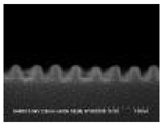
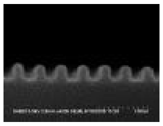
EUV Lithography at the SEMATECH-Berkeley Microfield Exposure Tool Facility (BMET)

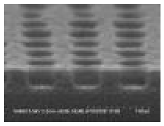
Printer-friendly version PDF version



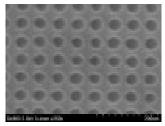
20nm



22nm



30nm



30nm

Addressing Critical Areas in EUV Lithography Research

The top three critical roadblocks on the path to realizing large-scale manufacturing use of EUV lithography, as identified by the 2008 International EUVL Steering Committee, are:

1. A reliable high-power source and collector module.
2. **The availability of defect-free masks.**
3. **Criteria for resist resolution, sensitivity, and Line Edge Roughness (LER) must be met simultaneously.**

The BMET focuses on the second and third of these issues. Resolution and sensitivity are largely solved issues, though LER still remains a challenge (see The World's Highest Resolution Projection EUV Lithography Tool, and Resist Development). Progress has been made in making defect-free masks (see Mask Development; CXRO also contributes to this field using the the Actinic Inspection Tool).

Lithography is the process by which a circuit pattern is transferred into silicon to produce computer chips. Lithography tools can be thought of as Xerox machines for computer chips. Extreme ultraviolet (EUV) lithography [1] uses light of 13.5 nm and is the leading candidate for high volume manufacturing of nano-electronics at feature sizes of 22 nm and below. To make this a reality, advanced research tools operating with numerical apertures (NA) of 0.25 or greater are required today. To address this issue, CXRO has developed a 0.3-NA EUV microexposure tool. This tool uses the Advanced Light Source (ALS) as its source of EUV radiation. The CXRO exposure station is designed to be capable of 12-nm equal-line-space printing.

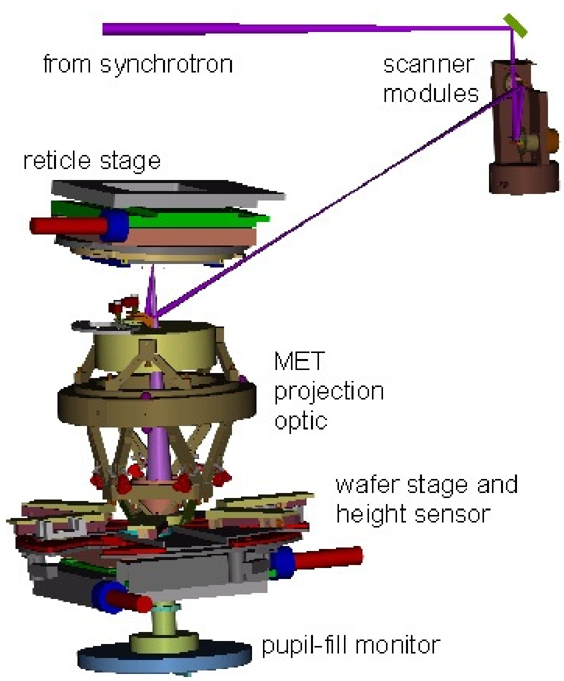


Figure 1: The MET system.

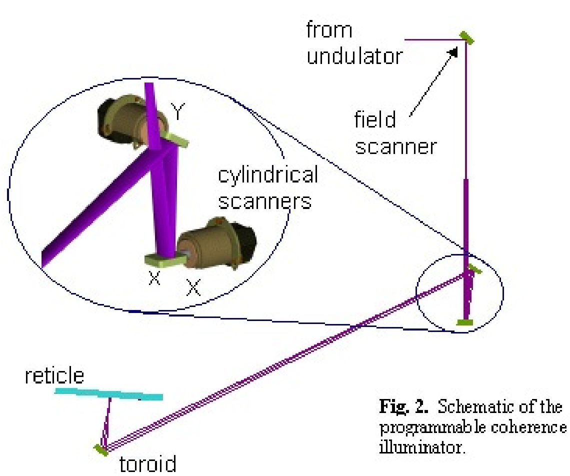


Figure 2: The active scanning illuminator.

Figure 1 shows a CAD model of the exposure system depicting the major components as well as the EUV beam path [2]. Effectively coherent radiation from ALS undulator beamline 12 [3,4] impinges on the scanning illuminator. The light is directed to a reflective reticle. From there the light is re-imaged by the all-reflective 0.3-NA optic with 5´ demagnification to the wafer plane. A grazing incidence laser system is used to monitor the height of the wafer at the print site ensuring that it remains in focus. With the wafer removed, the light propagates to a scintillator plate sitting effectively in the far field. Pupil-fill monitoring is achieved by re-imaging the scintillator plate through a vacuum window to a visible-light CCD camera. A significant difficulty with using a synchrotron source for lithography, however, is the poor match between the intrinsically high coherence of the source as compared to the partial coherence requirements of a lithographic tool. Directly using synchrotron sources would typically limit one to coherence factors below 0.1. To overcome this issue, an active scanning illuminator has been developed (Fig. 2). The use of this scanning illuminator allows lossless variable illumination in patterns such as Fig. 3, as well as those presented on the next page ("The World's Highest Resolution Projection EUV Lithography Tool").

a b

Fig. 3: Illustrations of lossless variable illumination using the scanning illuminator.

Select an image to view it full-size.

References *This research was supported by International Sematech.*

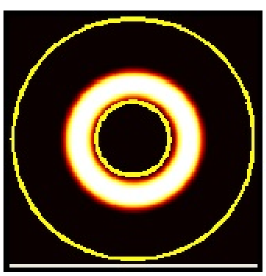
1. R. Stulen and D. Sweeney, "Extreme ultraviolet lithography," IEEE J. Quantum Electron. 35, 694-699 (1999).
2. P. Naulleau, K. Goldberg, E. Anderson, et al., Proc. SPIE Vol. 5374, 881-891 (2004).
3. D. Attwood, G. Sommargren, R. Beguiristain, K. Nguyen, J. Bokor, N. Ceglio, K. Jackson, M. Koike, and J. Underwood, "Undulator radiation for at-wavelength interferometry of optics for extreme-ultraviolet lithography," Appl. Opt. 32, 7022-7031 (1993).
4. C. Chang, P. Naulleau, E. Anderson, and D. Attwood, "Spatial coherence characterization of undulator radiation," Opt. Comm. 182, 24-34 (2000).
5. P. Naulleau, K. Goldberg, E. Anderson, J. Cain, P. Denham, K. Jackson, A. Morlens, S. Rekawa, F. Salmassi, "EUV microexposures at the ALS using the 0.3-NA MET optic," J. Vac. Sci. & Technol. B, in review (2004).
6. J. Cain, P. Naulleau, C. Spanos, "Advanced metrology for characterization of extreme ultraviolet lithography process effects," J. Vac. Sci. & Technol. B, in review (2004).
7. R. Soufli et al., Appl. Opt. 46, 3736 (2007)

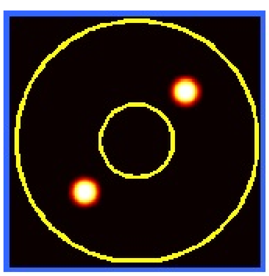
The World's Highest Resolution Projection EUV Lithography Tool

Printer-friendly version PDF version

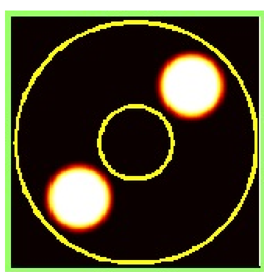
The SEMATECH-Berkeley MET achieves its world leading performance through the precise manipulation of illumination coherence. Through the use of the unique scanner module and undulator radiation from the ALS, lossless variable illumination can be achieved in patterns such as those pictured here.

Synthesized Pupil Fill Functions

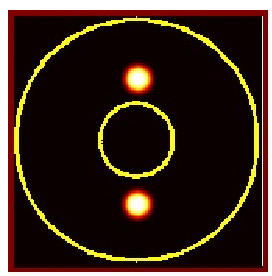




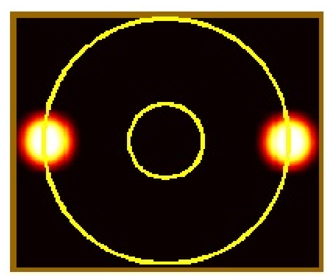
45-dipole, S=0.1, O=0.57



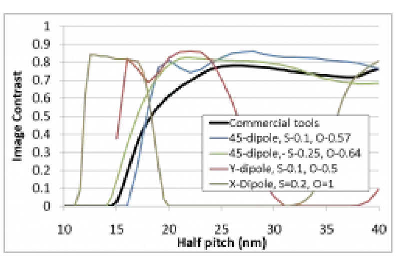
45-dipole, S=0.25, O=0.64



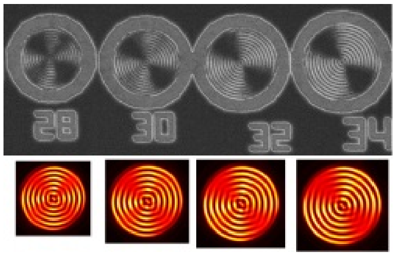
Y-dipole, S=0.1, O=0.5



X-dipole, S=0.2, O=1



This coherence control has been demonstrated experimentally at the BMET, as can be seen by comparing the predicted aerial images with actual printing results:



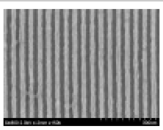
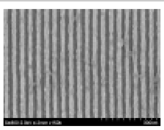
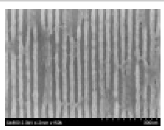
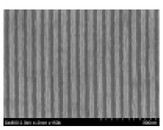
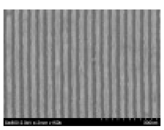
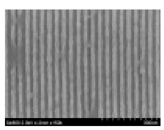
Resist Development

Printer-friendly version PDF version

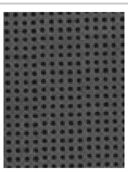
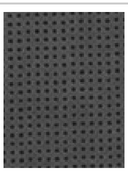
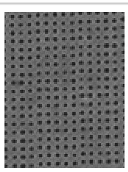
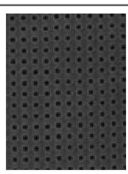
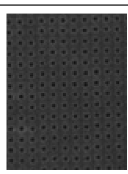
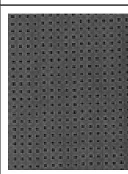
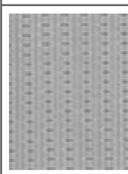
Future generations of computer chips will be manufactured with stringent requirements on three parameters: **Resolution**, **Sensitivity**, and **Line Edge Roughness** (**LER**). All three must be met and balanced, or the chips cannot be made. The following table summarizes the goals for each as laid out in the 2007 ITRS Roadmap:

Year	Resolution	LER	Sensitivity
2013	32-nm half pitch (21-nm iso)	1.2 nm	10 mJ/cm^2
2016	22-nm half pitch (15-nm iso)	0.8 nm	10 mJ/cm^2
2019	16-nm half pitch (11-nm iso)	0.6 nm	10 mJ/cm^2

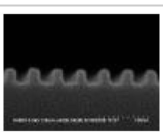
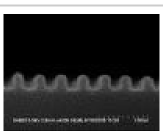
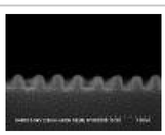
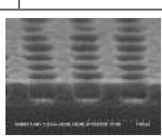
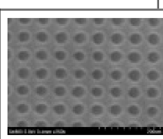
The Berkeley MET tool has been instrumental in improving resists so that resolution is now approaching 20 nm HP using 50 nm thick resists

	24 nm HP	22 nm HP	20 nm HP
Resist C 12.7 mJ/cm^2			
Resist D 15.2 mJ/cm^2			

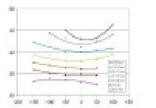
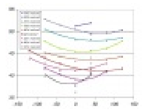
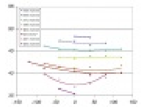
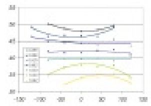
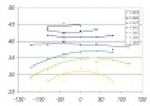
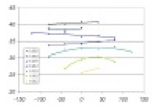
Contacts have also been printed 30 nm across at a variety of half-pitches

	45 nm HP	40 nm HP	35 nm HP	30 nm HP
1:1				Resist E 80-nm film thickness
1:1.5				

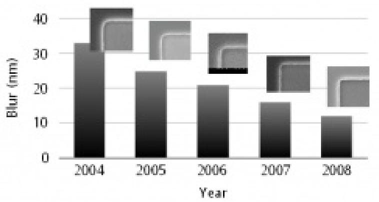
Further demonstrations of high pattern fidelity at small feature sizes

24 nm HP	22 nm HP	20 nm HP	
			
30 nm 1:1 contacts			

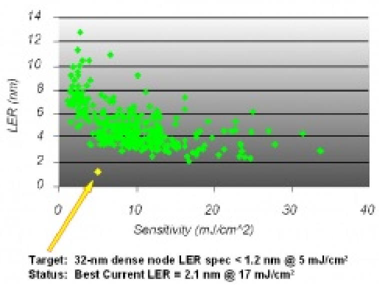
Line-space resolution: Progress over Time (***Click to see full-size images***)

Year	40 nm Half-pitch	36 nm Half-pitch	32 nm Half-pitch	Annular Illumination
2006				16% 200nm DOF
2007				15% EL 200 nm DOF
2008				8% EL 150 nm DOF

To characterize the performance of resists, systematic contact and corner resist blur metrics have been developed. Steady improvements in resist performance can be seen by comparing these metrics over time:



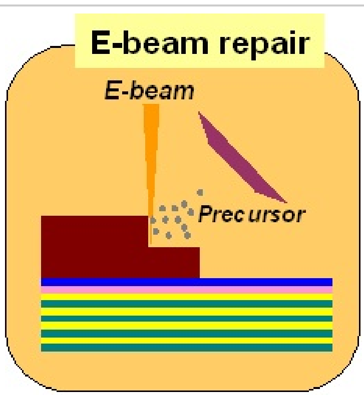
In contrast to the impressive improvements in resolution, line edge roughness (LER) remains the most difficult challenge facing EUV resists. This can be visualized by comparing LER to sensitivity for various resists to the target of LER < 1.2 nm at 5 mJ/cm^2 on 32 nm dense nodes:



Mask Development

Printer-friendly version PDF version

The SEMATECH Berkeley MET is used for the testing of mask repair methods. Masks have been repaired using E-beam etching, then used to print through-focus images in resists, demonstrating the effectiveness of the repair.



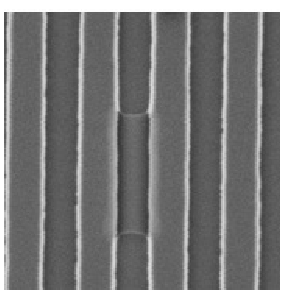
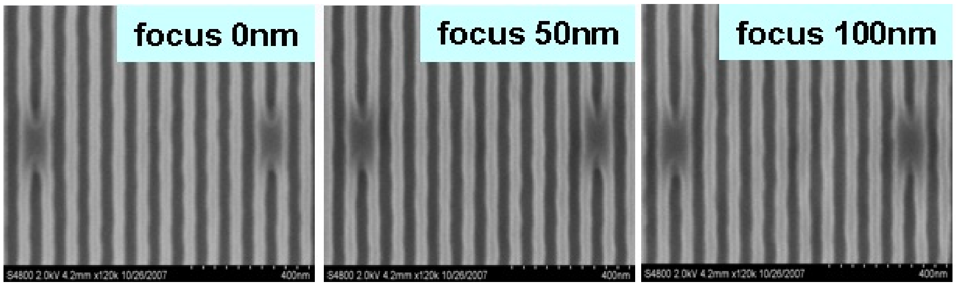
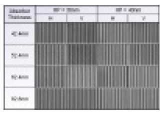
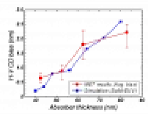


Image of repaired absorber defect on mask using e-beam etch technique



The SEMATECH Berkeley MET has also been used to verify mask shadowing models: ***(Select an image to view full size)***





References

1. Gi-Sung Yoon et al., 2007 International EUVL Symposium, 28-31 October 2007, Sapporo, Japan
2. Hwan-Seok Seo et al. EIPBN 2008

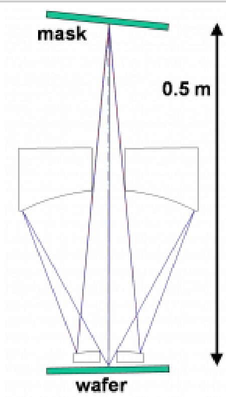
0.5 NA Tool: Pushing EUV Research to the Next Level

Printer-friendly version PDF version

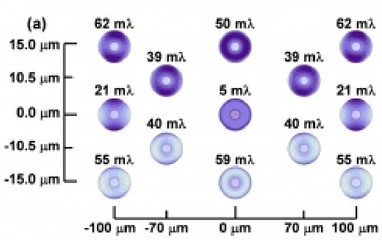
The next level of EUV Lithography research will require even greater resolution and control of optical aberration than is currently achieved. This will require building the successor to the Sematech-Berkeley MET facility, for which the optic design has been completed and optics manufacturers have been engaged. The new design will have:

Optical model courtesy of Russ Hudyma, Hyperion

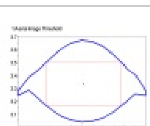
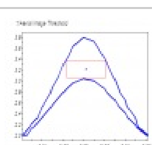
- **NA = 0.5**
- **Resolution = 8 nm**
- **Magnification = 5x**
- **Field of View = 200x30 m**
- **Mask angle of incidence = 6**

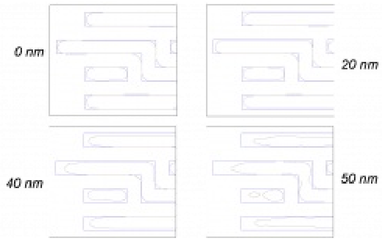


The design aberration across the field of view has been calculated courtesy of Michael Goldstein, SEMATECH:



Sizable process windows, for 12-nm features using conventional illumination

70 nm DOF on 12 nm dense lines	**40 nm DOF on 12 nm iso lines**
	


0 nm
20 nm
40 nm
50 nm