Carbon Contamination of Extreme Ultraviolet (EUV) Masks and its Effect on Imaging

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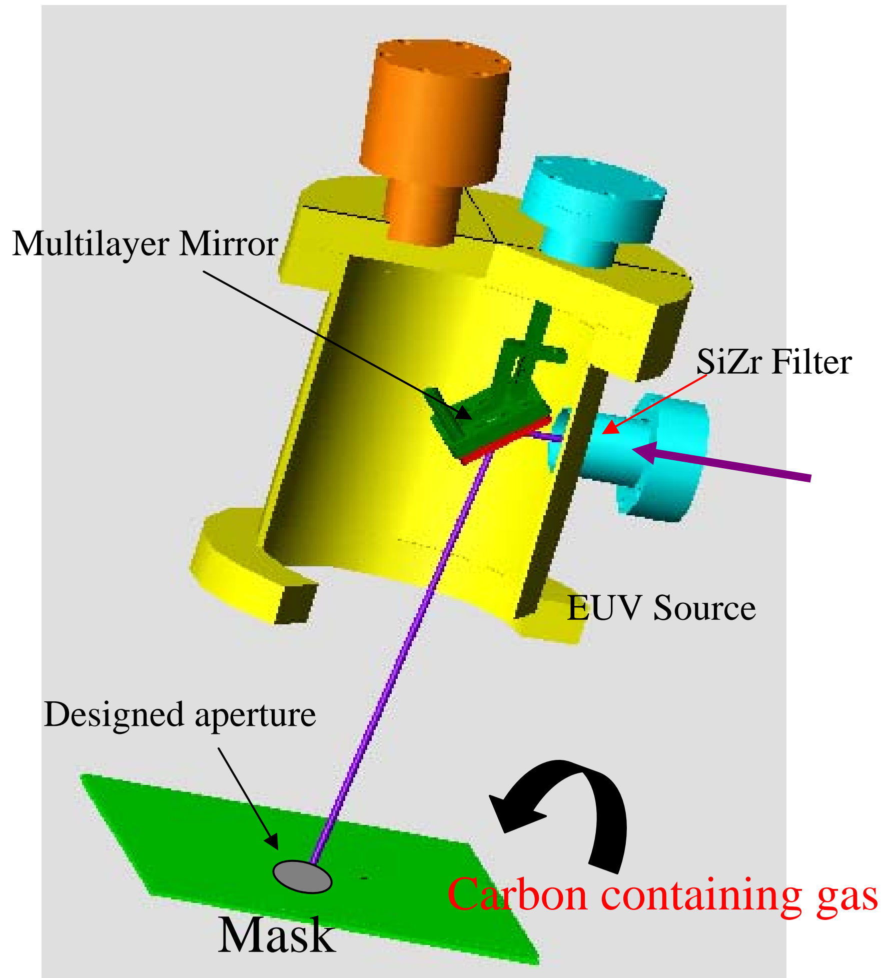
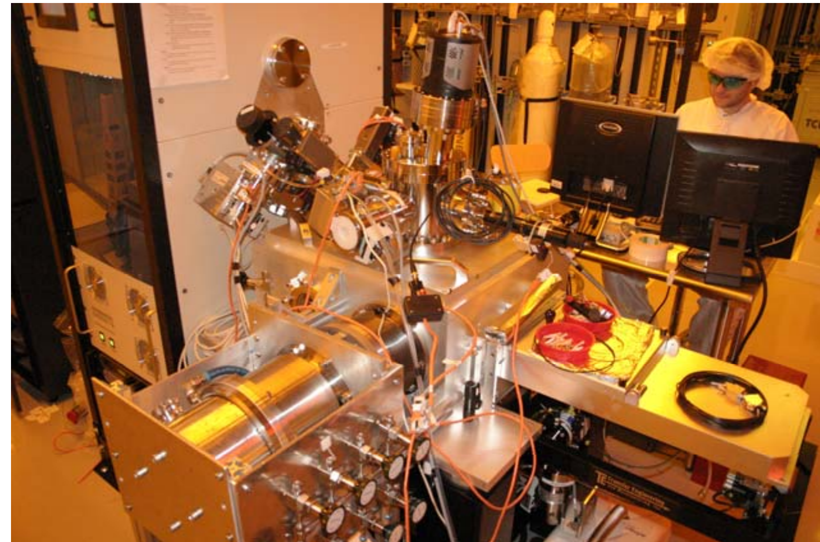
Outline

- System and background
- Characterization
  - MET → Printed images & reflectivity measurement
  - AIT → Aerial images in terms of process window & contrast
  - AFM → Surface roughness analysis
  - Simulation→ Estimation of topography & limitation of carbon thickness
- Conclusion

EUV MiMICS

(Microscope for Mask Imaging and Contamination Study)



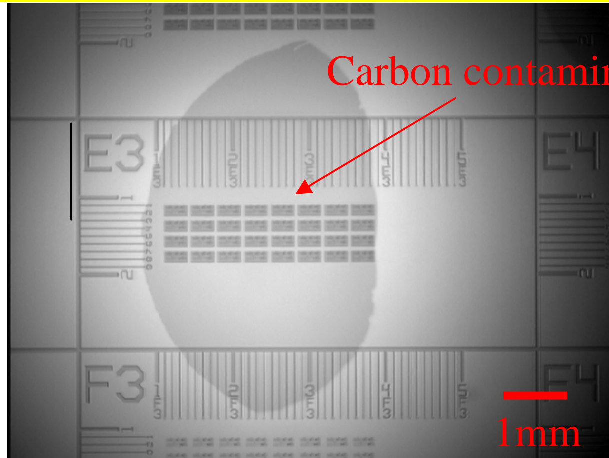


- XYZ stage to hold 6” mask and covers full travel range, with height adjustment
- Automated load-lock for mask loading
- Air table for vibration reduction with 3 point height adjustment
- Best pressure of $1*10^{-7}$ Torr

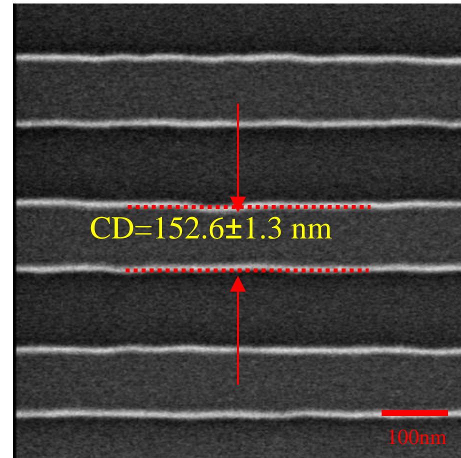
G. Denbeaux, et al., “Accelerated contamination testing of EUV masks.” *Proc. SPIE* 2008
Y.J Fan, et al., “Effect of carbon contamination of EUV masks on imaging.” *EUVL Symposium* 2008

Mask Inspection

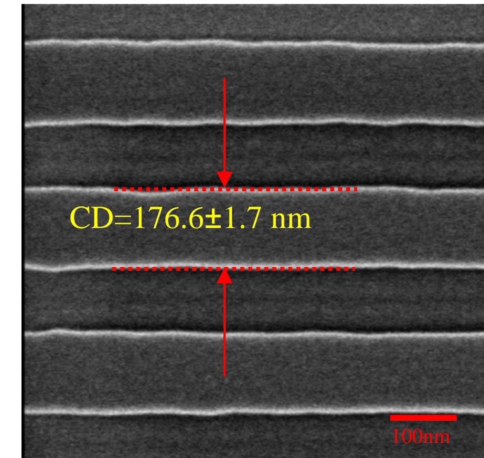
Contaminated with designed aperture



Before contamination



After contamination



- Reticle SEM was used to inspect the mask before and after the contamination
- Observed larger CD after contamination on the mask

Image Printed using Microfield Exposure Tool

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- More contaminati … error
- More contaminati … → lower throughput

Aerial Image Analysis using ThroughFocus Software

Cle SEMATECH Actinic Inspection Tool (AIT) **nated**

Contaminated region shows worse process window and contrast

Surface analysis using Atomic Force Microscope

Non-contaminated | Contaminated (~ 20 nm of carbon)

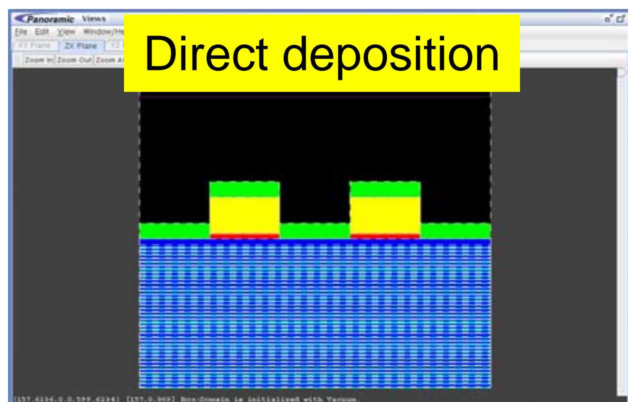
Veeco Dimension 3100

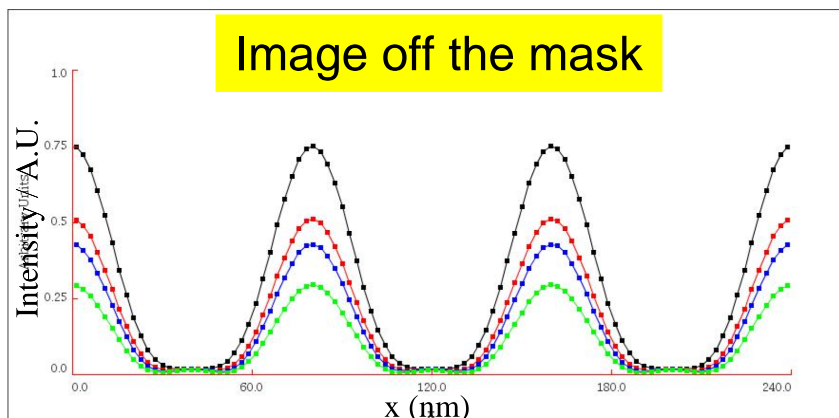
~0.4nm RMS roughness on absorber and multilayer

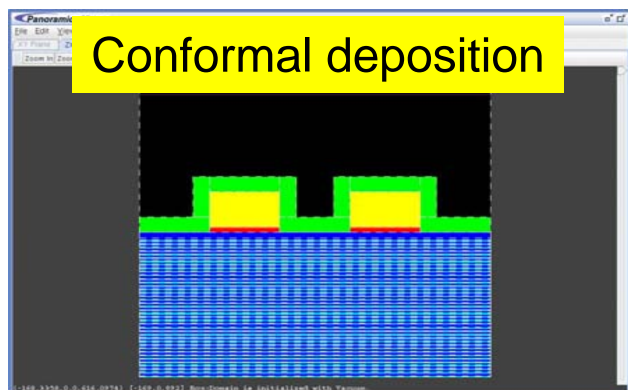
~0.6nm RMS roughness on absorber and multilayer

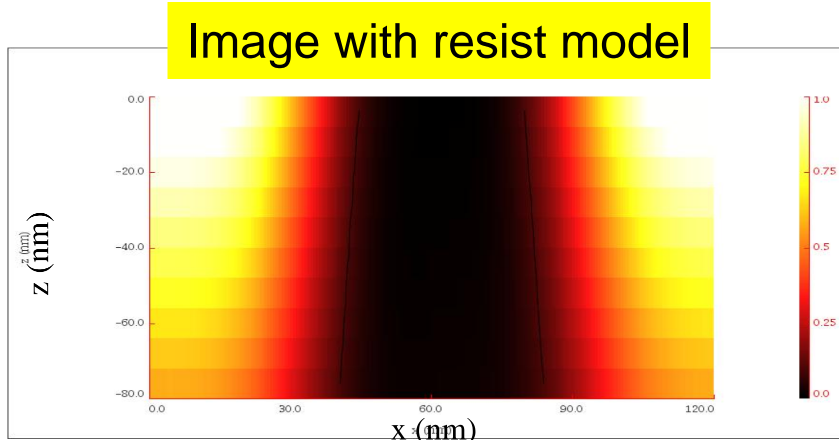
http://www.veeco.com/Products/metrology_and_instrumentation/AFM_SPM/Dimension_3100/index.aspx

Lithographic Simulation Using Panoramic Software









- Assume two extreme cases for topography of carbon contamination
- Simulation was done off the mask & with resist modeling

Estimation of Topography

Target CD @ 40nm Shadowed

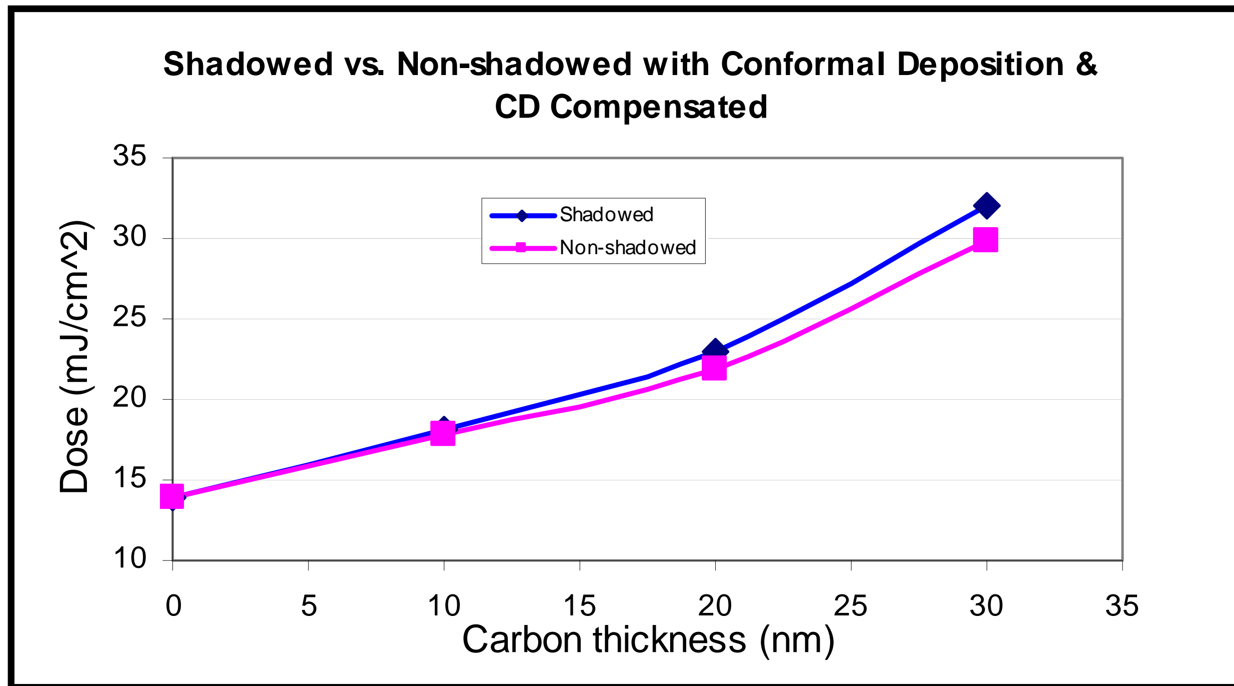
Dose (mJ cm-2): 10, 15, 20, 25, 30

Carbon thickness (nm): 0, 5, 10, 15, 20, 25, 30, 35

Legend: Direct, Conformal, Experiment

- Simulation compared to the experimental data
- Conformal deposition requires more dose to achieve target CD

Limitation of Carbon Thickness with CD Compensated



- Required dose to achieve target CD could be an issue when carbon contamination becomes more than 10nm
- Carbon contamination still affects imaging performance, although we correct the original feature size to compensate

Conclusion

- **Carbon contamination occurs in EUV exposure tools due to the residual carbon containing molecules in the vacuum chamber**
- **Carbon contamination affects imaging performance of printed features**
  - MET → CD error, dose shift, and reflectivity loss
  - AIT → Worse process window and contrast curve
  - AFM → Larger RMS roughness on contaminated surfaces
- **Simulation was applied to predict the effect of contamination topography**
  - 5 nm H-V bias was applied on clean mask to reduce the shadowing effect
  - ~10 nm of carbon causes the CD compensation to fail
  - The maximum allowed carbon could be even lower due to the lowered throughput of the tools