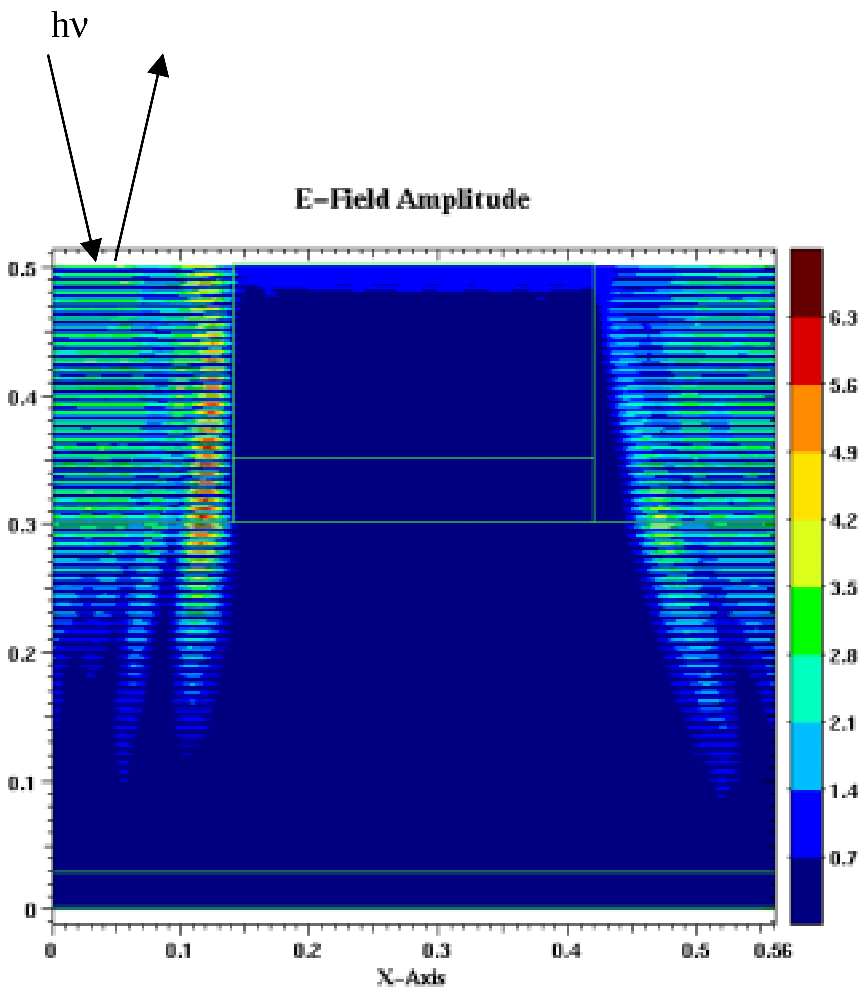
2. Calculate E-Fields



3. Calculate Wafer Image

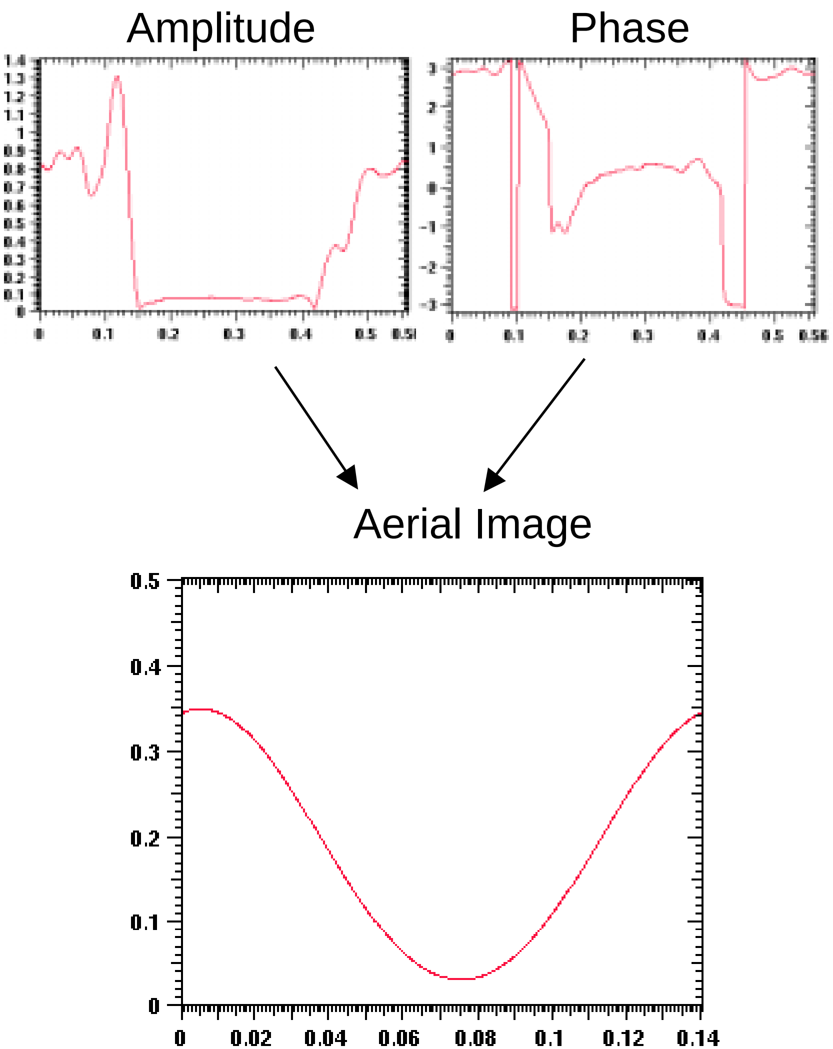


Electromagnetic Solver



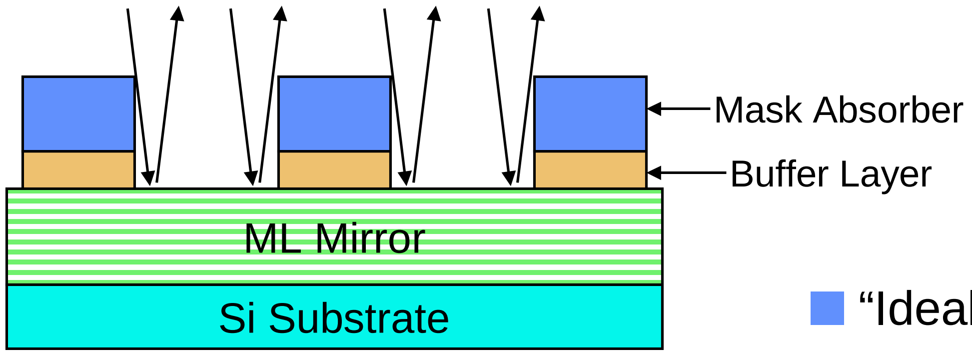
- EM Solver
  - Fast 2D Frequency Domain EM Solver
  - Analytical thin-film optics with differential method for inhomogeneous layers
  - Benchmarked against EMFLEX (commercial FE EM Solver)
- Solver Capabilities
  - CPU time ~10mins per simulation
  - Handles off-axis incidence, absorption in ML mirrors & mask absorbers

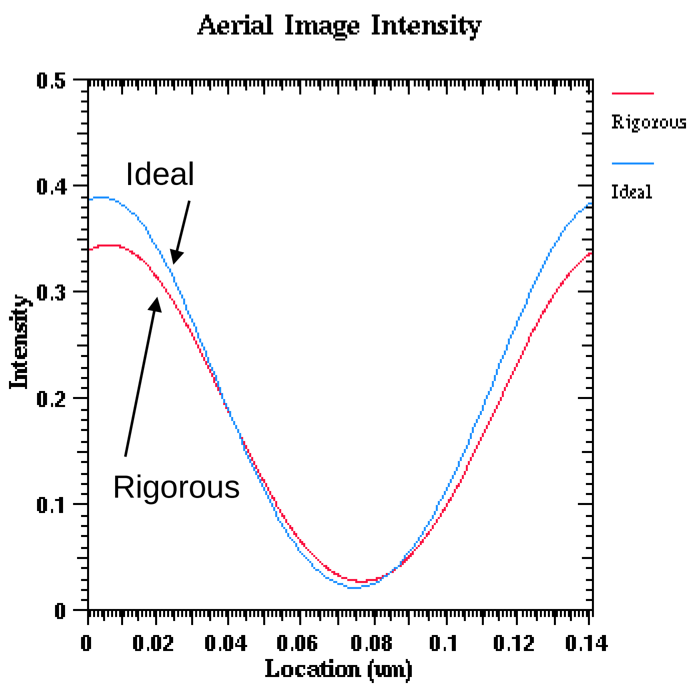
Lithography Simulation



- Lithography Simulator
  - IPHOTO Vector Lithography simulator developed at Intel
  - Import E-Field amplitude and phase at the top of the mask
  - Aerial Image is normalized to EUV mirror reflectivity, $I_{open\text{-}field}$=~0.68
  - CD measurement is based on aerial image threshold, I_{thr}=0.2

Ideal vs. Rigorous Simulations

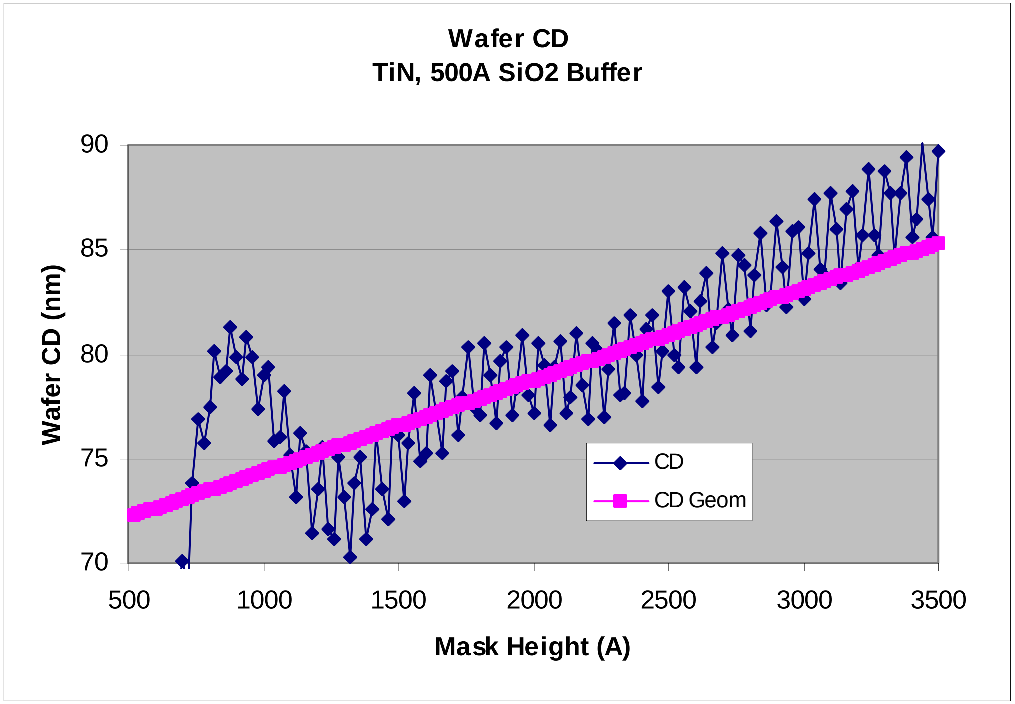


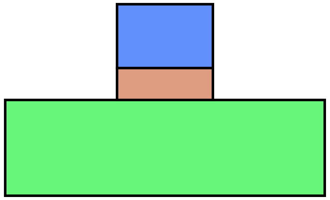


- "Ideal" Mask simulations assume infinitely thin absorber
- Need to account for shadowing effects & mask reflectivity in "Ideal" simulations
- Ideal vs Rigorous:
  - Rigorous simulations show higher minimum intensity due to absorber leakage
  - Lower peak intensity in clear areas for rigorous mask due to interference effects

Mask Absorber Height Study

Effect of Mask Absorber Height on Wafer CD



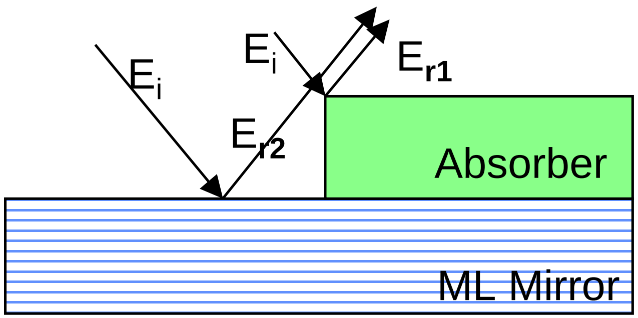


Ti Absorber
500A SiO2 Buffer Layer
90-deg mask wall angles

- Observations:
  - Wafer CD varies periodically with mask height, with ~4nm range, oscillation period of ~60Å ➨ "Small" Oscillation
  - Larger envelope of damped oscillation, with period ~1000Å ➨ "Envelope" Oscillation

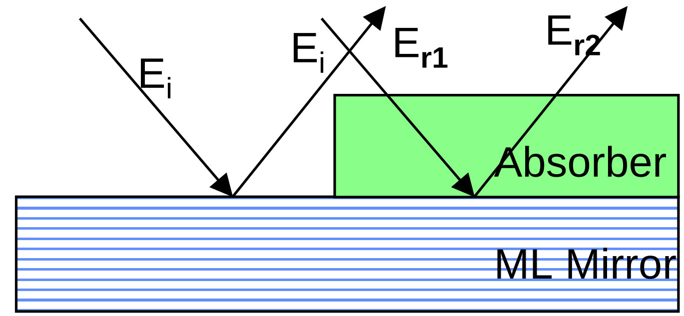
Oscillation Analysis

"Small" Oscillation



- Caused by interference between light reflected from the top of the absorber (E_{r1}), and light reflected off the ML mirror (E_{r2})
- Small Oscillation period, $P \sim 0.5\lambda_0/n_{air}$
- Reflectivity from Absorber top is constant for large absorber height ➔oscillation does not damp out!

"Envelope" Oscillation

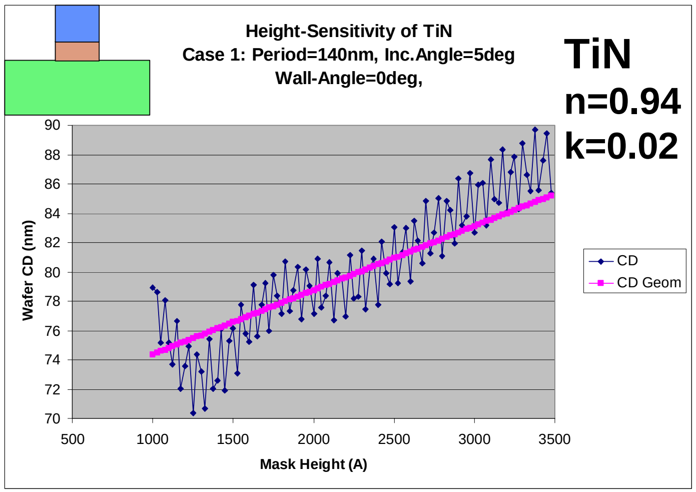


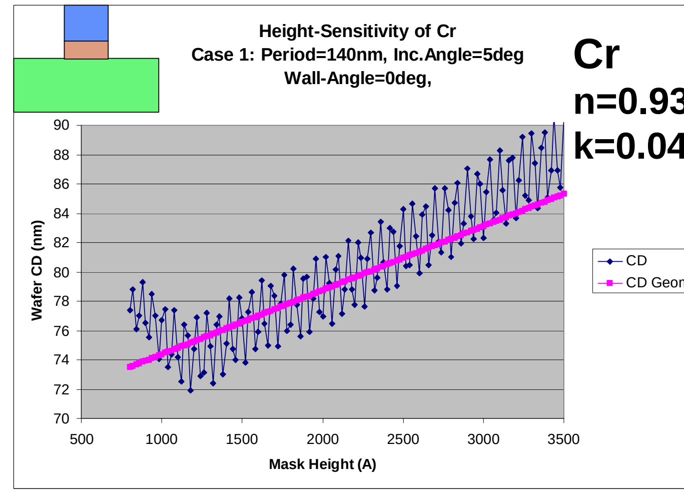
- Caused by interference from light reflecting off the ML (E_{r1}) and light passing through the absorber and bouncing off the ML (E_{r2})
- Large Oscillation period, $P \sim 0.5\lambda/(1-n_{abs})$
- Oscillation damps out eventually because light passing through the mask absorber is absorbed

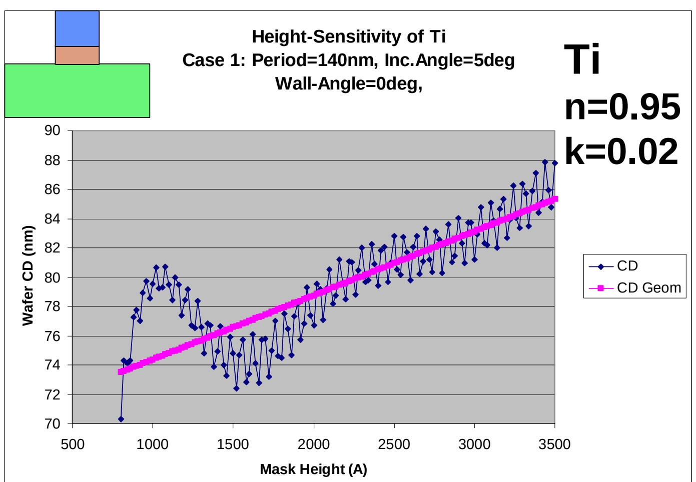
Effect of Absorber Material

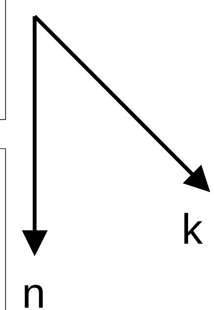
N → 1	Small Osc. Ampl ↓ Env. Osc. Period ↑

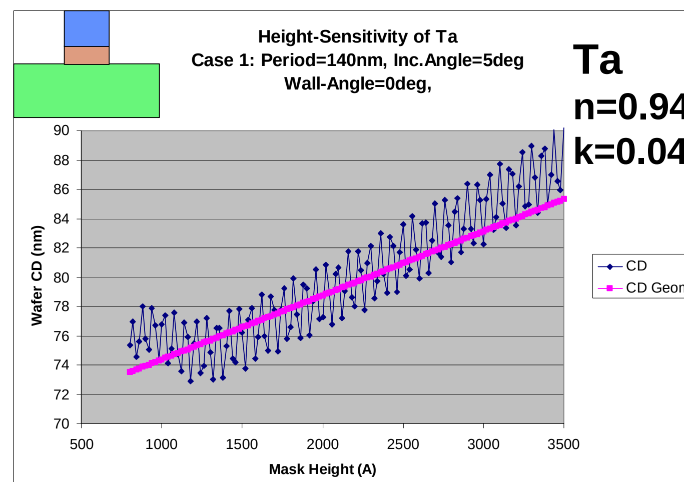
K ↑	Env. Osc. Damping Length ↓ Env. Osc. Amplitude ↓



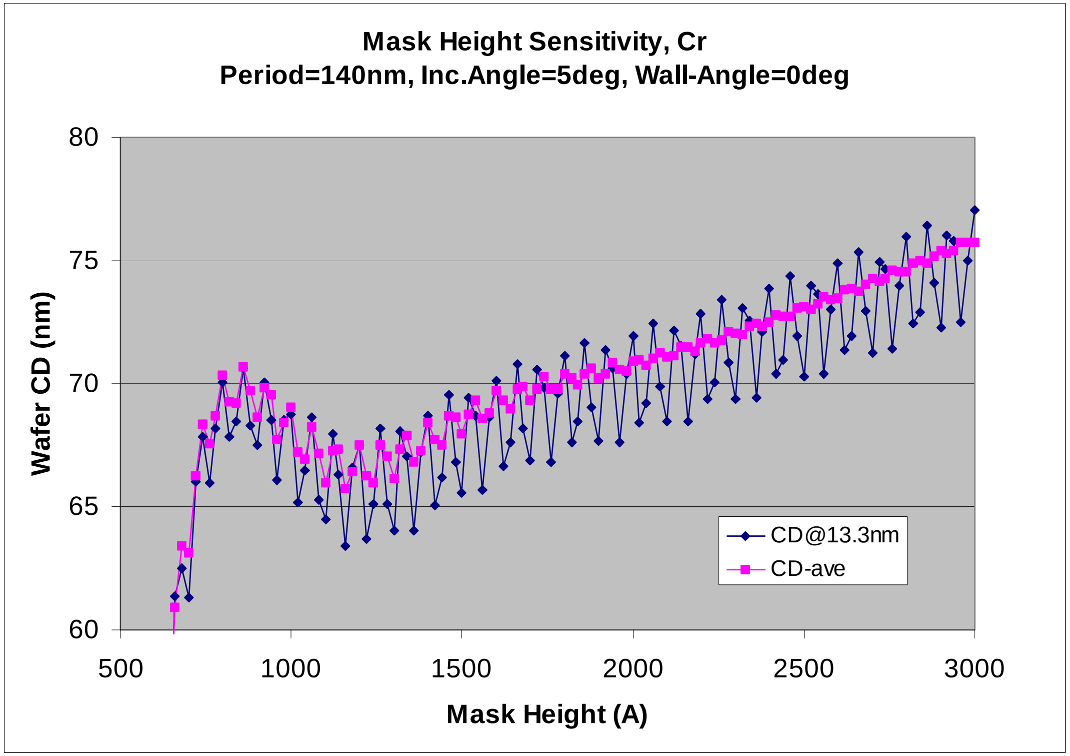


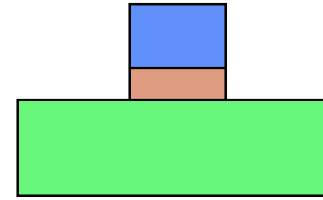




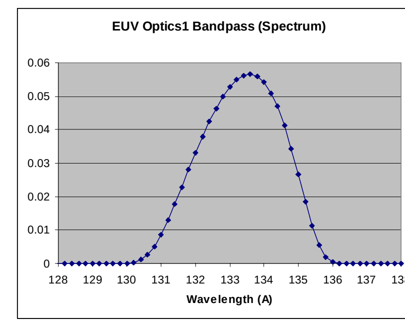


Effect of Illumination Bandwidth





Cr Absorber, Vertical Walls



EUVL Optics1 Bandpass

- Observations:
  - Simulations with narrow-bandwidth illumination (130-136A) show reduced CD oscillation
  - Envelope oscillation is still present
  - CD oscillation will not be observed in a practical EUV system

Aberration Modeling

- Effect of Aberrations on Static Imaging
  - Phasemaps or extracted Zernike coefficients can be used in the lithography simulation
  - As-designed Zernikes for ETS obtained from R.Hudyma & H.Chapman (LLC)
  - Impact of certain aberrations on CD and image placement error (IPE) can be investigated.
  - A comparison of thin mask (ideal) simulations to thick mask (rigorous) simulations can be performed.
- Effect of Scanning on Image Performance
  - Scan Averaged Imaging CD and Image Placement Error for ETS residual aberrations (As Designed).

Static Aerial Image for As-Designed Aberrations

Image at C1, Scan 2 (good IPE)
100nm L/S, Focus: -0.5 – 0.5um

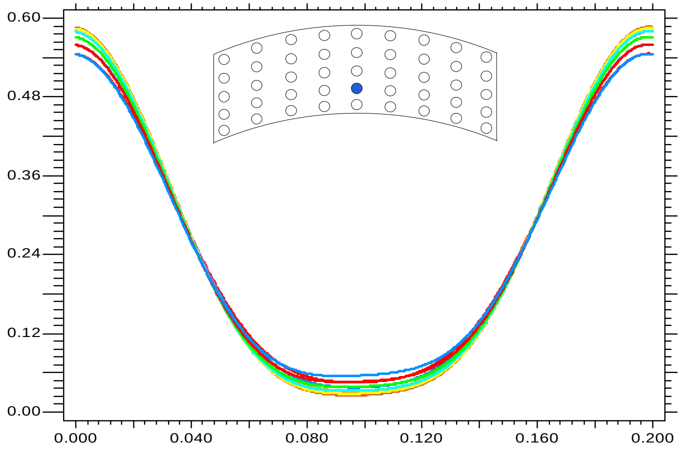
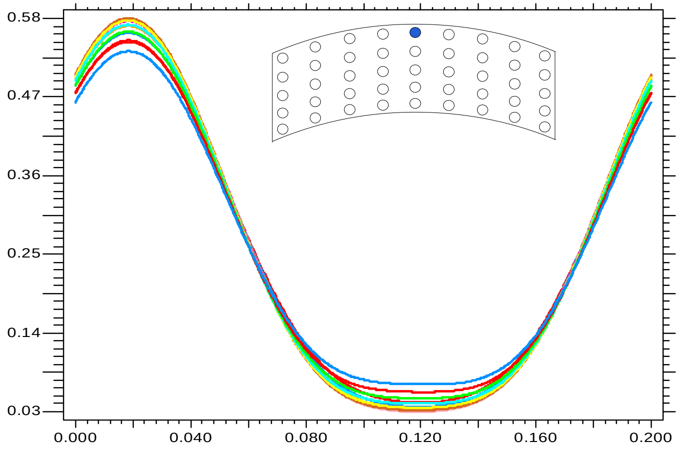


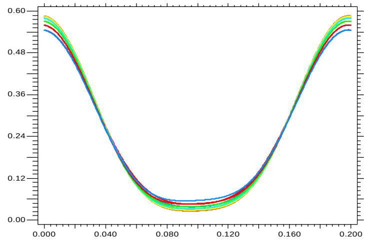
Image at C1, Scan 5 (bad IPE)
100nm L/S, Focus: -0.5 – 0.5um



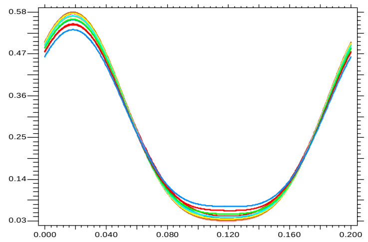
- Zernike Coeficients obtained for As-Designed ETS Aberrations
  - Illumination Plane of Incidence is the Y-Z Plane, Angle is 5° at Center of Ring Field & 3.5° at Edge
- Results
  - Large y-tilt at C1, Scan 5, which causes large image placement error (IPE)
  - Relatively small IPE at C1, Scan 2 (center of ring field), but some image asymmetry is observed

Effect of Scan Averaging

C1, Scan 2



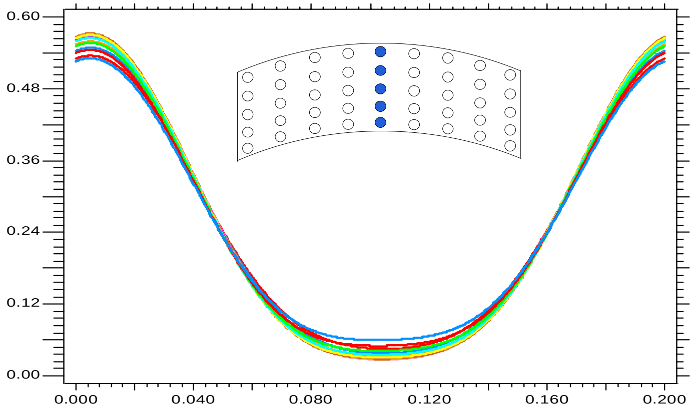
C1, Scan 5



- Scan-Averaged Images closely resemble unaberrated image
- Unaberrated simulations show center shift of 3nm
- Scan-averaged simulations show center shift of 5nm
- Center shift is constant through focus

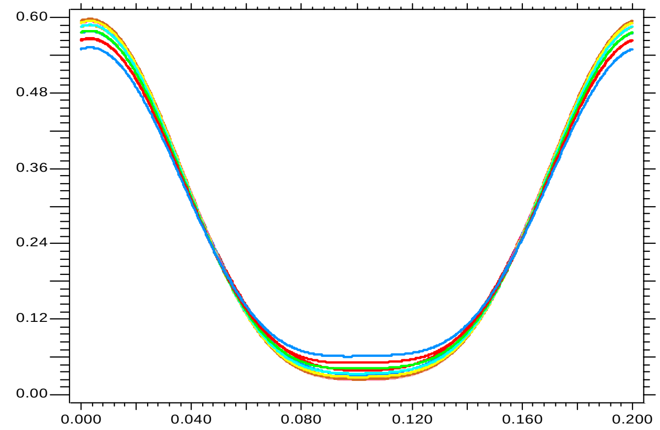
Image at C1, Scan 1-5

100nm L/S, Focus: -0.5 – 0.5um



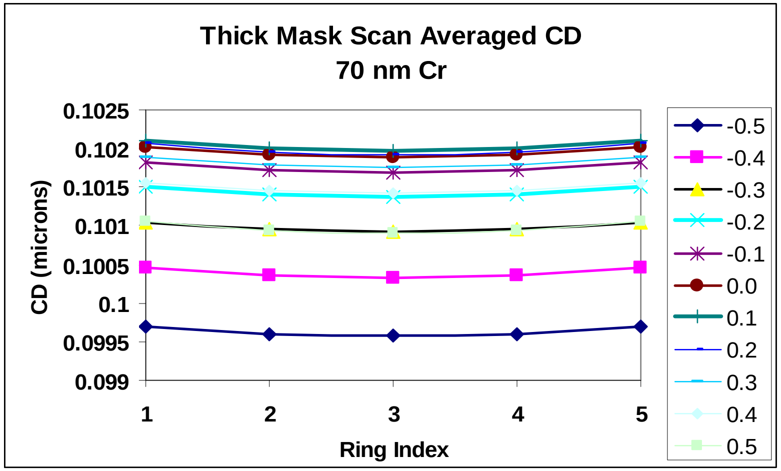
Unaberrated Image

100nm L/S, Focus: -0.5 – 0.5um

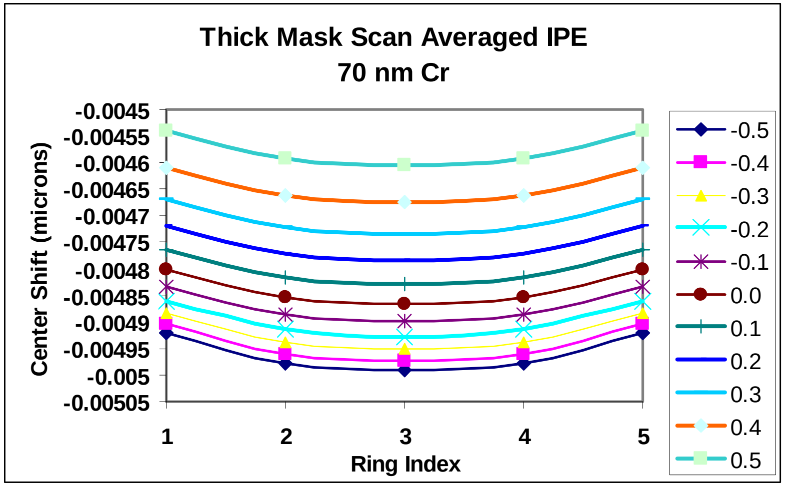


Thick Mask Scan Averaged Simulation (ETS)

- CD Range for scan average is 2.5nm for depth of focus of ±0.5um



- Image Placement Error is 4.5-5.0nm, through focus



Summary

- Lithography modeling with Rigorous EM Mask Models developed for 2D EUV Masks
  - Rigorous Mask modeling based on Frequency Domain
  - Uses Intel's IPHOTO lithography simulator
  - Includes aberration modeling capability (phasemaps, zernikes)
- Mask Height Sensitivity Studied
  - "Small" oscillations with ~4nm ΔCD, does not damp out
  - "Envelope" oscillations, damps out for absorber height > ~1000A
  - Oscillations are reduced with narrow-band illumination
- Aberration Modeling
  - Image Placement error is due to two causes: geometric shadowing of the thick mask(absorber height), and aberrations such as tilt and coma.
  - Scan Averaging greatly reduces the IPE.

Acknowledgements

- Pei-Yan Yang (Intel)
- Chris Krautschik (Intel/ASET)
- John Bjorkholm (Intel/LLC)
- Pat Troccolo (Intel)
- Heinrich Kirchauer (Intel/Infineon)
- Russ Hudyma (LLNL)
- Henry Chapman (LLC)