# Aerial Image Measuring System at 193nm – a tool to tool comparison and global CD mapping

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## ABSTRACT

Reticle inspection and qualification is getting very important due to the overall shrinking feature sizes on chips and CD values less than the exposure wavelength. Mask defects will matter increasingly and successful defect disposition and image qualification is becoming essential to improve yield. Currently ongoing studies demonstrate the beneficial use of AIMS™** (Aerial Image Measuring System) -besides its application in mask shops like repair verification- for various wafer fab applications like Incoming Qualitiy Check (IQC), Automated Reticle Defect Disposition (ARDD)1, OPC verification or litho process evaluation in engineering without the use of stepper time and image qualification through wafer SEM evaluation.

Among the important questions for the use of an aerial image measuring system is the level on which different tools compare to each other in terms of critical system performance parameters in order to judge the results of the data analysis in a global way.

In this work we conducted a tool to tool comparison study of AIMS™ fab 193 systems investigating parameters like: Normalized illumination uniformity, CD (critical dimension) uniformity over field, and static CD repeatability over time in x- and y-directions. The study is based on the evaluation of a data base collected with typical feature sizes of 1µm on the mask, ensuring with such feature sizes that tool results are independent of mask features being close to the resolution limit or the printability capability. Typical settings are NA = 0.7 and circular sigma = 0.6 on a set of tools in the field as well as in-house.

In addition the performance of the tools will be discussed in terms of a specific application, global CD mapping, for use in process control. It can be applied for different use in wafer fab and mask shop environment.

**Keywords:** AIMS, aerial image, stepper emulation, numerical aperture, mask, reticle, tool matching, global CD map

## 1. INTRODUCTION

The AIMS™ is an optical system for evaluating reticles under specific exposure tool conditions as numerical aperture (NA), partial coherence of illumination (sigma), wavelength and illumination type. By adjustment of NA and sigma including illumination type to match the conditions in 193 nm exposure tools, the AIMS™ fab 193 can emulate steppers or scanners to investigate reticles designed for 193 nm lithography like binary, optical proximity correction (OPC) and phase shift masks (PSM). The image taken with the system is optically equivalent to the latent image incident on the photo resist of the wafer, but magnified and recorded with a CCD camera. Features of interest, like critical structures, reticle defects or defect repairs are measured as through-focus stacks, acquiring typically an odd number like seven

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images comprising intra-focal, conjugated extra-focal planes and the focal plane to predict the full lithographic behavior. Data analysis allows to evaluate transmission loss, line width changes, contours based on a threshold model as well as line width versus defocus and to predict exposure-defocus windows. Thus, the AIMS™ tool allows a rapid prediction of the wafer printability of a reticle without the need to do real wafer prints using the exposure tool and following SEM measurement of the printed features.[2,3]

The AIMS™ tools are highly automated and efficiently sensitive for production environments. Since the end of 2003 the 248 nm AIMS™ system, the AIMS™ fab plus, is available with mini-environment, a robotic reticle handling system and a better than class 10 mini-environment. Since August 2004 the 193 nm AIMS™ system, the AIMS™ fab 193 plus, is complementing the AIMS™ product group allowing the use of the systems in mask shops as well as in the lithography area of the wafer fab. Figure 1 shows the picture of an AIMS™ fab 193 plus, the automated AIMS™ system including mask handling as it is used for 193 nm optical emulation of steppers or scanners.

Fig. 1: Picture of an AIMS™ fab 193 plus, an automated AIMS™ system including mask handling as it is used for 193 nm optical emulation of steppers or scanners.

## 2. MEASUREMENT SETUP

With the use of the aerial measurement systems in both the wafer fab environment and mask shops the question about the bandwidth of measurement results of reticle features among different systems gets raised. Therefore a data base of measurements obtained on 15 systems was collected. Thereby results were taken in various stages after system integration in the factory and after dismantling and re-installation in off-factory sites. Measurements were done on binary test reticles with typical feature sizes of 1 µm on mask. The settings used are NA = 0.7 , sigma = 0.6 circular illumination for 1:4 optical stepper condition. The through-focus series has been done in step sizes of 2.1 µm x 7 planes to sufficiently cover the depth-of-focus range of the stepper or scanner. The smallest feature size which an exposure tool can print is determined by

$$feature.size = k_1 * \frac{\lambda}{NA}$$

with $\lambda$ being the exposure wavelength, NA the numerical aperture of the stepper or scanner and $k_1$ the process related factor. With the settings of NA = 0.7, $\lambda$ = 193 nm, and feature size being 1 µm on mask or 250 nm on wafer level $k_1$ = 0.9 is achieved. This $k_1$ value ensures with such feature size of 1 µm on mask level that tool results are independent of effects becoming evident when operating close to the resolution limit or the printability capability.

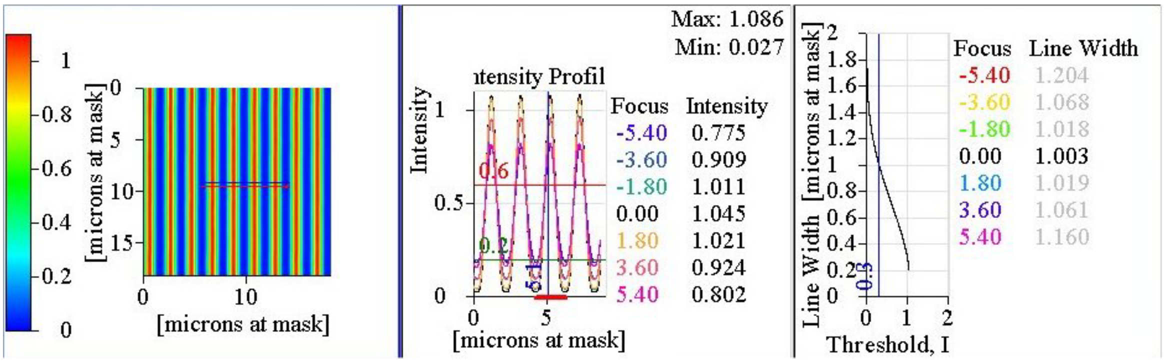

Fig. 2: CCD image at best focus of 1 µm lines and spaces on mask,
horizontal intensity profile of the through focus series and line width analysis.

Figure 2 (left side) shows the normalized aerial image of 1 µm lines and spaces on mask level taken at best focus. The picture in the middle shows the intensity profile for the focal layer and three conjugated out of focus planes. The indicated peak was chosen for line width evaluation. Based on a threshold model for a threshold value of 0.3 a line width of 1 µm on mask was determined. Static repeatability measurements on line width shown in the next chapter were taken by repeating measurements ten times at best focus. Uniformity measurements were taken by determining the 3 sigma variation between five points in the field of view using 4 corner points and one center point. Profile plots were averaged with 5 pixels width as indicated in Figure 2 (right).

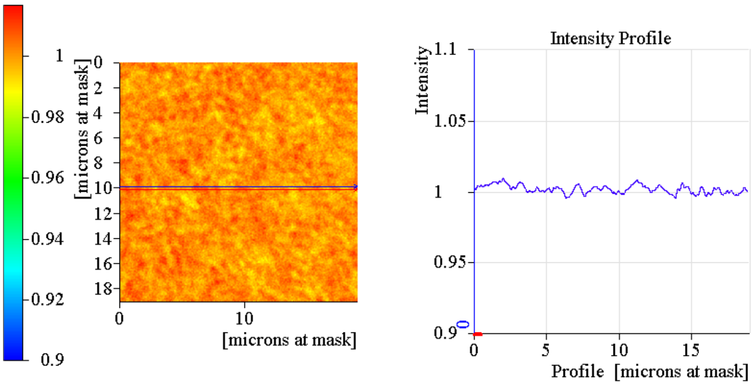

Fig.3: Normalized clear image and profile plot in horizontal direction.

In actual use a reference image is measured at a clear mask region. All measured images are normalized with such a reference image. The normalization eliminates any system dependent properties, such as field non-uniformity and image acquisition time, and allows a quantitative analysis of the mask properties for the given stepper or scanner settings. Figure 3 shows an example of a clear image which is normalized with a second clear image taken under exactly the same conditions of image acquisition and a horizontal profile plot is selected. From the intensity plot a minimum to maximum variation of 3.5% on the field homogeneity is found after normalization.

## 3. RESULTS AND DISCUSSION

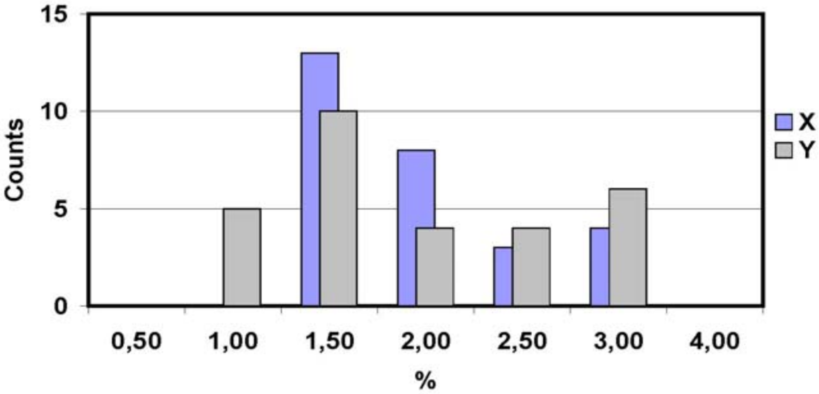

Fig.4: Variation of normalized field homogeneity values of clear area achieved for analysis in x and y direction

Normalized clear field measurements are used to determine the field illumination quality which is influenced by speckles of the laser light illumination, field homogenizer, pupil illumination and the optical system performance. Figure 4 shows a set of available data for 3σ values of field homogeneity on various tools at factory and field installations for analysis in horizontal (x) and vertical (y) direction in the image. It can be seen that most tools provide results in a range of 1.5% to 2% and all tools are below 4% variation independent of the profile selected between x and y direction.

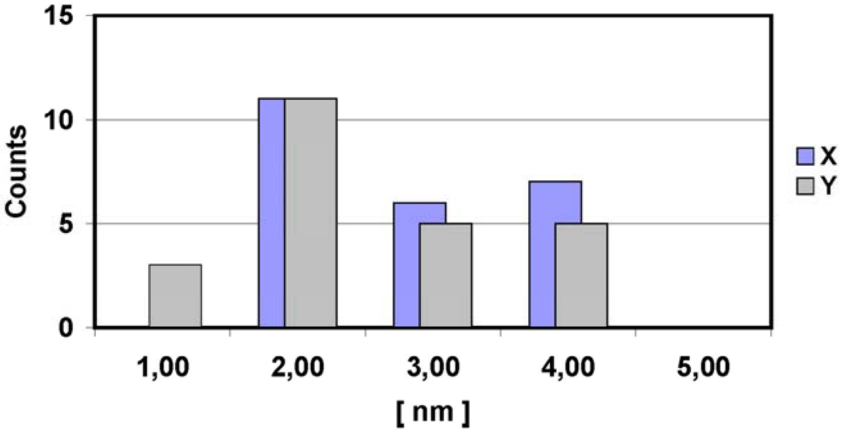

Fig.5: Static CD measurement repeatability achieved on various tools for analysis in x and y direction

Static line width or CD repeatability measurements are a measure for system stability from mechanics, vibrations and beam stability over time. Figure 5 shows a set of available data for 3σ values of static CD repeatability on various tools at factory and field installations for analysis in horizontal (x) and vertical (y) direction in the image. The data are scaled to wafer level taking 1:4 mask reduction into account. It can be seen that most tools are in a range of 2nm to 3nm and all tools are below 4nm variation independent of the profile selected between x and y direction.

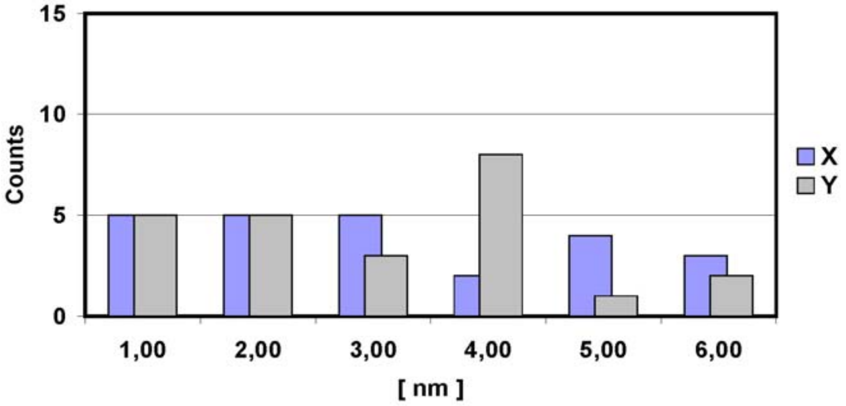

Fig.6: CD measurement uniformity achieved on various tools for analysis in x and y direction

Figure 6 shows a set of available data for 3σ values of CD measurement uniformity on various tools at factory and field installations for analysis in horizontal (x) and vertical (y) direction in the image. The data are scaled to wafer level taking 1:4 mask reduction into account. It can be seen that most tools are below 4nm and all tools are below 6nm variation independent of the profile selected between x and y direction. The CD uniformity values depend on the one hand on illumination uniformity on the other hand they can also depend on the mask quality issue which is discussed in the next chapter.

## 4. APPLICATION

A new software feature called "global CD mapping" for investigation of the mask quality has been introduced and added to the AIMS™ software package. Features of the exact same geometry or size which are repeated on the mask are measured automatically and the trend of the line width variation over space is visualized through a color coded "CD map" of the reticle. Specific points can be randomly selected across the reticle or within a specific area on the reticle to automatically measure and generate the global CD uniformity map. For this task the AIMS™ tools are newly set up with software providing a recipe operation. Lithographic settings, image parameters, mask coordinates and alignment marks, tool configurations, etc. can be predefined and stored in a single recipe. The tool can automatically set up the mask and measure in an inspection mode the pre-defined points to generate the global CD maps. The CD values for generating the global CD map are automatically extracted from the various images measured. The demonstrated stability and uniformity specifications found from tool to tool as discussed in the previous chapter are important to achieve reliable mapping results based on an automated series of measurements.

Figure 7 shows a 1:1 lines and spaces aerial image and the initial slice selected to do the CD evaluation (upper left corner). A global CD map is created from 9 measurement points defined within a field of 300 µm x 150 µm on the mask. The measurement points in the field are indicated with the marks in the global CD map. The measurements were done with the AIMS™ fab 193 with NA = 0.7 and a circular sigma = 0.8. The features are lines and spaces determined to 186 nm feature size of the spaces on wafer level using the threshold model (lower left corner). In the lower right corner the global CD map shows that the horizontal CD uniformity is very good within this field, however in vertical direction we can find a change of up to 29 nm over 261 nm on mask. As we have the measurement capability of better than 6nm CD uniformity on the tools this result can be related to the mask quality.

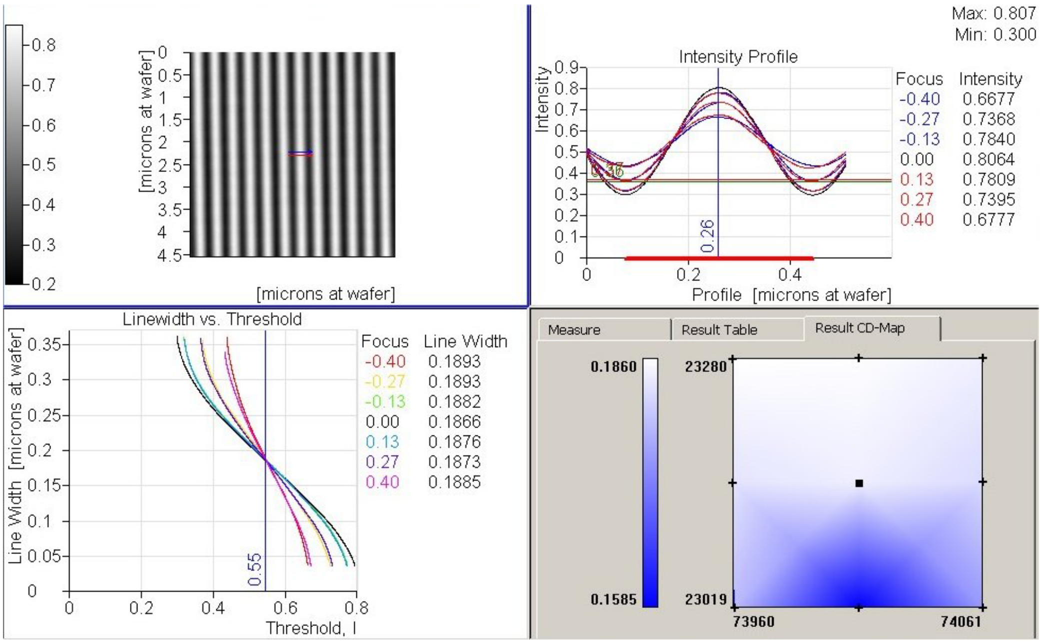

Fig.7: Setup of CD measurement and global CD map result

In a further investigation we used a mask with 15 dies and repeating patterns of contact holes. Figure 8 shows a sketch of the reticle and each aerial image taken in the respective die for use of CD measurement. In the upper left picture a box is shown which boarders 4 contact holes. The four contact holes were evaluated for their horizontal CD value and averaged. Automatically all pictures were correlated with sub pixel resolution and the same evaluation procedure repeated for each image. Figure 9 shows the resulting global CD map. Each cross indicates the respective measurement field on the reticle. An average CD value of 252 nm on wafer level was found. The overall variation on the mask is between 248nm and 256nm. In this investigation there is a trend to larger CD values found from the lower left corner to the upper right corner.

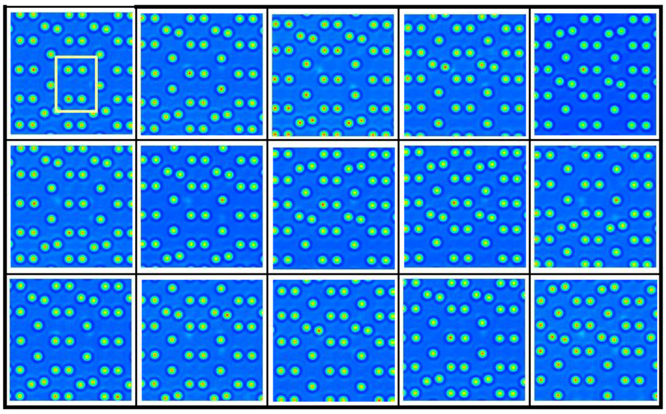

Fig.8: The picture is indicating the 15 dies of a mask and shows the aerial images in the focus plane taken in each die for evaluation of the global CD behavior

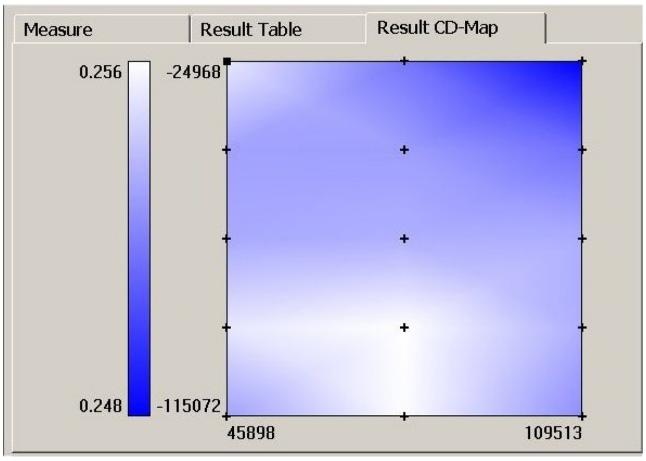

Fig.9: Global CD map for contact hole mask

In further measurements we have repeated CD maps generated on the same mask features with the mask rotated 180° in the tool. The equivalent CD maps have been generated with less then +/- 2 nm CD value deviation which proves that the results depend on the masks.

The creation of global CD maps is very beneficial to control if problems occurred during the mask manufacturing process and allows to investigate the global uniformity behavior across a full reticle.

In the wafer fab establishing global CD maps on reticles allows to predict the impact on the common process window. If repeating features print non-uniform on wafers, the CD map allows to distinguish whether such an effect is resulting from the reticle itself or the wafer manufacturing process like the resist.

## 5. SUMMARY

The overall tool analysis has shown that all tools can be brought into 3% or better normalized field uniformity, less equal 6nm CD uniformity and less equal than 4nm CD repeatability. This performance level allows to execute global CD (linewidth) mapping in an fully automated inspection mode which was demonstrated for a specific small field on the reticle and globally for a full reticle.
Global CD mapping on AIMS™ was demonstrated to support both reticle and lithographic process analysis.

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