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Aerial Image Microscopes for the inspection of defects in EUV masks

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The high volume inspection equipment currently available to support development of EUV blanks is non-actinic. The same is anticipated for patterned EUV mask inspection. Once potential defects are identified and located by such non-actinic inspection techniques, it is essential to have instrumentation to perform detailed characterization, and if repairs are performed, re-evaluation. The ultimate metric for the acceptance or rejection of a mask due to a defect, is the wafer level impact. Thus measuring the aerial image for the site under question is required. An EUV Aerial Image Microscope ("AIM") similar to the current AIM tools for 248nm and 193nm exposure wavelength is the natural solution for this task. Due to the complicated manufacturing process of EUV blanks, AIM measurements might also be beneficial to accurately assessing the severity of a blank defect. This is an additional application for an EUV AIM as compared to today's use

In recognition of the critical role of an EUV AIM for the successful implementation of EUV blank and mask supply, International SEMATECH initiated this design study with the purpose to define the technical requirements for accurately simulating EUV scanner performance, demonstrating the feasibility to meet these requirements and to explore various technical approaches to building an EUV AIM tool.

AIM TOOL REQUIREMENTS

There are two distinct modes of operation useful for an EUV mask inspection microscope. First there is the aerial imaging mode, indispensable to perform the tasks as described in the former section. Secondly a high resolution mode for in-situ characterization of the defect would be a beneficial extension of the tool. The detailed application as well as the requirements for both modes are described in this section.

Aerial Image Microscope (AIM) mode

In AIM mode the microscope must emulate the illumination and imaging characteristics of a stepper to enable rapid evaluation of mask defects without the need for a resist exposure step. The main uses of the microscope in AIM mode are anticipated to be:

- Review of multilayer and pattern defects to determine their printability
- Defect review following a repair process to assess the success of the operation
- Investigation of the effects of illumination and NA on the printed image
- Process window analysis of defects and other mask features
- Characterising defects on both patterned and unpatterned masks (i.e. blanks)

For AIM mode, where the tool is used to provide reliable data for defect printability analysis, it is essential that the results obtained by measuring the aerial image with an AIM tool provide the same information that would be obtained in a stepper system. Mimicking the performance of a stepper, albeit over a smaller field, is therefore essential if the results obtained using an AIM tool are to provide a reliable assessment of defect printability in a production tool. Production stepper optics strive to achieve diffraction-limited performance across the field, thus for an AIM tool we also desire a system capable of mimicking this diffraction limited imaging – albeit producing a magnified rather than reduced image. Probing through-focus behaviour of defects for process window analysis is one of the main applications for AIM mode, thus it is also essential that the through-focus behaviour of the AIM tool mimic that of a typical stepper system.

High-resolution mode

In high-resolution mode the microscope is used to obtain the highest possible resolution on the mask for understanding and characterising defects. Potential uses for this imaging mode include:

- Gaining sufficient information to associate defects with particular processes, such as multilayer deposition or patterning
- Assessing the size, reflectivity and phase impact of surface and multilayer anomalies
- High-resolution data for repair of features that do not clearly appear in AIM mode (eg: OPC features)

In high-resolution mode it is not essential that the illumination and imaging conditions match that of a production stepper system as the goal is to obtain high-resolution data on the mask defects for the purpose of, amongst other things, determining a suitable repair strategy. The design options for high-resolution mode are more analogous to traditional microscope design where the goal is to maximise spatial resolution. It is not essential to emulate the through-focus imaging performance of a stepper system, thus there is greater flexibility in system design and a greater range of potential values for parameters such as angle of incidence, NA and wavelength. The specifications on these quantities are therefore open to variation but are anticipated to be in the range of values described in Table 2.

	AIM mode	High-resolution mode
Wavelength	13.5nm	13.5nm (TBD[1])
Bandwidth	2% FWHM	TBD
NA[2]	0.0625NA	0.2-0.45NA (TBD)
Resolution limit	$\delta = 107nm$	$\delta = 15nm$ (at 0.45NA)[3]
Pixel size at mask[4]	$\Delta x = 26nm$	$\Delta x \leq 7.5nm$ (at 0.45NA)
Field of view[5]	50x50μm	TBD
Angle of incidence	6°	TBD
Physical size[6]	Optics package <2m long Preferably <1m long	Same
Throughput	<2s per exposure	Same
Source	Compatible with a compact source	Same

Table 1

Likely specifications and functional requirements for an EUV AIM tool in both AIM and high-resolution modes.

[1] The actual wavelength and bandwidth for high-resolution mode will depend on angles of incidence at the mask.
[2] Investigation of the patent literature indicated that the specifications for a first-generation production tool are likely to be 0.25NA at 4x reduction, giving an NA of 0.0625 facing the mask.
[3] The resolution for a 0.45NA high-resolution mode implementation have been included in this table; however, there is flexibility in the definition of high resolution mode, which can in practice encompass any system with at least twice the resolution of AIM mode.
[4] A factor of 2 oversampling has been included in this figure.
[5] This is a suggested value. The actual field of view and size of the field over which imaging should be corrected to AIM quality imaging is open to determination between customer and vendor.
[6] The main requirement is that the unit fit readily into existing mask shop environment. In this regard it is the size of the overall optics package that is important – the total system path length may be much greater due to multiple reflections within the optical system.

Note the difference in likely specifications between AIM and high-resolution modes. In AIM mode the key optical system specifications must match the mask-side specifications of a production stepper tool and are likely to be in the range of values summarised in Table 2. Whilst final specifications on production tools are not yet available we list the likely functional requirements for an EUV AIM tool. For high-resolution mode there is significantly more scope for variation in design parameters as it is not essential that imaging performance match that of a stepper.

SATISFYING AIM MODE REQUIREMENTS

Whilst through-focus aerial image simulation across the AIM field is required for full design qualification, we adopt the following approach to evaluating and down-selecting different optical system designs:

1. The design must be of a practical size and satisfy the requirement of 0.0625NA clear aperture at 6° angle of incidence using 13.5nm EUV light with a bandwidth of 2%, as described in the Table 2. If a design departs from these requirements the manner in which it does so is clearly identified and the consequences of doing so discussed.

2. A preliminary system characterisation is performed by comparing the incoherent modulation transfer function (MTF), through-focus behaviour and distortion of the optical system across the field. These must be shown to not degrade the optical performance in order for the optical system to faithfully emulate the imaging performance of a stepper system. We perform this analysis across the field of view quoted for AIM mode imaging in order to demonstrate how the measurement will be affected by where the object is located in the field of view[7].

3. Once the requirements of (1) and (2) are satisfied, aerial images are calculated across the field for a characteristic feature size to demonstrate the equivalence of aerial images measured using the AIM objective with the performance of a stepper system. For the purposes of this study we choose to calculate the aerial image at 6250 line pairs per mm (lp/mm), corresponding to 80nm dense features on the mask or 20nm dense features on the wafer. As discussed later this is close to the resolution limit of a 0.25NA, 6-mirror camera, thus performance at this feature size provides a good threshold estimate of aerial image performance of a particular design.

4. Full system qualification requires comparing 2D aerial image simulations of different types of defects at both the best and worst field points within the AIM mode area and demonstrating equivalence with the aerial images anticipated for a stepper system. This should be done for both perfect patterns of critical CD dimensions as well as masks with amplitude and phase defects, and should take into account the effects of flare, design aberrations and anticipated residual aberrations from manufacturing and alignment. Manufacturing aberrations affect both in-focus and through-focus behaviour, and therefore impact on aerial image assessment. Flare directly affects contrast and, thus, the image slope used for printability analysis, and it is therefore important that some capacity be included for either matching the flare of a stepper system in hardware or simulating the effect of flare by convolution of the image in software with a flare point spread function[8]. The important point is that conclusions about defect printability must be the same in an AIM tool as in a stepper system, and should be consistent across the field of view quoted for AIM mode (which may or may not be a sub-region of the total field of view). In the case of a system where the EUV light is converted into electrons or visible light, the effect of conversion and subsequent imaging systems on the measured aerial image must also be considered with particular regard to degradation of spatial resolution and contrast across the field.

For the purposes of this study we restrict our analysis to points 1-3 above, which enables us to identify preliminary designs which are in principle capable of satisfying the requirements of AIM mode imaging. Full design qualification,

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[7] Depending on design the field of view for AIM mode imaging may be less than the field of view of the whole system. For example, an objective may have a visible field of view of 50x50μm which can be used for navigating around the mask, whilst AIM quality imaging is restricted to a 20x20μm sub-field in the centre of the field of view. In this case the field of view useable for AIM mode must be clearly identified and equivalence of AIM mode imaging with stepper performance demonstrated over the entire AIM field. Discussion of the performance expected over the whole field of view would also be useful so that the amount of image degradation at the edge of field can be assessed.

[8] If the effect of flare is to be modeled in software the total flare of the AIM optics would have to be less than that of the stepper system to be emulated.

which is beyond the scope of this preliminary design review, would require point 4 to be addressed and could form the first phase of a design and construction project.

TYPICAL PERFORMANCE OF A 6-MIRROR 0.25NA SYSTEM

To enable quantitative comparison of AIM system designs with the image quality expected in a production tool it is necessary to baseline against the expected imaging quality of an EUVL scanner. Surveying the currently available commercial and patent literature it is anticipated that the first production systems will be 6 mirror designs with a numerical aperture of about 0.25NA. There are designs for such systems in the literature and for this study we pick an existing 6-mirror, 0.25NA Hudyma design as representative of the type of EUV system likely to be built. Two such system configurations are shown below in Figure 1.

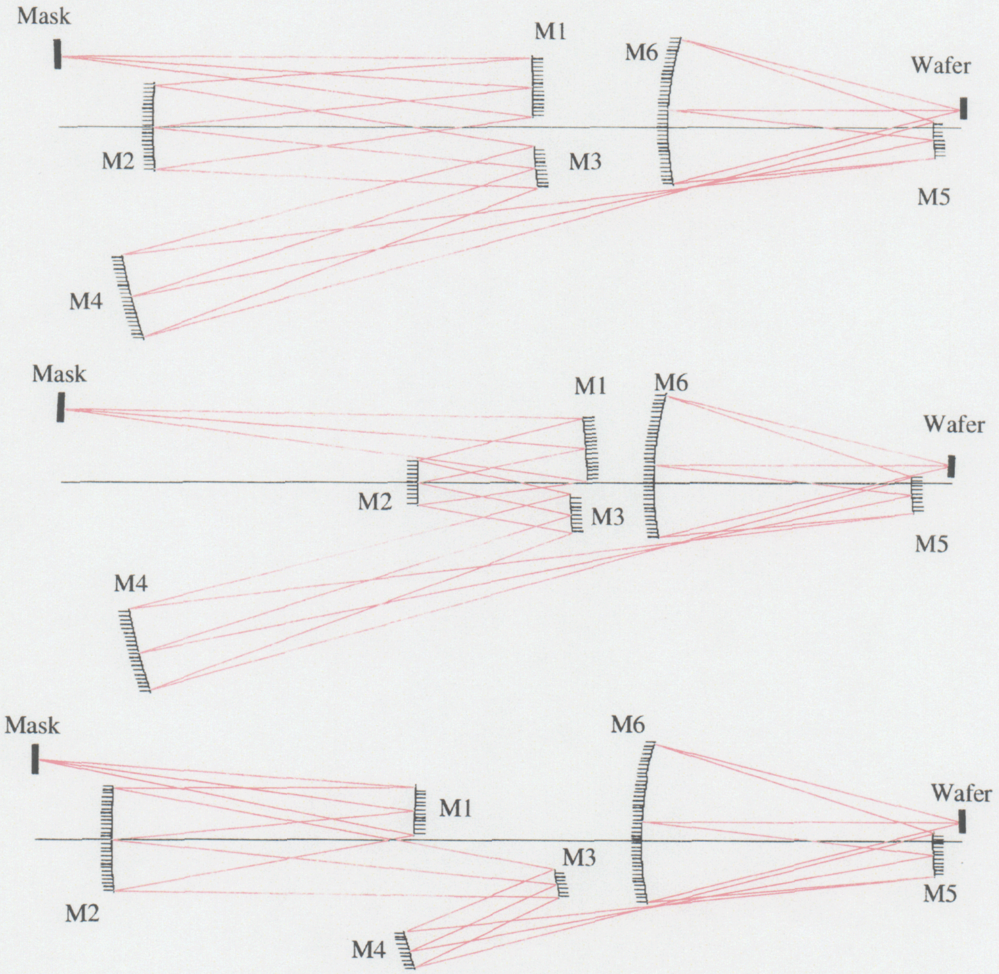
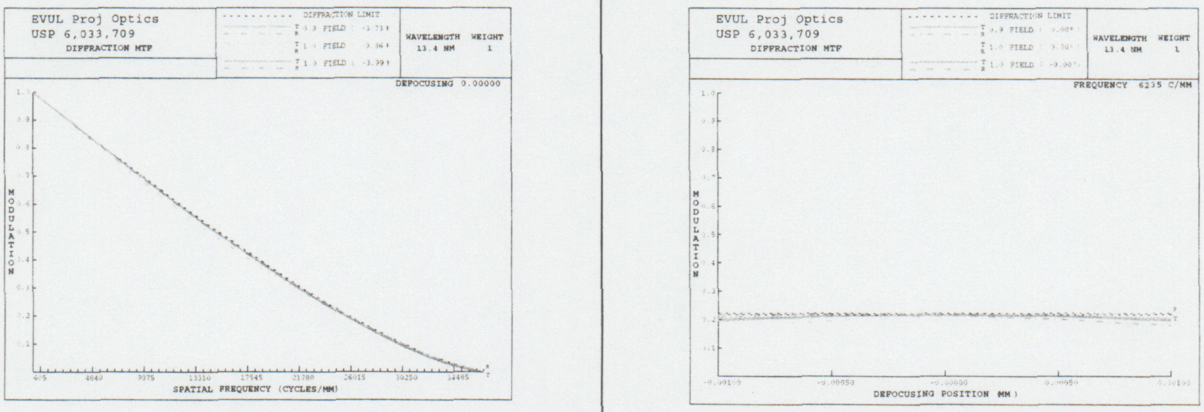


Figure 1
A selection of typical 6-mirror EUV projection optic systems with a numerical aperture of 0.25-0.3NA.

The optical performance of these systems approaches the "zero aberration" condition by design across the ring field. Depending upon the actual design form, the field composite root mean square (RMS) wavefront error of these designs varies in a ranges from 0.010λ to 0.020λ (λ = 13.4 nm). The static distortion across the ring field is corrected to values less than 0.5 nm at any point in the ring field, and there is no appreciable concentration of design error in any one particular Zernike term. This high level of aberration correction enables excellent CD control, the best possible depth of focus, and optimum exposure latitude. Performance of actual EUVL scanners will not be limited by the optical design, but by the fabrication errors present on the mirrors.

An EUV AIMS tool must be capable of resolving the as-designed projected imagery from the aforementioned system because it is anticipated that eventually mirror fabrication will improve to the point where the design aberrations become the factor limiting system performance. This high level of performance is illustrated simply by the incoherent MTF and its through-focus behaviour characteristics shown in Figure 2. For good lithography, a diffraction-limited incoherent performance is a necessary, but not sufficient condition for production quality imagery. Rigorous partially coherent aerial image calculations for 30nm dense features and 20nm isolated features, Figure 3, confirm that the imaging performance across the field is highly uniform across the whole field exhibiting little or no CD variation by design.



Incoherent modulation transfer function (MTF) | Through-focus behaviour at 6250lp/mm

Figure 2

Incoherent MTF (left) and through-focus behaviour (right) for a typical 6-mirror projection optic system. For an AIM tool we seek to emulate this diffraction-limited performance across the region quoted as useable for AIM mode imaging.

CANDIDATE OBJECTIVES FOR AIM MODE

It would be advantageous from a schedule, budget and fabrication perspective to be able to use an existing lens design for AIM mode imaging. To this end several existing EUV lens designs were studied to evaluate whether they could be adapted for use in AIM mode across a 50x50μm imaged field. We examined three generic systems: an all-spherical Schwarzschild system, an aspheric Schwarzschild system, the MET design[9], and a novel equal radii design. These are respectively analogous to the 10x optics at Sandia, the BEL optics and the MET optics, plus a novel objective specifically designed for AIM mode imaging. The possibility of using diffractive zone plate optics rather than normal-incidence mirrors was also investigated. The analysis performed was deliberately kept general so that the conclusions are generic and equally applicable to designs of a similar type, and should therefore be viewed as a technology survey of many different ideas for an AIM microscope implementation.

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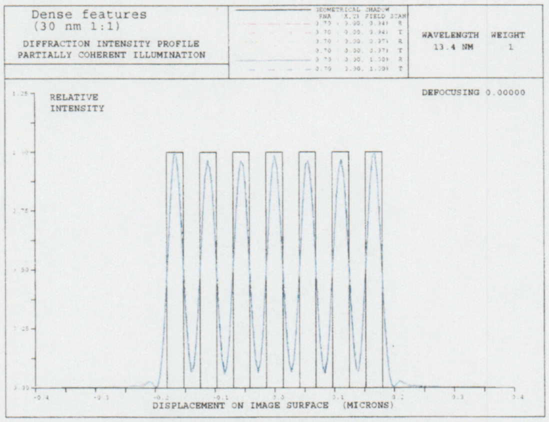
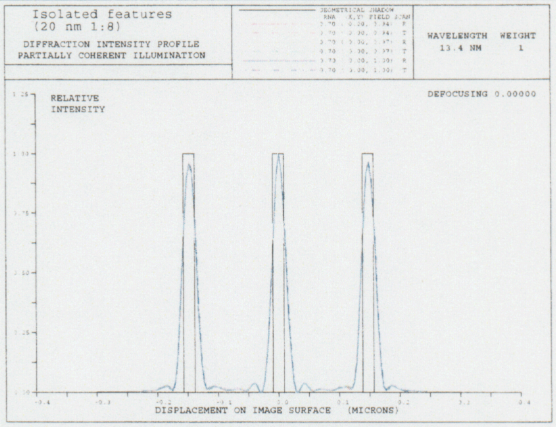
[9] The micro-exposure tool (MET) is a 0.3NA small-field EUV exposure tool that will be installed at International SEMATECH in their Resist Test Centre. It employs an aspheric 2-mirror 5x reduction camera with 10% central obscuration.



30nm dense features, 1:1 pitch
(σ=0.7, λ=13.4nm)



20nm isolated features 1:8 pitch
(σ=0.7, λ=13.4nm)

Figure 3

Design-limited aerial image performance across ring field for typical 0.25NA 6-mirror system.

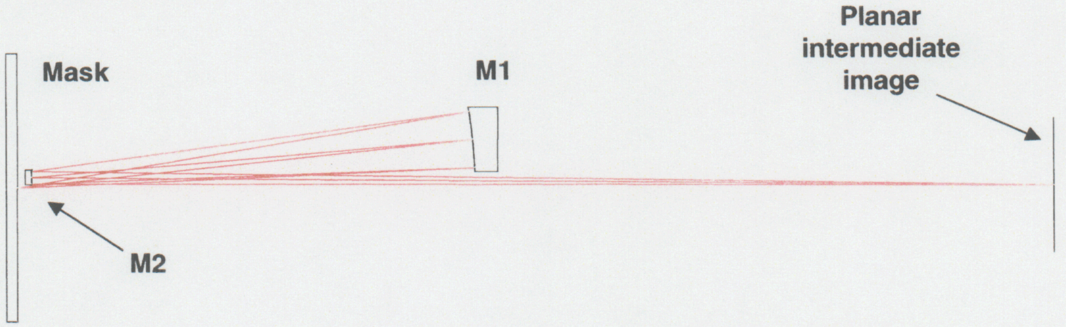
Investigation of these candidate optical designs demonstrated the challenge involved in designing an objective to meet the requirements of AIM mode imaging. Schwarzschild designs that image the mask on-axis, including variants that depart from the classic Schwarzschild configuration, require the angle of incidence at the mask to be increased significantly above the desired 6 degree angle of incidence in order to avoid obscuration by the secondary mirror. We desire an angle of incidence close to 6 degree at the mask in order to match the wavelength and angle-of-incidence on the mask-side of a production stepper system, but on-axis Schwarzschild designs force the angle of incidence at the mask to be at least 11.8 degrees. The only practical way in which the 6 degree angle of incidence at the mask can be captured using a Schwarzschild design is by tilting the objective with respect to the objective axis, which in turn seriously degrades the optical performance. Simply tilting a Schwarzschild objective by 4 degrees captures the desired angle of incidence, however this causes the aerial image to vary significantly across the field and degrades through-focus performance. The performance can be improved by tilting the image plane as well as the mask, however this both degrades through-focus performance and introduces significant distortion into the image.

The MET system is another existing candidate objective design and its suitability for AIM mode imaging was also investigated. Locating the mask where the wafer is placed in an exposure tool provides for 5x magnification across a 200x600μm field. However, the size of the cut-outs in the MET mirrors lead to significant obscuration of the AIM-mode pupil if the angle of incidence is fixed at 6 degrees; it is therefore necessary to re-size the cutouts in the MET mirrors so as to accommodate the requirements of an AIM tool. By re-sizing the cutouts in the MET mirrors to 5mm in M1 and 8mm in M2 and increasing the angle of incidence at the mask slightly to 7 degrees it is possible to accommodate the 0.0625NA clear aperture required for AIM mode imaging. This would provide diffraction-limited imaging across the field at a modest 5x magnification with only a small departure from the wavelength and angle of incidence in a stepper tool.

A novel objective specifically designed for AIM mode imaging was also designed and its performance evaluated[10]. This particular design, illustrated in Figure 4, uses mild aspheric mirrors with <1μm aspheric departure on all optical surfaces, and has a total magnification of 10x over a 600mm track length, although preliminary investigation suggests that the design should be scaleable over the range of approximately 5x to 20x magnification. The composite RMS wavefront error for this system of 0.6mλ suggests that excellent contrast transfer through the system is feasible. Analysis of the MTF plot and through-focus behaviour demonstrate consistent diffraction-limited imaging performance across a 50x50μm field of view. Note also that the distortion of 3nm maximum over the entire field is very low, thus we

[10] "Design and Evaluation of system configurations for an EUV Mask Inspection Microscope" , report to International SEMATECH, August 2002.

do not expect any distortion-induced changes in CD with this design. The numerical aperture for this particular design is 0.0625NA at 6 degrees angle of incidence so shadowing effects on the mask are properly captured and the wavelength matches that of a production stepper system. This, combined with the excellent overall imaging performance, leads us to anticipate that this objective design would faithfully capture the imaging performance of a stepper system across the field of view. Therefore conclusions about printability and CD would be the same regardless of where the object was placed in the field of view.



Parameter	Value	Parameter	Value
Wavelength (λ)	13.4 nm	Composite RMS	0.6 mλ (0.008 nm)
Magnification	10x	Distortion (max)	3 nm
Numerical aperture	0.0625	Aspheric departure	< 1 μm
Field	50 μm x 50 μm	Mask illumination	6.0°
Total track	600 mm	Working distance	2 – 4 mm

Figure 4

Novel objective design for AIM mode imaging.

We summarise the comparative performance of different objective configurations in the table below. This table represents a summary of the options considered and can not describe a full system analysis, which is provided in detail elsewhere[11]; however it does highlight at a glance the relative strengths and weaknesses of each option considered. Inspection of this table reveals that the novel design discussed above is the most promising candidate for an AIM objective as it satisfies all the criteria of AIM mode imaging.

There may be a significant cost advantage in employing a zone plate design. A set of zone plates may cost as little as $5,000 to fabricate using established E-beam lithography techniques, significantly less than the anticipated cost of fabricating and coating normal-incidence multilayer optics. However, there are a number of issues particular to diffractive optics which must be addressed in order to evaluate the feasibility of this approach. In particular, issues that need careful attention for a zone plate system include bandwidth and its effect on the aerial image, working distance to the mask, zone placement errors and their effect on flare and contrast transfer, keystone distortion and field curvature.

[11] "Design and Evaluation of system configurations for an EUV Mask Inspection Microscope" , report to International SEMATECH, August 2002.

	Field of view	NA facing mask	Angle of incidence at mask	Magnification	Composite RMS wavefront error[12]	Distortion	MTF performance across field	Through-focus performance across field
Spherical Schwarzschild	50x50μm	0.0625	11.8°	10x	55mλ	87nm	Poor	Variable
Aspheric Schwarzschild	50x50μm	0.0625	11.8°	10x	0.6mλ	3nm	Good	Good
Tilted Schwarzschild (4°) Parallel image plane	50x50μm	0.0625	6°	10x	66mλ	246nm	Poor	Poor and variable
Tilted Schwarzschild (4°) Tilted image plane	50x50μm	0.0625	6°	10x	1.9mλ	5833nm	Good	Poor and variable
Modified MET	600x200μm	0.0625	7°	5x	21mλ	2.2nm	Good	Good
Novel AIM design	50x50μm	0.0625	6°	5-20x	0.6mλ	3nm	Good	Good

Table 3

Summary of performance characteristics of candidate AIM-mode objective configurations studied.

SYSTEM INTEGRATION OPTIONS

Visible light microscope based system

Adapting a visible light microscope for use in an EUV AIM system has attraction as it leverages the experience gained by existing 193nm and 157nm AIM tool vendors. Adapting visible light microscopes for use as an AIM tool can not be done directly with EUV as the optics have to be in vacuum. However use of a visible light microscope platform for secondary magnification is possible if a scintillator is used to convert an EUV image into visible light. We note two potential user benefits of adopting this approach over an all-EUV system: (1) From a user point of view there is minimal change in method and ergonomics compared to existing AIM tools, and (2) visible-light epi-illimination introduced from the microscope may provide sufficient illumination to view the mask directly using visible light, providing some capacity for parallel visible light and EUV inspection of the mask on the same platform.

Technical aspects of the scintillator, visible light microscope and CCD technologies are well understood and these components can be sourced from vendors. The main areas of technical risk are uncertainty about the conversion efficiency, which directly links to optical throughput and required source parameters, and some potential loss in spatial resolution within the visible-light microscope.

[12] In general, errors that arise in fabrication from polishing or other material removal operations, as well as from metrology, tend to be much larger than residual design errors. It has been demonstrated with both spherical aspherical imaging systems that optics can currently be polished to figure accuracies of 0.2-0.3 nm rms, where the system wavefront errors are of order 1 nm rms in the first 36 Zernike terms. It might be inferred that 2-mirror systems will have somewhat lower combined errors than systems with a larger number of mirrors, although the difficulty of the specific surfaces should be considered. The degree of difficulty in meeting figure specifications will depend on issues such as the amount of aspheric departure, the aspheric slope, size, the proximity of the clear aperture to an edge, and the required specifications on surface finish. Size affects the difficulty of fabrication for both large optics and small optics. Clearly, large optics have a greater area that needs to be controlled, while figure errors for small optics may overlap with spatial periods typically associated with surface finish. Spherical optics may offer some advantages over aspheric surfaces, particularly in testing. However, in meeting the stringent specifications for EUV optics, it is likely that the fabricator will employ aspheric methods on spherical surfaces to meet the final requirements. There is also a trade-off in meeting figure and/or finish specifications. Typically, fabrication processes tend to address either figure or finish, and often cause the other category to degrade. So, a specification that stresses both figure and finish will often result in an iterative process where different removal tools are employed in such a manner that one category may improve at the expense of the other.

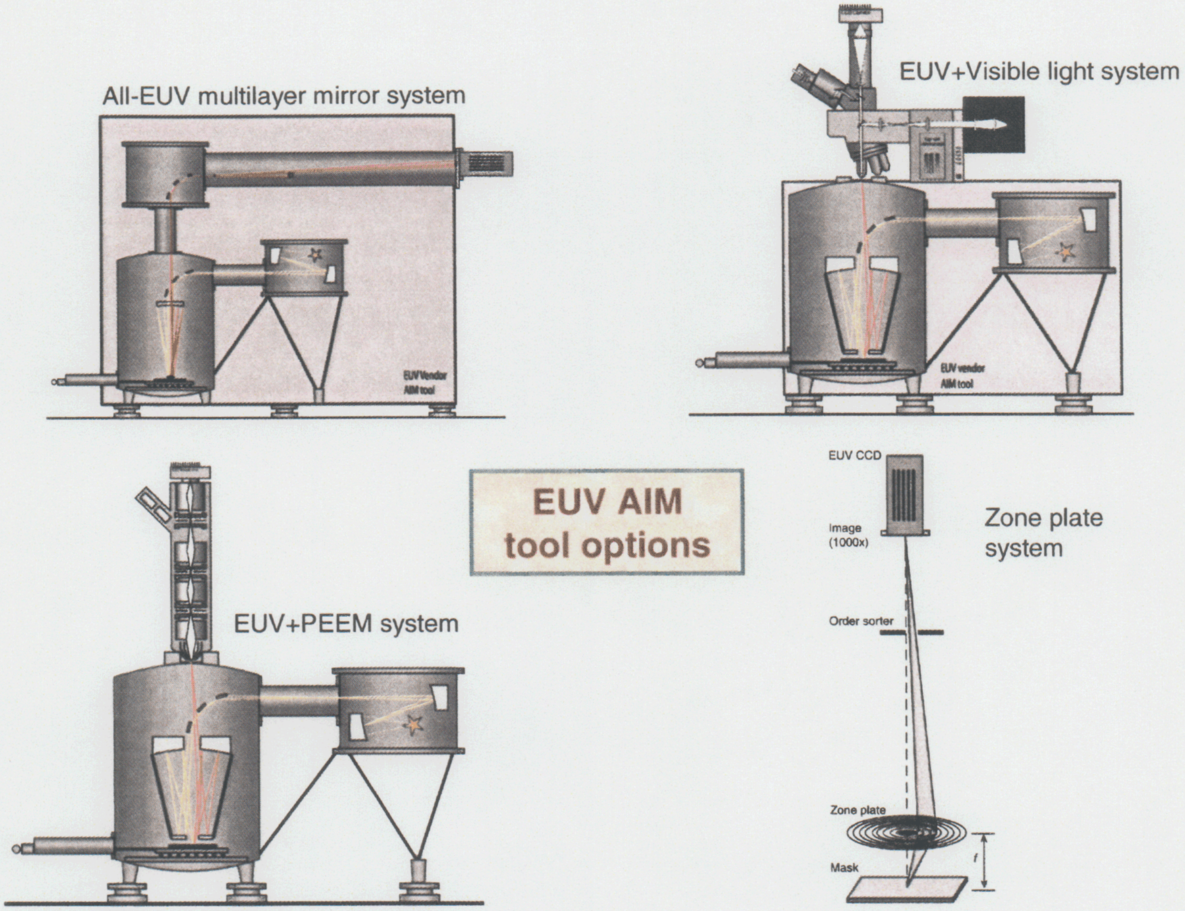


Figure 5
System integration options for an EUV AIM system

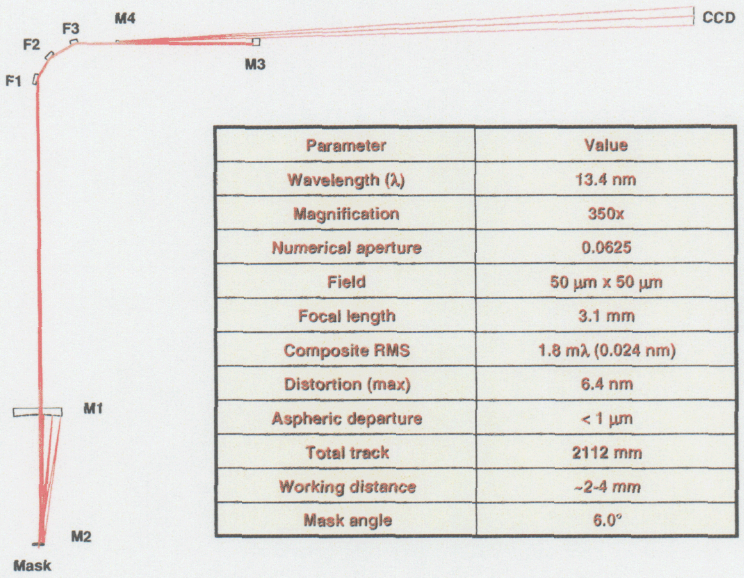
PEEM based system

Combining an EUV objective with a high resolution electron microscope for secondary magnification provides the capability to obtain high magnification using electron optics, relaxing the magnification requirements of the EUV objective. In this configuration the EUV image from an AIM mode objective is projected onto a photocathode that converts the EUV image into a photoelectron image which is further magnified using an electron microscope column. The advantage of this design is that it may provide the most rapid integration path for using an existing low-magnification EUV optics, for example the 5x MET adapted for AIM use.

One significant drawback of this approach is the low conversion efficiency of known photocathode materials and the relatively low throughput of available PEEM columns. This low conversion efficiency leads to significantly higher source power requirements than other options considered. The addition of gain, for example by addition of a multi-channel plate (MCP), can significantly decrease the required source power at the expense of higher noise levels in the final image. Initial calculations indicate that it is practical to build a PEEM based system for use with a compact source provided an MCP with gain of approximately 1000x is used to amplify the image intensity; however this comes at the expense of a significant increase in noise level in the measured image.

All-EUV multilayer mirror system

It is possible to design a high-magnification system consisting of all normal incidence EUV mirrors for the purposes of an AIM design. A high-magnification imaging system is the critical element in this design approach. Starting with the AIM-mode EUV objective design discussed above and adding a second stage of magnification it is possible to design an EUV imaging system with sufficient magnification for imaging directly onto an EUV CCD with diffraction-limited performance across the field of view. The system design is sketched in **Error! Reference source not found.** below: note that the total track length required to obtain this magnification is 2.1m, thus three plane fold mirrors have been included in order to bend the system at right angles so it can fit in an enclosure of practical size. Note, however, that these fold mirrors could just as easily be replaced with a normal-incidence mirror to fold the system back on itself rather than projecting the image at right angles. The composite RMS wavefront error of this system as designed is 1.8mλ and should provide excellent contrast transfer through the system.



Parameter	Value
Wavelength (λ)	13.4 nm
Magnification	350x
Numerical aperture	0.0625
Field	50 μm x 50 μm
Focal length	3.1 mm
Composite RMS	1.8 mλ (0.024 nm)
Distortion (max)	6.4 nm
Aspheric departure	< 1 μm
Total track	2112 mm
Working distance	~2-4 mm
Mask angle	6.0°

Figure 6
High-magnification EUV imaging system for AIM mode. The three plane fold mirrors have been included in order to bend the system at right angles so it can fit in an enclosure of practical size, as described in the text.

Zone plate system

The simplest zone plate concept employs a single imaging element (zone plate) imaging the mask with a 0.0625NA. The zone plate is tilted with respect to the mask so that the optical axis of the imaging system is at 6° to the mask. The imaging system is therefore a tilted optical system and as such will suffer from keystone distortion and require a tilted image plane[13]. It is possible to correct for this by using an off-axis portion of an on-axis zone plate to eliminate keystone distortion and to have the object and image planes parallel to one another and the zone plate, as shown in Figure 5. This on-axis zone plate design has the advantage that the zero and first order diffraction orders are physically separated, reducing flare in the system and allowing for more relaxed placement of the order sorting aperture. In order to capture the marginal ray of the 0.0625NA AIM pupil at 6° angle of incidence using the on-axis design it is necessary to have a parent zone plate with a numerical aperture of 0.166NA.

The main concerns with a zone plate implementation are bandwidth, contrast and image quality. Due to chromatic aberration effects in standard zone plate designs the specification of a zone plate is completely defined by the numerical aperture (NA), wavelength and bandwidth; for AIM mode imaging the wavelength and NA are determined by the requirement of emulating stepper imaging, leaving bandwidth as the only free variable in system design. For example, in the off-axis design contemplated above emulating the full 2% bandwidth of a stepper system leads to a design with a focal length of 24μm, 8μ diameter and a useable field of 2μm; relaxing the bandwidth requirement to 0.1% leads to a focal length of 477μm, 160μm diameter and a useable field of 53μm. Because of the requirement to maintain

[13] The effect of tilting an objective on keystone distortion, image plane tilt and through-focus behaviour was discussed in the section on tilted Schwarzschild concepts, and much of this discussion is also relevant to a tilted zone plate system.

the zone plate in close proximity to the mask, and the desire for a practical working distance to avoid accidental contact, it is likely that the bandwidth will have to be restricted to less that 2% in order to achieve a practical working distance.

For AIM mode imaging we desire to replicate the imaging performance of a stepper system, thus it is necessary to consider the effect of zone placement error on imaging performance. The far-field intensity pattern from a zone plate is a sensitive indicator of small zone positioning errors, and this effect has been studied in the literature[14]. The accuracy of zone placement over the entire zone plate as well as smallest write-able feature size, and its impact on the aerial image, must therefore be considered in determining the fabrication requirements of a zone plate for EUV mask inspection. Furthermore, a single-element lens, of which a zone plate is an example, will in general suffer from curvature of field as the Petzval sum can not be driven to zero for a single element[15], thus the planar mask surface will be imaged onto a curved image surface in the detector plane. Since both the mask and commercially available CCD detectors are inherently flat[16] this curvature of field will lead to a change in focus across the field, which will in turn affect the CD measurement through focus. This must be taken into account when determining the useable field of view over which stepper-equivalent AIM measurements should be made.

CONCLUSION

A number of potential configurations for an EUV AIM tool have been studied and technical aspects of the design approaches investigated. The requirements for AIM mode of emulating stepper quality imaging have been spelt out and strategies developed for assessing the suitability of different approaches to satisfying the technical requirements for AIM mode. A synopsis of the approaches considered, and conclusions reached, is presented in Table 4 below. The identification of risk or required development in this table does not disqualify a particular approach; rather it serves to raise an issue which must be addressed in any attempt to build a tool.

	Advantages	Disadvantages	Key technical risk
All-EUV with Normal incidence mirrors	• Lowest power requirements • Good match to stepper imaging	• Expensive optics • Long path length	• Small mirror fabrication
Zone plate	• Short path length • Inexpensive optics	• Reduced bandwidth • Increased source power requirements	• Flare and contrast in image • Field curvature
EUV objective + visible light system	• 2nd stage already in use	• Increased source power requirements	• Conversion efficiency and resolution needs to be verified
EUV objective + electron microscope	• 2nd stage commercially available • Suitable for use with low magnification optics	• High EUV power requirements • Conversion from EUV-electron-visible	• Photocathode conversion efficiency • Throughput and aberrations of PEEM • Noise introduced by multichannel plate

Table 4

Summary of advantages and disadvantages of the approaches considered in this study.

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[14] E.Tejnil, K.A.Goldberg, E.H.Anderson and J.Bokor "Zonal placement errors in zone plate lenses" OSA Trends in Optics and Photonics Vol. 4, Extreme Ultraviolet Lithography, G. D. Kubiak and D. R. Kania, eds. (Optical Society of America, Washington, DC 1996), pp. 138-142

[15] Born and Wolf, Principles of Optics, 7th ed., §5.5.3.

[16] We note that curved detectors have been manufactured for custom applications, and are typically based on fibre-coupled CCDs which use the optical fibre bundle to transfer the curved detector surface to the CCD plane.

AUSPICES

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