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Invited Paper

AIMS™ EUV first insertion into the back end of the line of a mask shop: a crucial step enabling EUV production

Renzo Capelli[1], Nathan Wilcox[2], Martin Dietzel[1], Dirk Hellweg[1], Scott Chegwidden[2], Joseph Rodriguez[2]

[1] Carl Zeiss SMT GmbH, Rudolf-Eber-Str. 2, 73447 Oberkochen, Germany

[2] Intel Corporation, Bowers Avenue, Santa Clara, CA, USA

ABSTRACT

EUV lithography is being prepared for insertion into the semiconductor production processes to continue the reduction of critical feature sizes at subsequent process nodes. To support that EUV wafer lithography development and production, the EUV photomask infrastructure similarly needs to be ready to support the shipment of EUV photomasks. EUV photomasks will require tighter process controls and tighter defect specifications to meet the requirements necessary for the wafer manufacturing insertion node. The novelty of the EUV lithography process combined with the high degree of complexity of the EUV photomask structure and process each contribute to the tightening of EUV photomask requirements, requiring accurate metrology to ensure fidelity to the photomask specifications.

To fully address the industry requirements for EUV defectivity review and actinic mask qualification, ZEISS and the SUNY POLY SEMATECH EUVL Mask Infrastructure consortium have developed and commercialized the EUV aerial image metrology system, the AIMS™ EUV. The first commercial platform is already installed at a customer site and is available to support the EUV photomask production pipeline.

This paper shows how the proven technology of the ZEISS aerial image system implemented into the AIMS™ EUV platform supports EUV photomask production in the back end of the line of Intel photomask manufacturing shop. Alongside with describing the essential development phases of the platform at customer site, examples of the reproducible measurement quality, as well as stability of the imaging fidelity of the system in production will be shown. In addition, the system output together with the experience on uptime and availability of the AIMS™ EUV platform in production is presented.

Keywords: Mask metrology, AIMS™, Aerial image review, EUV, scanner emulation, defect review, EUV optics

1. INTRODUCTION

The EUV mask infrastructure has seen tremendous achievements in recent years, with the EUV semiconductor industry requesting and supporting the effort to develop the needed infrastructure. It is with this shared effort that the industry can now count on the current availability of metrology techniques, actinic metrology tools, and optimized blank and mask manufacturing processes to meet the requirements for EUV pilot production and eventual high volume manufacturing. As the first EUV scanner systems were being delivered by ASML, requiring source power increases to reach the 250W production goal, the top EUV mask manufacturing challenges requiring significant improvement were EUV blank and mask defectivity [1].

Since then, many areas have seen consistent improvement. Excluding solutions for manufacturable EUV pellicles and availability of an actinic patterned mask inspection tool, the mask shop may now be equipped with all tools necessary in the EUV mask production flow [2]. During these early days of EUV pilot production, EUV mask defect review and repair verification have been approached from two different perspectives. The first approach involves the use of extensive simulation capabilities to estimate the expected wafer defect arising from mask defects. The mask defects are characterized using defect information gathered from several disparate metrology methods, and then the expected wafer defect is simulated based upon these available mask defect characterizations. While this approach exploited the existing 193nm metrology and commercial software infrastructure, this option introduces many sources of errors leading to uncertainty in the predicted wafer defect. Furthermore, this approach may be challenging to setup in a production environment due to the complexity and risk management of the combined systematic sources of uncertainty. The second approach, more simple and direct, is based upon mask aerial image technology and delivers the aerial image of the potential mask defects identified during prior mask inspection operations. Amongst actinic metrology solutions available for a mask shop, the AIMS™ systems offer an industry standard for mask aerial imaging, guaranteeing performance according to industry requirements by fully emulating the EUV scanner imaging conditions: illumination scheme, numerical aperture (NA), scanner quality aberrations, and pupil rotation emulation [3]. These capabilities guarantee that all relevant information collected by the scanner optics in order to form the aerial image exposed onto the wafer, are collected in the same way by the AIMS™ EUV. The defect disposition and repair verification processes can therefore flow quickly, efficiently, and without the associated uncertainties accompanying

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the simulation approaches, improving reliability and turnaround time for mask defect verification within a production environment.
Figure 1 shows the mask production flow in a mask shop employing the AIMS™ EUV: the back end of the line processes are dominated by defect review and repair verification, along with the repair performed by the MeRiT® tool. The ZEISS AIMS™-MeRiT® closed loop solution has become an industry standard for 193nm systems, and it now continues doing so for EUV masks, fulfilling the industry's requirement to support EUV mask manufacturing.

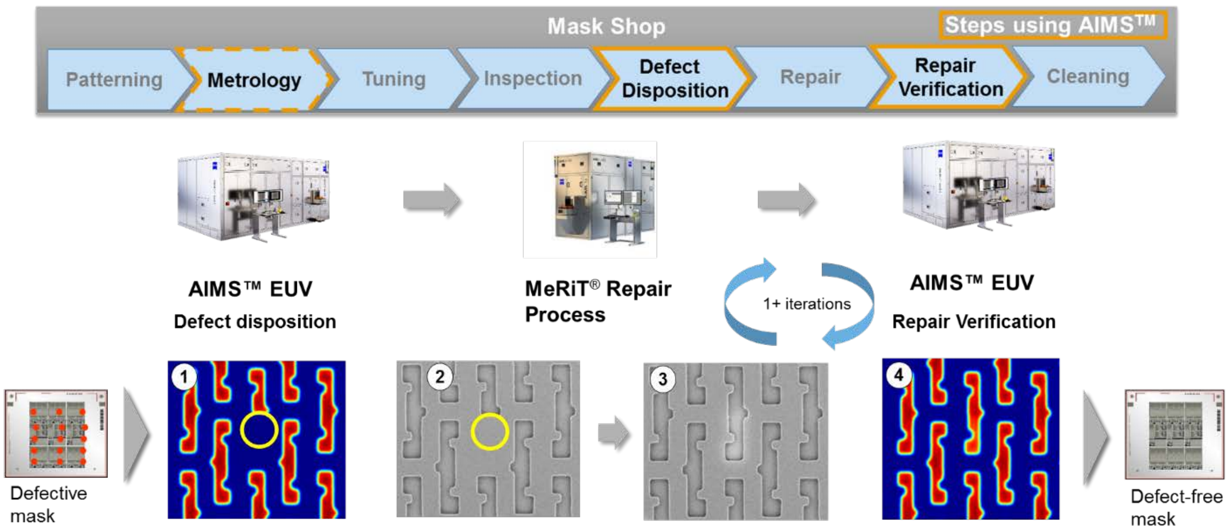


Figure 1: Exemplary mask production flow process. On the top line and in orange highlighted, the steps in which AIMS™ EUV is used. Bottom panel: 1. AIMS™ EUV aerial image of the defect. 2. Mask SEM image of the defective area acquired by the MeRiT® before repair. 3. Mask SEM image of the repaired area. 4. AIMS™ EUV aerial image of the repaired defect.

In this paper, the performance and achievements of the AIMS™ EUV tool in production at Intel Mask Operations will be presented. Chapter 2 includes a comparison of the performance results achieved during factory acceptance and final acceptance at customer site, with special focus on imaging parameters such as critical dimension (CD) measurement repeatability and Edge Placement Error (EPE) measurement stability. Chapter 3 will present data acquired with the AIMS™ EUV tool in production at Intel: particle contamination monitoring, tool availability, metrology and imaging stability will be the topics discussed. To conclude, an example of AIMS™-MeRiT® closed loop solution for defect disposition and repair verification will be shown, together with the full automated analysis capabilities provided by ZEISS digital solutions.

2. AIMS™ EUV BEFORE ENTERING PRODUCTION: FACTORY AND FINAL ACCEPTANCE

The first AIMS™ EUV commercial system was delivered to Intel in 2017, after a successful factory acceptance test program which involved a performance demonstration of the system's main capabilities, including imaging, handling, and cleanliness. In terms of imaging performance, measurement accuracy and measurement repeatability are the two main requirements which a commercial tool needs to fulfill. To judge the stability of the imaging following disassembly, shipment, and re-integration at the Intel mask shop, the same set of measurements were repeated both at factory acceptance at Zeiss and also final acceptance at the Intel site. The results of the two measurement sets were compared to confirm good agreement was achieved and to thereby ensure the necessary optical performance stability required to qualify the tool into production.

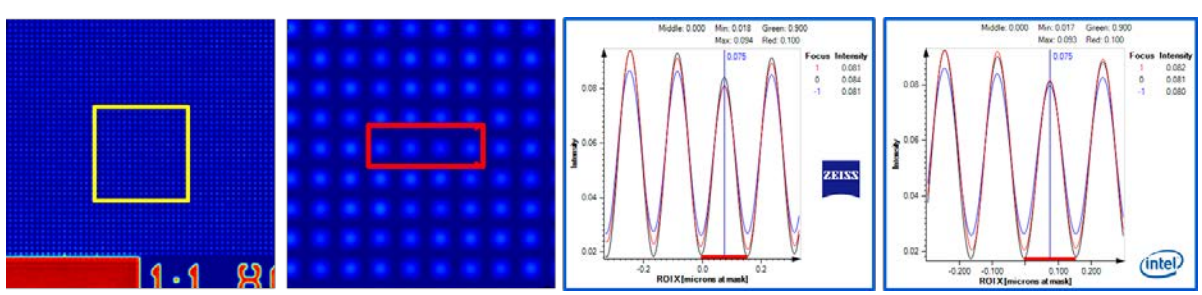
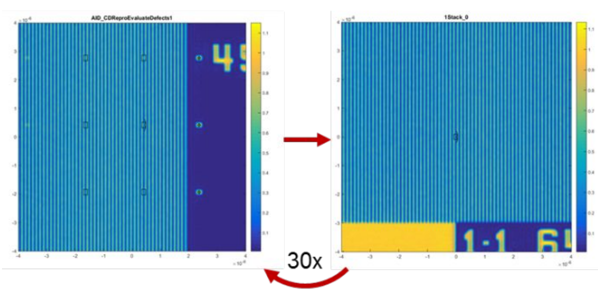


Figure 2: Comparison of intensity profiles of one contact hole array as acquired at factory acceptance and final acceptance. Left: full AIMS™ EUV aerial image (8 by 8 um at mask). Center left: Zoom in the yellow region of left panel image. Center

right: Intensity profile of the normalized aerial image for three focal planes as acquired during factory acceptance. Right: Intensity profile of the normalized aerial image for three focal planes as acquired during final acceptance.

The first set of results reported in this paper present the comparison between two through focus stacks of aerial images acquired at the same mask position during factory and final acceptance. The ZEISS proprietary metrology embedded within the AIMS^{TM} EUV control system budgets all components which contribute to the overall quality of the final aerial image in order to ensure good repeatability of the measurements over long time spans and varied tool conditions. An example of such repeatability is shown in Figure 2 above: from left to right, the 80nm contact holes dense array used for this comparison is shown as full field of view (8 by 8 um), a zoom in in the yellow area, and the two intensity profile plots of the four contact holes selected in the red region of interest as acquired at ZEISS headquarter and Intel mask shop during factory and final acceptance respectively. Of note is the overall excellent agreement between the absolute intensities of each of the four contacts, as well as their relative intensity with respect to one another in the two intensity profile plots. The lower intensity of the third contact from the left is also very well reproduced between the two measurements, and it is a feature of the mask itself (local CD variance).

Having confirmed the reliability of the system metrology at guaranteeing the required repeatability of the measurement process, the second item we report is the actual CD measurement repeatability on the short run, i.e. the variance of repeated CD measurements of the same feature within one measurement run, and from run to run.



Structure	FAT	ATP	Spec (a.u.)
64nm L/S 1:1	0.4	0.4	1.0
80nm CH 1:1	0.5	0.6	1.0

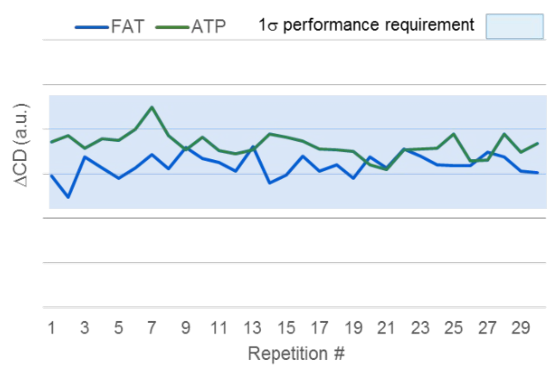


Figure 3: Top left: Exemplary defect and reference images of a lines and spaces dense array used for qualification of CD reproducibility measurements. Right: ΔCD values measured for the central defect ROI at factory and final acceptance, in which the blue area represents a 1σ performance requirement. Bottom left: CD reproducibility results at factory (FAT) and final acceptance (ATP) normalized to a specification value of 1.0.

Amongst the various features used for CD reproducibility qualification, one example from a dense array of 64nm (at mask level) lines and spaces with embedded programmed defects is presented in Figure 3. In one measurement run, 30 repetitions of the defect-reference pair are acquired and the CD deviation introduced by a defect is measured with respect to the reference CD. The right panel of Figure 3 shows the results of such measurements achieved during factory (blue) and final (green) acceptance, with the shaded light blue area representing the one sigma performance requirement. The variance of the ΔCD values measured within each run is also very well reproduced in following runs, with a delta variance < 6%. Furthermore, the absolute agreement between the two set of values is excellent, and contributes to the fulfillment of the dynamic performance qualification, in which imaging stability is qualified over several days, tool conditions, and mask loads. The CD reproducibility results achieved at factory and final acceptance are shown in the table inlet within Figure 3, where the CD reproducibility values are normalized to the target 1σ specification. The reproducibility values achieved by the AIMS^{TM} EUV system for both static and dynamic loads shown are all less than 60% of the target specification.

Together with the demonstration of the system capabilities and performance defined upon commercial agreement between ZEISS and Intel, a further imaging qualification was requested in order to acquire the necessary confidence needed from the mask shop to bring the defect disposition and repair verification tool into production. Intel requested the measurements of EPE on a mask other than the ZEISS calibration mask used for acceptance tests. These qualification were run on different defect types and included CD variations within each given defect type. The top row of Figure 4 shows exemplary defect (A) and reference (B) images acquired within a dense staggered contact hole array, as well as the defect-reference difference image zoomed into the defective area (C), in which the red slice indicates the area used for CD measurement, i.e. the dark feature between two bright holes. For this specific case, the edge placement error is defined as the absolute value of the difference between the CD values of this absorber area in the defect and in the reference image. The bottom panel of Figure 4 shows the results of the EPE measurements for one specific defect type, for which an exemplary case is shown in the aerial images above: within this defect type specifically, the EPE values of six programmed defect CD steps were measured both at factory and final acceptance, with the results reported in the histogram in Figure 4 (nm at wafer). For this test, the quantity to qualify is the difference between the EPE measurements performed at factory and final acceptance, i.e. the difference between the dark and light blue in the histogram. The EPE long term stability measurement achieved by the AIMS^{TM} EUV system in production at Intel are safely fulfilling the customer requirements to bring and operate the tool into production environment. This excellent stability enables the customer to take very reliable repair and mask defect disposition decisions. To conclude this chapter, AIMS^{TM} EUV demonstrates superior imaging stability providing Intel with the confidence needed for the insertion of the tool into the EUV mask processing flow.

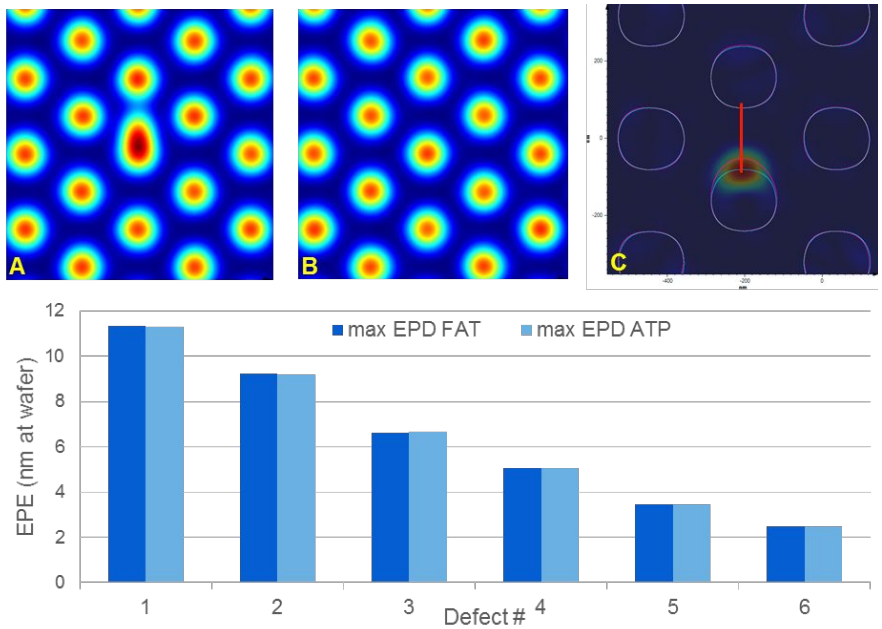


Figure 4: Top: aerial image of the staggered contact holes array used for EPE measurement during factory and final acceptance. A. Defect image. B. Reference image. C. Reference and defect image contours superimposed to the defect – reference difference aerial image. The slice used for CD measurement is displayed as a red line connecting two adjacent contours.

3. AIMS^{TM} EUV IN PRODUCTION AT INTEL

3.1 Tool Availability

After successful final acceptance at the customer site and subsequent pre-qualification of the AIMS^{TM} EUV system, the system was integrated into the EUV mask process flow at the Intel mask shop. This system is the first AIMS^{TM} EUV tool to operate in production environment. Figure 5 reports the tool availability monitoring results for the first ~2.5 months after entering production, with each week represented by a column of the histogram. Three tool availability categories are shown in green (tool available - uptime), yellow (scheduled downtime), and red (unscheduled downtime). By averaging the weekly uptime data provided by Intel, an uptime of ~ 65% was reached by the AIMS^{TM} EUV tool in Intel mask shop. To give a high level overview of some of the downtime items the system encountered in the first months of operation, please refer to the yellow and red bars in the histogram. Scheduled downtime includes the planned replenishment of the tool with the necessary consumables, planned parts replacements, necessary system preventive maintenance (including fine adjustment of the EUV light path and required system stabilization times), and planned tool monitors to assess system health. Unscheduled downtime events were also observed on the AIMS^{TM} EUV System at Intel. Amongst these, the failure of two controllers for handling and imaging components as well as erroneous metrology calibrations were the dominant sources of unscheduled downtime. The system availability is further expected to improve beyond the reported 65% with the release of updated software specifically targeted towards uptime improvement.

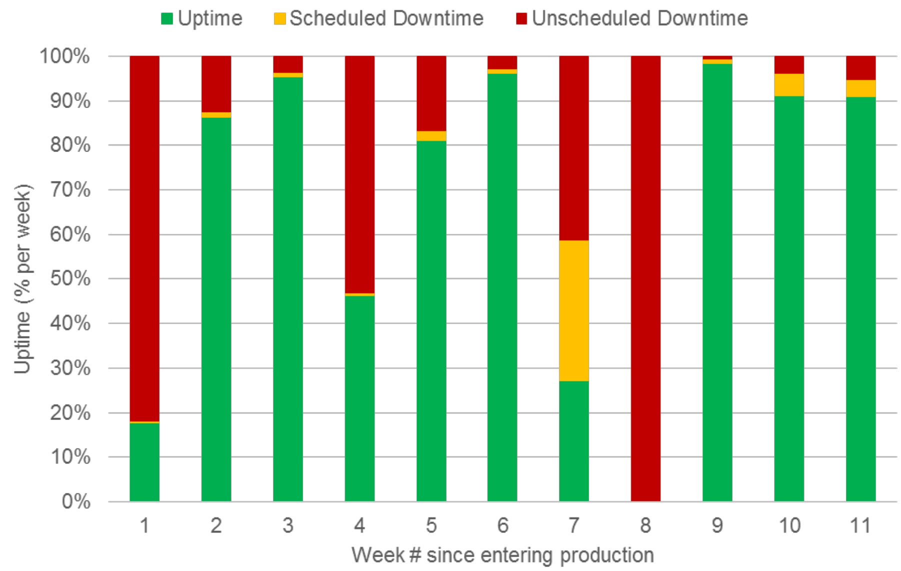


Figure 5: Tool availability recording. The different columns represent the weeks for which uptime has been recorded by Intel after tool insertion into production. The categorization Uptime-Downtime is shown in color code, in which a full week time is set to 100%.

3.2 Particle contamination monitoring

Besides tool availability, the cleanliness of the mask environment and of the full handling path is an important factor for the AIMS^{TM} EUV system, as it is for all EUV metrology, exposure, and processing tools. The ever shrinking feature sizes and defect size requirements due to the improved imaging resolution afforded by EUV exposure, place stringent cleanliness requirements on the AIMS^{TM} EUV system. The AIMS^{TM} EUV system includes implementation of new materials and technologies to better control the particle generation within the system which could contaminate the EUV photomask.

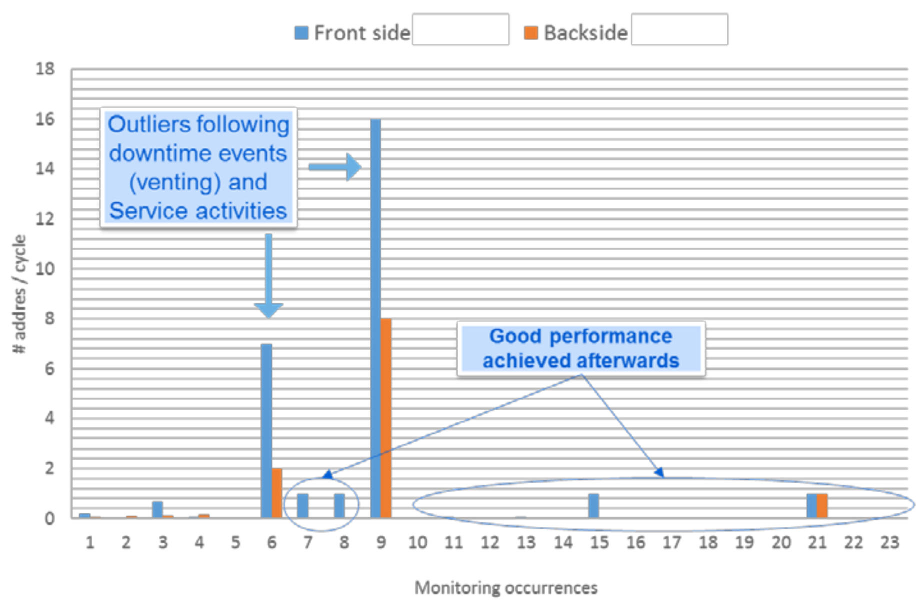


Figure 6: Particle contamination monitoring results. The number of adders per cycle is plotted in blue and orange for the mask front and back side respectively. Monitoring runs contain different number of cycles.

The particle contamination inside the AIMS^{TM} EUV tool is monitored constantly by customer in production environment. To carry out this monitoring, mask blanks are cycled in the machine from the operator load port onto the reticle stage and back. Within the loading and unloading cycles, dummy measurements are also executed with the EUV light spot well aligned on the mask blank, in order to closely emulate the measurement procedure and to identify potential sources of mask contamination. The results of the particle contamination monitoring run by Intel in the mask shop are shown in Figure 6. The sample blanks are measured for particles before and after the blanks are introduced into the AIMS^{TM} EUV system. The contamination result for each monitoring sequence is reported on the vertical axis in units of number of particle adders per load/measurement/unload cycle for each monitor, where the number of cycles may be varied depending upon the nature of the particle monitor being performed. The particle adders/cycle are reported separately for mask front side (absorber or patterned side) to ensure no printing defects are added, as well as for the mask back side, for which cleanliness assures the success of the electrical chucking onto the scanner reticle stage. The histogram in Figure 6 shows that the AIMS^{TM} EUV tool currently in production in Intel mask shop provides mostly low contamination and particle free runs. For completeness, two outliers were also reported in the same dataset (see monitoring occurrences 6 and 9): these high contamination results are resulting from cycles run right after tool down events which also involved venting of the vacuum chamber, for which service activities were run on the tool and a higher contamination is somewhat expected. This observation is confirmed and supported by the low contamination results achieved by cycles which were run before and after these outliers. Excluding the two outlier monitors measured immediately after the service activities, all other monitors have met the particle adder requirements for the system, confirming the good level of cleanliness of the AIMS^{TM} EUV system as fulfilling the contamination requirements for the mask shop production environment.

3.3. Metrology budgets monitoring: pupil and field illumination homogeneity

In order to guarantee the platform performance, measurement stability and image quality over time and across all different use cases, the system metrology embedded within the control system needs to establish and monitor budgets from the tool components which actively participate in the creation of the mask aerial image. In order to meet the required imaging specifications, such as measurement accuracy and reproducibility stability, the internal monitor budgets are assigned to meet, among others, illumination uniformity requirements both in the field and in the pupil. To confirm system illumination uniformity stability, normalized field illumination uniformity and pupil pole imbalance are routinely measured and assessed.

Field illumination uniformity

As opposed to the 193nm AIMS^{TM} systems, which employ a condenser lens inserted into the illuminator to provide Köhler type illumination, in which all rays coming from the light source are parallel in the object plane, the AIMS^{TM} EUV System employs a critical illumination scheme. By having a critical illumination scheme, the AIMS^{TM} EUV must assure that all inhomogeneity that may arise within the plasma source are compensated for in the creation of the product aerial image.

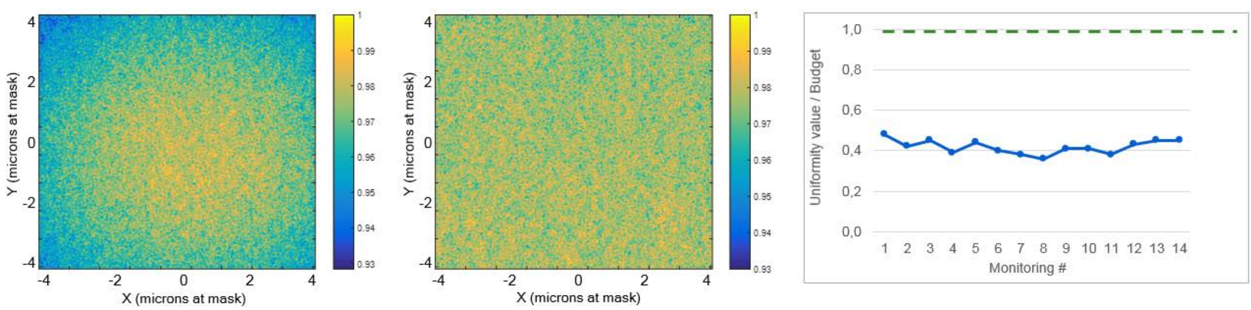


Figure 7: Description and monitoring result of the AIMS^{TM} EUV field illumination uniformity. Left: raw aerial image of a clear field on a EUV mask as acquired by AIMS^{TM} EUV (see text for features description). Center: clear normalized aerial image of the same mask reflective field. Right: Field illumination uniformity for all monitoring occurrences, values are normalized by the budget requirement.

The left panel of Figure 7 shows an exemplary 8μm by 8μm field of view image of a clear field on the mask as imaged by AIMS^{TM} EUV. The cloud shaped intensity structure is a direct image of the source light spot, which exhibits a radial intensity gradient across the field of view. This intensity gradient requires compensation to ensure an accurate aerial image across the field of view. In order to compensate for the difference between the actual imaging intensity distribution and the desired ideal uniform illumination of the full field of view (Figure 7, middle panel), the acquired measurement image is post processed to account for the measured intensity non-uniformity. The aerial images of defective areas or structures in the field of view are thus normalized by the aerial image of the collected clear field image. In order to provide excellent CD measurement repeatability, the system ensures that the uniformity of a normalized clear field constantly stays within budget. The stability of this normalized clear field uniformity is monitored by Intel in production and the results of this monitoring are displayed in the right panel of Figure 7, normalized to a budget of 1.0. It can be seen, that the uniformity of the AIMS^{TM} EUV field illumination remains stable over weeks of operation, and always very comfortably within metrology budget. Moreover, it is important to mention, that the measurements presented here are taken over a duration of ~2.5 months, during which consumables were exchanged and the tool optical path was re-adjusted multiple times.

Pupil illumination uniformity

The uniformity of the AIMS^{TM} EUV illumination is also guaranteed and monitored in the pupil. The intensity imbalance is measured in the horizontal and vertical directions for three pupil images as acquired on three different position on the mask: center, left and right edges (see left panel of Figure 8). The pupil taken at these positions are inherently different because of the various chief ray angle orientations corresponding to the NXE:33X0 and 34X0 arc shaped illumination slit. The pupil illumination uniformity budgets are designed to be fulfilled for all mask positions, and for this purpose the worst of the pole imbalance values is monitored and plotted in the right panel of Figure 8. From the results, it is clear that illumination uniformity budgets of AIMS™ EUV metrology are also fulfilled in the pupil, as well as in the field. It is finally noted that for CD measurements on the AIMS™ EUV system, the pole imbalance measured in the pupil is not as critical as the inhomogeneity measured in the field, as a limited pole imbalance mainly affects overlay and the placement of the pattern profile within the aerial image field of view.

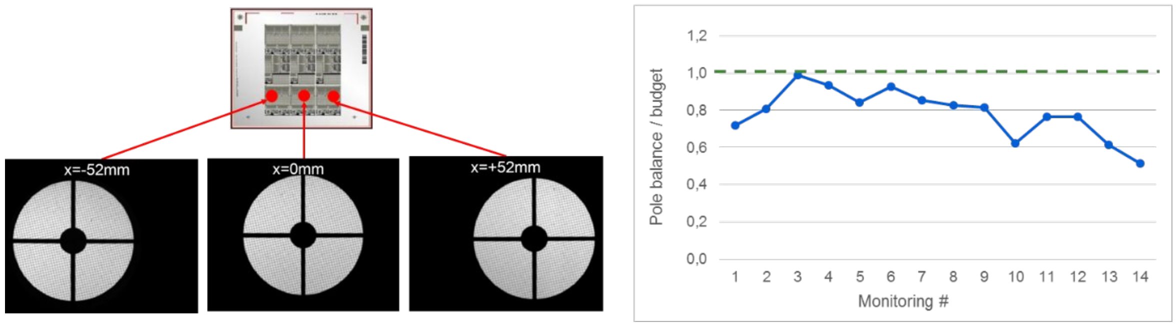


Figure 8: Description and monitoring result of the AIMS™ EUV pupil illumination uniformity. Left: an exemplary mask is shown on which three clear fields are selected for pupil measurements at the mask center and left/right edges. Below the respective pupil images. Right: pole imbalance as measured for the Quasi-Conventional pupil (NA=0.33, σ=0.20-0.90) for all monitoring occurrences, values are the worst between the three positions on the mask and are normalized by the budget requirement

3.4 Edge Placement Error stability monitoring

Since the first introduction of the AIMS™ EUV into the production flow of Intel mask shop, the EPE measurement stability is constantly monitored by the customer for a pre-defined set of programmed defects on a test mask, in order to assure the image quality and measurement results satisfy internal qualification requirements for defect disposition and repair verification. These four defects are intrusion and extrusion types (positive and negative ΔCD with respect to reference), and are manufactured within 2D structures like those reported in Figure 9.

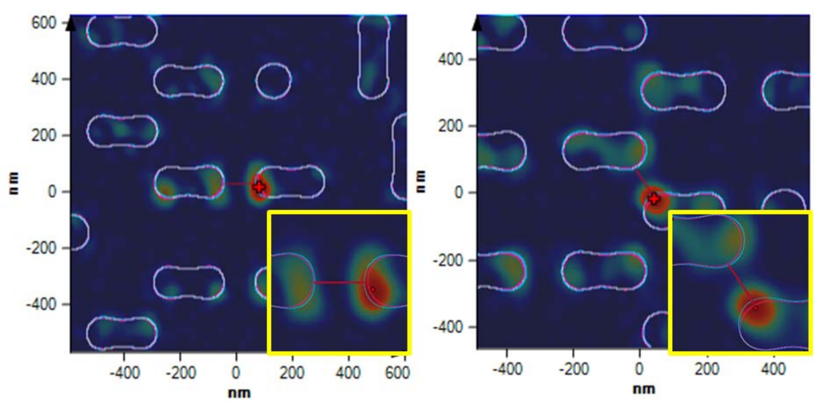


Figure 9: Defect – Reference difference aerial image and contours of two defect types used for AIMS™ EUV EPE measurement stability monitoring in Intel mask shop. The red cross highlights the defect center, whereas the defective area is displayed within the central area. Within the yellow frame, a zoom in the defective region is displayed.

Within this customer driven EPE stability monitoring, the aerial images of the four defects are acquired together with their corresponding references. Once the defect center of gravity is found by the analysis software (Figure 9 shows snapshots from the AIMS™ AutoAnalysis for EUV software interface), the slice (see red line in Figure 9, both panels) which goes through the defect center of gravity and connects the two closest bright features is selected. The CD of the dark area in between the two features is measured within this slice, and the difference with respect to the same feature CD in the reference image is taken as EPE value for one specific defect. The results of the monitoring of each of the four defects' EPE are reported in Figure 10: the left panel shows the EPE measurement values for each monitoring occurrence, the color code referring to the defect type as shown at the bottom right sequence of aerial image snapshots. The standard deviation analysis of each data points series (i.e. defect type/id) is also shown in Figure 10 as a histogram of 3σ values, normalized to the customer provided requirement, of EPE stability measurements run over 23 monitoring occurrences. The results show an excellent measurement stability performance over the existing AIMS™ EUV production lifetime, providing the customer with the confidence necessary for operating such an actinic tool in a production environment. It is clear from the results of the EPE stability monitoring that the AIMS™ EUV tool imaging stability meets the customer requirements and provides an excellent platform for actinic defect disposition and review of EUV photomasks.

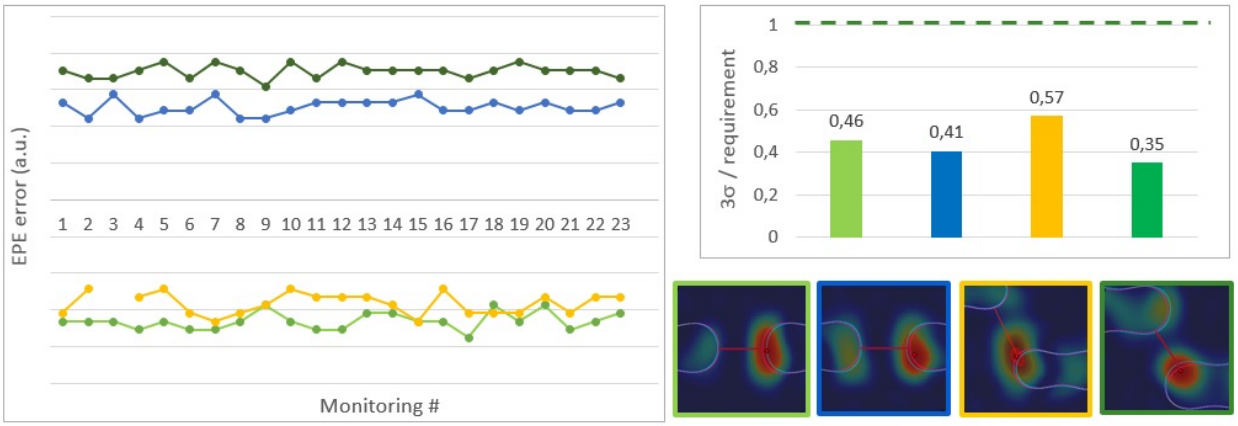


Figure 10. Left: Results of the EPE measurement stability monitoring, reported in arbitrary units. The four series shown in the plot refer to the four different defects analyzed by the monitoring, displayed at the bottom right with color coded frames. Right: statistical analysis of the EPE measurements for the four defects. The values reported are 3σ normalized to the budget requirement.

3.5 AIMS™ EUV – MeRiT® closed loop

To conclude the sequence of production data from the AIMS™ EUV tool at Intel mask shop presented in this paper, a demonstration of the AIMS™ EUV - MeRiT® closed loop has been run on an Intel programmed defect mask for an exemplary defect. Having the actinic review capabilities provided by AIMS™ EUV within the mask shop provides shorter turnaround times for the EUV production processes, as well as shorter time to market for the product itself. The printability of any defect type (absorber, particle, phase defect) can be assessed with full scanner emulation in one single exposure with full confidence, avoiding the setup and calibration of complex processes in which the defects are classified by other means of inspection, and their printability on the wafer estimated by a combination of metrology techniques and simulation tools, whose systematics may introduce an uncomfortable level of uncertainty in the final result.

For this specific demonstration, a ~500nm long (4x) extrusion programmed defect within a periodic line and space array has been selected, in which the nominal CD variation (before defect repair) is larger than 20%.

Figure 11 shows the sequence of measurements employed in this process. The pre-repair defect disposition is shown on the top row, in which the mask SEM image of the defect is displayed on the far left, with the programmed defect clearly visible in the center of the image. The AIMS™ EUV aerial image of the defect is displayed second from the left, sided by the aerial image of the reference acquired with the same illumination condition (sigma: Dipole-X). Second from the right is the difference of the two aerial images, in which the contours of the reference and defect are overlaid and the defect area is displayed within a closed red line. Pixel size slices used for the CD deviation analysis are placed within the defective bright feature and are shown in red (fail, $\Delta CD>8\%$), yellow (critical, $5\%<\Delta CD<8\%$), and green (pass, $\Delta CD<5\%$). Note that the printability tolerance criteria are configurable, and the criteria applied in this example are set arbitrarily by ZEISS during the aerial image analysis, for illustrative purposes. The sequence of data derived for the pre-repair step is concluded with the plot of the CD deviation measured for each slice selected in the difference aerial image, again with the same color code being applied.

The aerial image analysis has been executed with the fully automated AIMS™ AutoAnalysis EUV, a digital product by ZEISS enabling the customer to automatically identify and analyze the defect within AIMS™ EUV aerial images according to standard recipes and generate user customizable summary result reports [4]. Three advantages are clear for the customer production flow. First, highly repeatable results are provided thanks to a reliable and reproducible defect repair and repair verification. Second, the software adapts to the mask shop flow by providing customizable analysis strategies and reporting. Third, and finally, the software contributes to decreasing the turnaround time, since the data analysis runs in parallel, on a dedicated computing kernel, with the measurement acquisition, thus allowing engineers to have measurement reports available for review by the time the mask is unloaded from the tool.

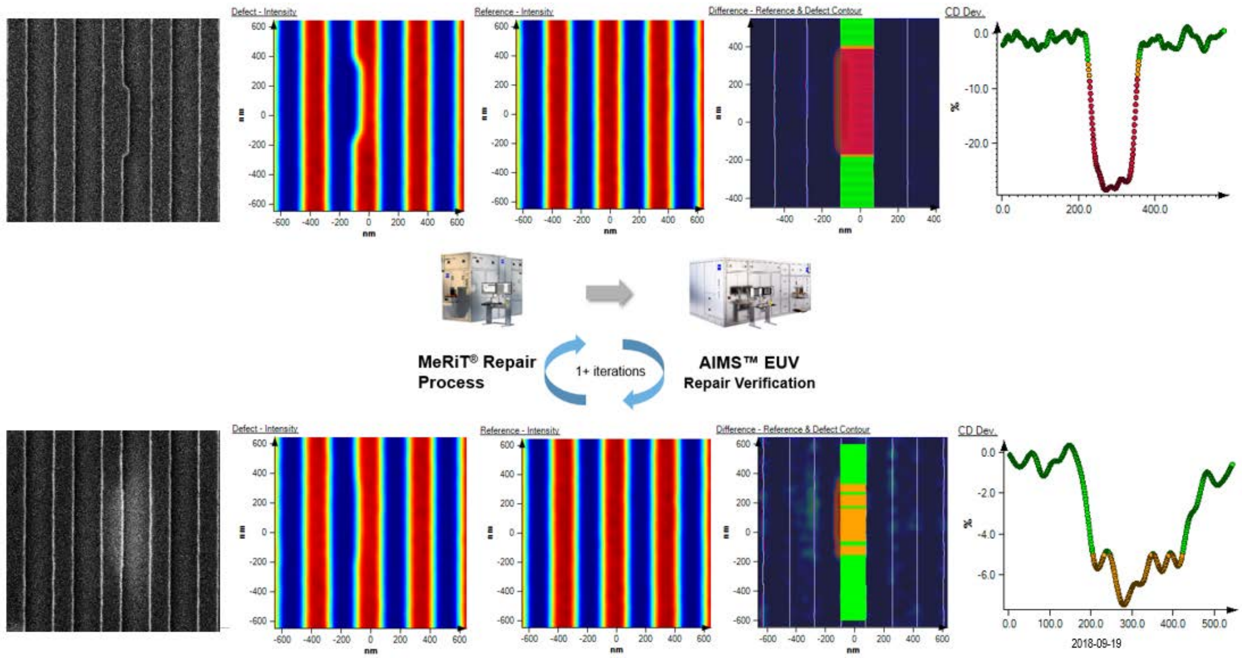


Figure 11. Top row: pre-repair loop. Bottom row: post-repair loop. From left to right: mask SEM image, defect and reference aerial images, defect-reference difference aerial image superimposed to both defect and reference contours in which the slices used for CD analysis are shown in red, yellow and green (respectively fail, critical and pass). The right panel in both rows shows plots of the CD deviation (%) of each slice along the vertical line, with the same color code as on the slice placement image.

With all data from the defect review step available, the mask was sent to the MeRiT® for repairing the defect with an etch process, following which the mask returned back to AIMS™ EUV to close the loop with the repair verification step. The post repair process steps are displayed in the bottom panel of Figure 11, with the same sequence as for the pre-repair sequence. First from the left, the mask SEM image of the repaired defect location is displayed, showing some residual etch process charging effects near the defective region which are visibly noticeable within the SEM image and which may contribute to the intensity measured in the aerial image. Next, the post repair aerial image of the defect shows a somewhat not ideally straight line, when compared to the same reference acquired for the pre-repair loop. This is confirmed by the CD analysis of the aerial image, in which some slices placed within the defective area (tolerance criteria for the post-repair are unchanged) still show some critical value of CD variation between 5% and 8% (see rightmost and second from the right plots in the bottom row of Figure 11). Whereas, an experienced operator might have judged the repair as outside of tolerance, due to the visibly perceivable CD distortion and charging, the AIMS™ EUV precisely qualifies the defect printability under scanner illumination conditions. According to the arbitrarily defined tolerance criteria for defect printability setup for this demonstration, the presented repair would be considered successful. The objective of the defect repair is not the replica of the mask structure; its only goal is to create the conditions on the mask so that the defect will not print on wafer [5]. The AIMS™ EUV assessment contributes, therefore, to the avoidance of unnecessary loops of repair and inspection metrology (SEM, AFM,…), which will increase mask manufacturing throughput due to their uncertainty in assessing the final wafer printability result.

4. SUMMARY AND OUTLOOK

In this paper, the performance and stability results of the first AIMS™ EUV system in production at Intel mask shop have been presented. The platform has demonstrated excellent stability and fulfills customer expectations:

- The results obtained at factory and final acceptance are very well comparable and well within the requirements for the acceptance tests.
- The EPE measurements before and after tool startup at customer site show excellent reproducibility.
- The embedded system metrology and EUV optics deliver excellent stability performance.
- The monitoring of the imaging performance in production shows very stable results (consumable swap and service activity included)
- The excellent quality and reproducibility of the AIMS™ EUV measurements have been demonstrated over time and different mask loads
- The AIMS™ EUV system availability since entering production at Intel shows AIMS™ EUV uptime larger than 65% on the first months of operation. Upcoming Software upgrades specifically targeted at platform usability will guarantee an increasing tool availability in the near future.

- Particle contamination control: the AIMS™ EUV system at Intel shows low contamination and mostly particle free runs.

Concluding, the AIMS™ EUV tool in production at Intel does not only meet its performance specifications, but it fulfills customer requirements to operate a tool ion a production environment.

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