Update on the SEMATECH 0.5 NA Extreme Ultraviolet Lithography (EUVL) Microfield Exposure Tool (MET)

Kevin Cummings*[1], Dominic Ashworth[1], Mark Bremer[2], Rodney Chin[2], Yu-Jen Fan[1], Luc Girard[2], Holger Glatzel[2], Michael Goldstein[1], Eric Gullikson[3], Jim Kennon[2], Bob Kestner[2], Lou Marchetti[2], Patrick Naulleau[3], Regina Soufli[4], Johannes Bauer[5], Markus Mengel[5], Joachim Welker[5], Michael Grupp[5], Erik Sohmen[5], Stefan Wurm[1]

[1]SEMATECH, Albany, NY 12203

[2]Zygo Corporation, Extreme Precision Optics (EPO), Richmond, CA 94806

[3]Center for X-Ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA 94720

[4]Lawrence Livermore National Laboratory, Livermore, CA 94550

[5]Carl Zeiss, Oberkochen, Germany

In support of the Extreme Ultraviolet Lithography (EUVL) roadmap, a SEMATECH/CNSE joint program is underway to produce multiple EUVL (wavelength of 13.5 nm) R&D photolithography tools. The 0.5 NA projection optic magnification (5X), track length and mechanical interfaces match the currently installed 0.3 NA micro-field exposure tools (MET) projection optic [1] [2] [3]. Therefore, significant changes to the current tool platforms and other adjacent modules are not necessary. However, many of the existing systems do need upgrades to achieve the anticipated smaller exposure feature sizes [4]. To date we have made considerable progress in the production of the first of the two-mirror 0.5 NA projection optics for EUVL [5]. With a measured transmitted wavefront error of less than 1 nm root mean square (RMS) over its 30 μm × 200 μm image field, lithography modeling shows that a predicted resolution of ≤ 12 nm and an ultimate resolution of 8 nm (with extreme dipole illumination) will be possible.

This paper will present an update from the 0.5 NA EUVL program. We will detail the more significant activities that are being undertaken to upgrade the MET and discuss expected performance.

Keywords: EUVL, extreme ultraviolet lithography, high NA.

1. INTRODUCTION

Over the history of semiconductor-based computing hardware, the microchip performance has dramatically increased giving what was once supercomputing capability in devices that today fit into the palm of a hand. SEMATECH has been enabling this performance increase by supporting resist materials research through access to micro exposure tools (MET) for 157 nm, 193 nm immersion, and extreme ultraviolet lithography (EUVL) [6] [7] [8]. Since 2008 the current two SEMATECH 0.3 NA EUV METs have been supporting EUV resist materials readiness for a 22/16 nm half-pitch introduction [2] [9] [10]. However, a higher NA next generation EUV MET is now needed to support materials development for ≤ 10 nm nodes. SEMATECH completed the design of such a 0.5 NA MET in 2007 [4] and started the build of the system in late 2011 with the goal to have two such systems available for supporting materials research in 2014. The optical design of its projection optics modules is based on a modified Schwarzschild design. The key distinction to a modified Schwarzschild optic is that its mirrors are 16th order aspheres with separated centers of curvature while a Schwarzschild optic uses two concentric spheres.

To upgrade the 0.3 NA METs, a 0.5 NA system (MET5) was designed and proposed with a ≤ 10 nm node target resolution goal [4]. The purpose of these small field (20 μm × 300 μm) tools is to provide very early learning into the extendibility of EUV lithography and in particular in the area of resists to help drive materials learning for patterning

* Corresponding Author: K.D. Cummings, email: Kevin.Cummings@SEMATECH.org, phone: 518 649-1198

at ≤ 10 nm node. Given that 0.33 NA high-volume manufacturing (HVM) tools, in principle, capable of 16 nm resolution are now being deployed, it is crucial that advanced learning platforms such as the MET5 be capable of significantly higher resolution.

The 0.5 NA projection optic magnification (5X), track length and mechanical interfaces match the currently installed 0.3 NA micro-field exposure tools (MET) projection optic [1] [2] [3]. Therefore, significant changes to the current tool platforms and other adjacent modules are not necessary. However, many of the existing systems do need upgrades to achieve the anticipated smaller exposure feature sizes [4]. Carl Zeiss was chosen to assist this program by supplying the reticle metrology platform, several key component upgrades and to be the company responsible for final integration, alignment and installation of the MET5 upgrade.

This manuscript outlines the on-going activities to improve these modules.

2. UPGRADE CONSTRAINTS AND REQUIREMENTS

The design for the MET5 originally came out of the realization that existing 0.3 NA (MET3) tools would reach the limit of their usefulness [4]. This is a natural progression and the MET3 itself was conceived when the earlier small field 0.1 NA 10X Schwarzschild systems in use began to reach the end of their usefulness to the semiconductor industry [11]. The main difference this time is that in addition to having < 14 nm patterning expectations, the MET5 design would also have to be compatible with the existing MET3 platforms [3].

The 0.5 NA design of the MET5 gave us a comfortable 0.59 Rayleigh criterion at 16 nm resolution; however the need to re-use the MET3 platform imposed some difficult constraints.

Error! Reference source not found. Table 1 shows the key resulting MET5 system changes. To be able to fully utilize this tool and the corresponding ~ 35% reduction in resolution we are upgrading and adding several features to the current MET system.

Table 1. Overview system upgrade

Tool	MET-2c current	MET-5d 2H2014
CRA	6°	6°
wavelength	13.54	13.50
NA PO lens	**0.3**	**0.5**
Sigma	0.93	0.93
Collector shells	S2-8	S2-7
Obscuration	33%	>35%
Field@wafer	**0.6 mm**	**0.2 mm**
Uniformity	**6.5%**	**2%**
Resolution DL	**14nm**	**9nm**

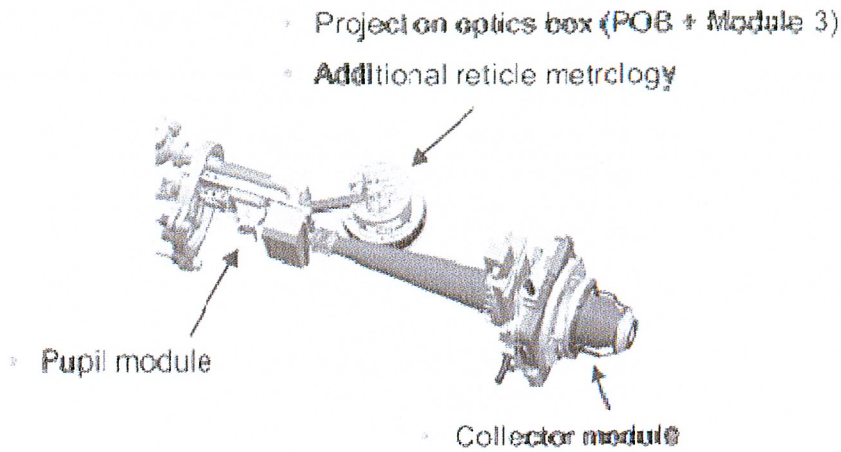

Figure 1. Key components of the 0.5 NA Micro Exposure Tool system

Figure 1 show the overview the Micro Exposure Tool beam path as it will appear after the 0.5 NA upgrade and modifications to the current platform. The collector module has been redesigned to improve the cooling in vacuum so that it will support higher power from a future planned source upgrade. The projection optics box (POB) built by Zygo [5] will be attached to a newly designed reticle metrology module built and integrated by Carl Zeiss. Key features of this module are discussed in the following section. Finally, a new pupil exchange systems has been designed and built to replace our current system. This system doubles the number of pupil shapes that we have access to and in combination allows 3x more pupil settings than we have in the current system. This, too, will be discussed in the following sections.

3. UPGRADES AND ADDITIONS TO EXISITNG MET SYSTEMS

3.1 Reticle alignment cameras

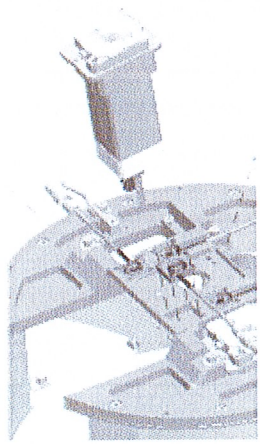

Figure 1. Design of newly added vision metrology system for reticle alignment

Figure 2 shows how we will be adding cameras to the reticle metrology module to enhance our ability to position the reticle accurately in the XY plane. These cameras are in addition to the capacitive sensors we are upgrading to determine the Z plane (height) position of the reticle. As described in Table 1, the exposure field size of this system is greatly reduced and we felt it necessary to be able to find the sub-arrayed features on this mask accurately, repeatable and efficiently. These cameras, in conjunction with new alignment marks on the reticle, will allow quick and repeatable positioning of the reticle in our system and hence allow shifting to different patterns (dense lines and then contacts for example) on time scales that will allow these features to be exposed from the reticle in one shift. These cameras are based on off the shelf items but modified to perform in the limited confines of the current system and under vacuum.

3.2 Pupil uniformity metrology

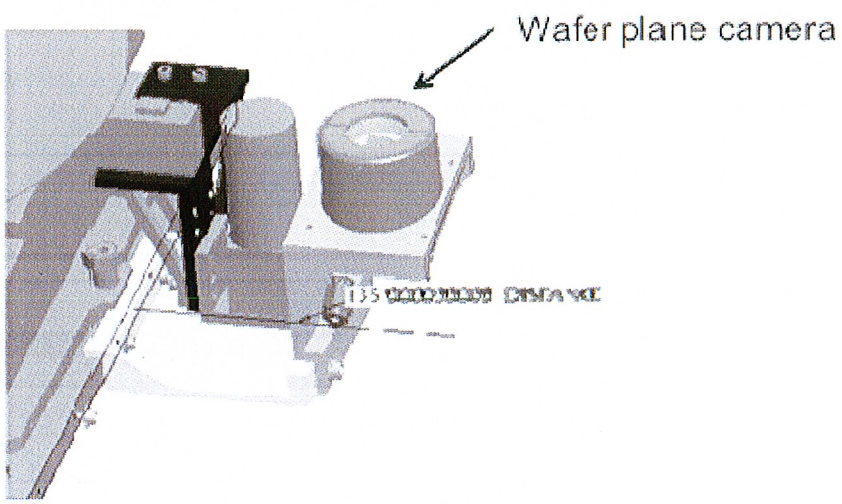

Figure 3. Added camera for illuminator to projection optic alignment

Figure 3 shows how the pupil uniformity camera will be added to the wafers stage. During operation of this unit the wafer will not be present and the stage will be moved to allow this camera to sit underneath the lens. The main purpose of this system will be to allow accurate and efficient alignment of the illuminator to the projection optics box during installation and maintenance of the illuminator, something that today can take considerable time to accomplish. In addition it should allow accurate measurement of illumination uniformity which will allow for correcting X,Y and Z drift in the source.

3.3 Pupil shape and settings

Figure 4 is a composite drawing showing a close up of the newly designed pupil exchange system and how it will fit within the current space requirements. By replacing the current single wheel with six predefined pupil defining masks the new system will have two wheels where combinations of two masks can be used create up to 20 different sigma settings. We will utilize these setting to allow greater flexibility in exposures and implementation of a new Aerial Image Sensor that will be included in the upgrade.

One of the issues that arise from the higher NA of this lens and the design is a significant obscuration. This leads to a *forbidden* pitch phenomena in the exposures of, for example, line and space patterns. By allowing additional sigma settings for the illumination we can not only extend the resolution of the system but also remove these forbidden

pitches. Figure 5 shows a small sample of pupil settings that we will have in our upgraded system and Figure 6 shows the predicted contrast of line and space patterns through pitch for the settings shown in Figure 5. In this example choosing the settings which give us ultimate contrast for the best resolution (#3 Leaf dipole) also produces a significant region of low contrast (forbidden) pitch exposures. However by combining exposures with both the Leaf dipole and the Leaf Quadrapole (#4) we have significant contrast for a full range of pitch exposures.

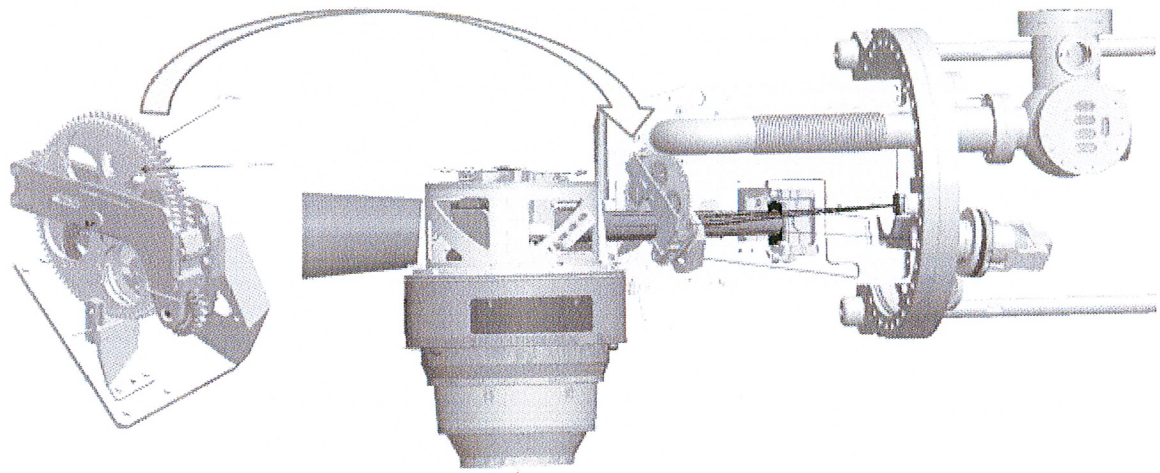

Figure 4. Pupil exchange system and its position in the MET system

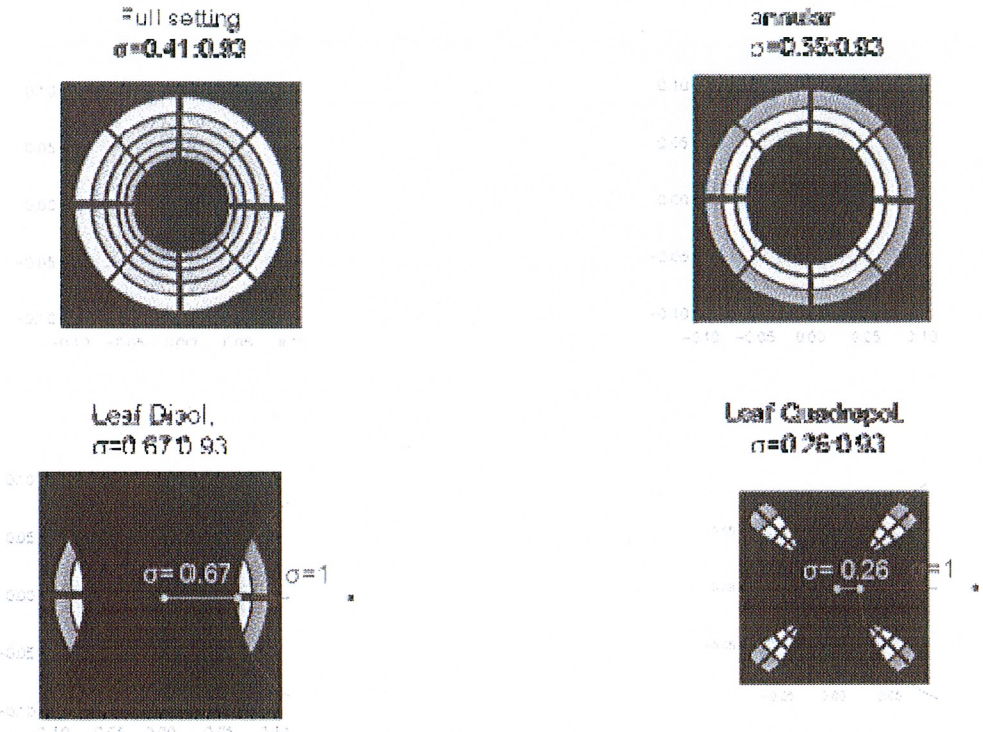

Figure 5. Example of pupil settings obtained with the newly added system

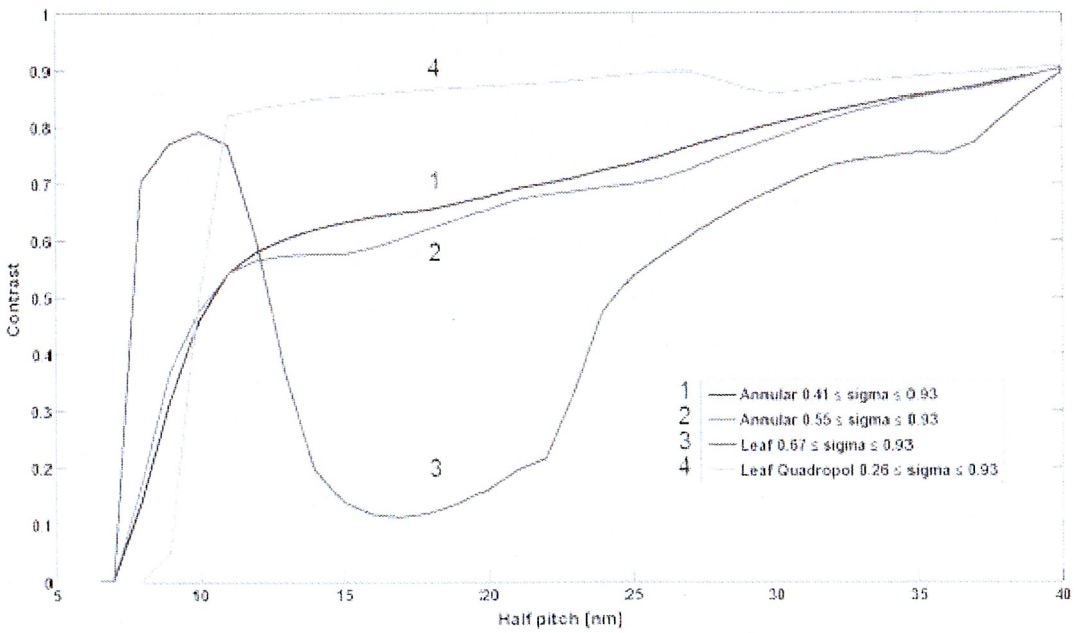

Figure 6. Large obscuration of the lens gives significant regions of forbidden pitches (#3). Multiple pupil settings now allow printing through pitch

3.4 Aerial Image Sensor (AIS)

The principal behind the AIS system has been described [12] and works by measuring the localized curvature at various points across the pupil. Aberrations in the optical system cause a departure in the local curvature from that of an ideal optic which manifests as a small focus shift in the image plane. These focus shifts are recorded at each pupil probe location and are converted into a series of wavefront curvature maps. The wavefront is then reconstructed from its curvature maps using a least-squares approach.

Figure 7 shows the items that were necessary to modify to have the AIS function within the EUV Microfield Exposure Tool. In addition to having significant numbers of features dedicated to the probing and measuring of the pupil placed onto our newly designed and created reticle, a specific set of pupil inserts will be created to allow the monopole illuminations needed to access various regions of the pupil. These multiple monopole settings allow a full characterization of the pupil curvature to be created and hence the wavefront error determined. In addition to the description of the pupil wheels discussed in Section 3.3 there will be in addition an easy (manual) exchange option for the pupil wheel sets to accommodate the AIS.

Figure 8 shows the new sensors needed at the wafer plane that will be included for the AIS to function in the upgraded MET. The picture below is a mockup of the system that we are checking in the current MET to determine its effects on stage motion and to create the procedures needed for accurate alignment and data collection from the monopole probe. Once these items are established we can continue with the upgrade knowing that the AIS detector components are functional and properly aligned.

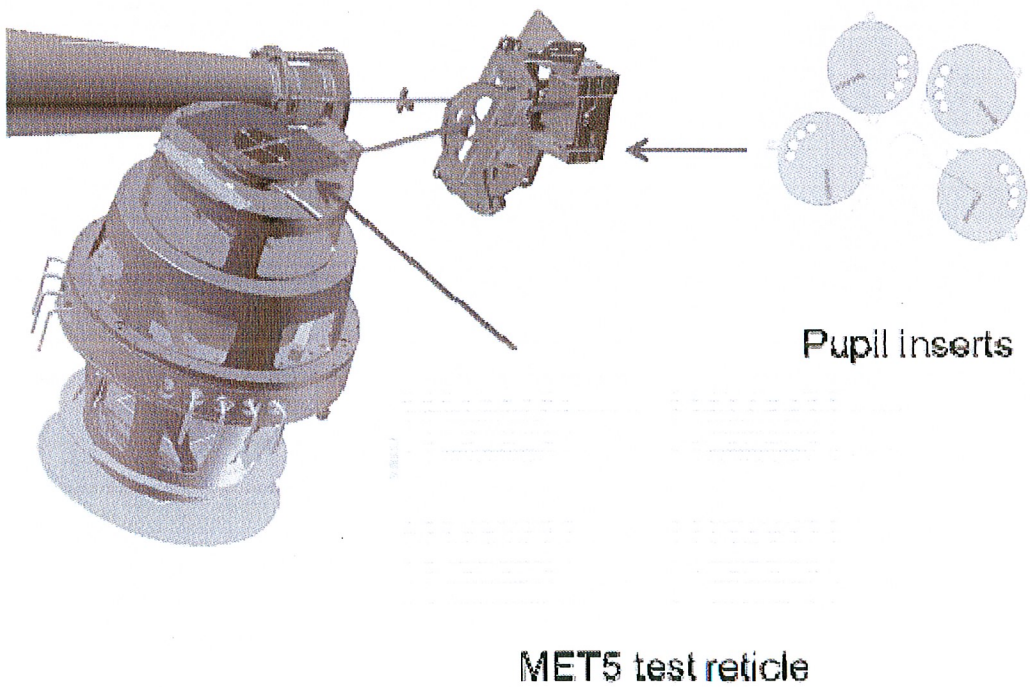

Figure 7. Modifications needed to support the Aerial Image Sensor system developed for the MET.

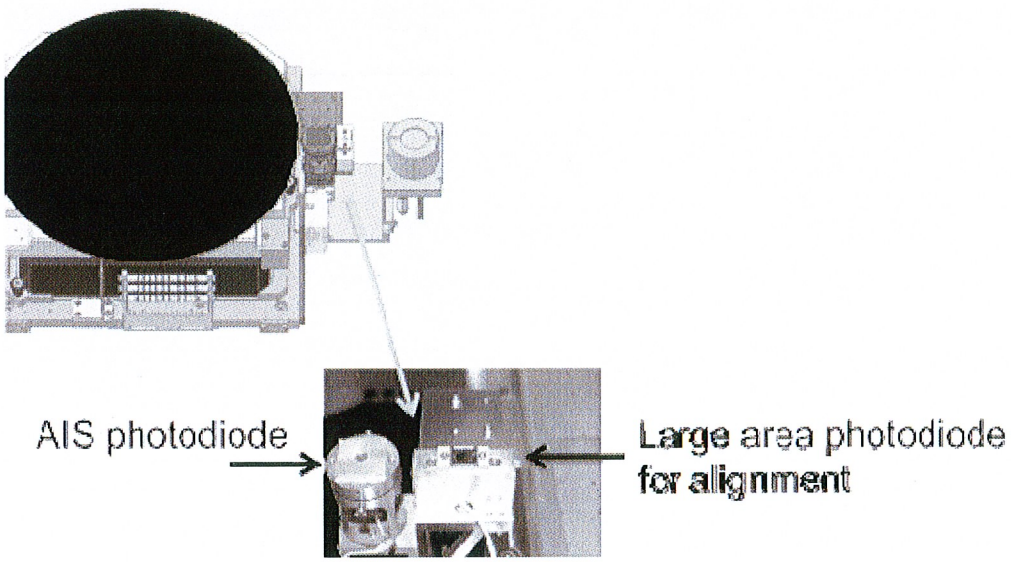

Figure 8. New items needed to support the Aerial Image Sensor system developed for the MET.

4. SUMMARY

The need for improved lithographic performance of the MET, while maintaining the dimensional envelope of the current MET module, resulted in numerous technological challenges to not only the lens but also the platform. These challenges have been analyzed, solutions identified and modifications created. The purpose of these MET tools is to provide very early learning into the extendibility of EUV lithography and in particular in the area of resists to help drive materials learning for patterning at ≤ 10 nm node. By utilizing our current existing systems with the described modification we will achieve the anticipated smaller exposure feature sizes.

5. REFERENCES

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