Application results at 193nm: Lithography emulation by aerial imaging and supplementary high resolution measurements

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ABSTRACT

The "AIMS™ fab 193"[2] tool is an aerial image measurement system for ArF-lithography emulation and is in operation worldwide. By adjustment of numerical aperture, illumination type and partial coherence parameter to match the conditions in 193nm steppers or scanners, it can emulate lithographic exposure tools for any type of reticles such as binary masks, OPC and phase shift structures, down to the 65nm node. The AIMS™ fab 193 allows the rapid prediction of wafer printability of critical features, such as dense patterns or contacts, defects or repairs on masks without the need to prepare real wafer prints using the stepper or scanner. Recently, a high resolution mode has been introduced based on a sophisticated microscope objective, characterized by a high numerical aperture (NA) and large working distance that allows working with pellicle mounted mask. With this lens system a high contrast image with resolution down to 150 nm lines and spaces (L/S) on mask has been demonstrated. In addition to the AIMS™ through-focus mode for printability which is optically equivalent to the latent image in the photo resist of a wafer, the high resolution mode allows the imaging of mask structures in focus and at printing wavelength to review defects or repairs. Such viewing capability is also helpful at the binary stage of a first writing step in the mask manufacturing process. In this work we will present application results for defects and critical features using both, aerial imaging and high resolution mode.

Keywords: aerial image measurement, AIMS, photomask, reticle, immersion, high resolution inspection, polarization, PSM, phase shift, OPC, global CD map

1. INTRODUCTION

The principle of measuring the aerial image was introduced in a commercially available system for semiconductor applications first by Carl Zeiss ten years ago based on the groundbreaking work at IBM's R&D center [1,2]. A decade is a very long time in the fast evolving semiconductor industry and the "Aerial Image Measurement System" ("AIMS™") has evolved accordingly to keep pace with industry demands.

The so called "AIMS™ fab" systems are available either with 248 nm or 193 nm light sources and support the latest requirements of mask shops as well as the highly automated and efficiency sensitive production environment of wafer fabs. Figure 1 shows the latest AIMS™ fab 193 system including the option of robotic reticle handling and SMIF capability. It is a characteristic of all AIMS™ systems that the litho parameters "numerical aperture", "illumination type" (circular and off-axis such as annular, dipole or quadrupole etc.) and "partial coherence" can be adjusted over a wide range in order to emulate various steppers or scanners. This allows for the evaluation of any type of reticle, binary including OPC features and PSM for example. The aerial image recorded by the system is optically equivalent to the

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The 21st EMLC 2005, Dresden, Germany

latent image on the photo resist of a wafer, but magnified and rapidly captured with a CCD-camera. The field of view is recorded as a through-focus stack with several aerial images in order to provide full depth-of-focus information.

Recently, the first systems of the 2nd generation of this tool family were brought into operation. As with the previous units all tool settings can be executed automatically and the overall system is operated through a software interface and a control panel. The new generation systems now feature significant improvements in electronics, software and optics to fulfill the demanding requirements of the 65nm node [3]. The development of the optics train was focused on improving the homogeneity of the pupil illumination and thus the overall field homogeneity over time as well as over the exposure field of view. Figure 2 shows an example for the field homogeneity over time. A clear image has been taken and normalized with a reference clear image in the same field of view. Every 5 min a clear image measurement was repeated for one hour and normalized with the first clear reference image. It can be seen that the time dependent change is < +/- 1.5%. A simplified internal electronics bus system was utilized to improve the communication between the controllers of single components at a low level in order to execute the commands for the component adjustments faster and more reliably. This also allows for the system controlling software to take advantage of the faster communication on component level and improve the adjustment and measurement time and thus the overall throughput.

The challenge of the emerging immersion technology are currently addressed in two ways: Extended depth of focus effects – by introducing a fluid with higher diffraction index in the lens space between the last lens element of the projection optics and the wafer surface – can be taken into account with software already. Secondly, the development of polarizing components for the illumination unit are under way [4].

Fig. 1: Picture of an AIMS™ fab 193 plus, an automated AIMS™ system with a better than class 10 mini-environment and a robotic mask handling unit. Recently, the first systems of the 2nd generation of this tool family were shipped to customers.

The AIMS™ systems are very well established in mask shops around the world, mainly in the field of defect analysis and repair verification, where AIMS™ data of repair sites is provided to customers of mask shops as an industry standard. Defects and repairs are analyzed and printability classification performed for their lithographic significance, also known as defect disposition. Just recently introduced in wafer fabs, there are several applications being further developed such as the field of on-going reticle qualification in the face of "crystal growth" or "progressing" defects. In the so called "Advanced Reticle Defect Disposition" or ARDD process [5], the actinic through-focus capabilities of the AIMS™ system are utilized to make final printability assessments of these types of defects to enhance the utilization time of reticles and contribute to optimizing mask costs [6]. Other applications include mask R&D work where main structures and their sub resolution features or optical proximity corrections (OPC) are assessed for their printability on the wafer. Global CD maps can be generated to investigate the global linewidth or CD uniformity in a region or across the whole mask [7]. Process optimization can be performed based on the variable, fast changeable settings including different illumination types which are available in any customized patterns.

Especially for defect inspection and OPC analysis a high resolution image can deliver complimentary information of mask defects. Such a high resolution image can be achieved by an additional high NA objective lens mounted in the AIMS™ lens turret. It is obvious, that such a high resolution mode implemented in the AIMS™ will be strongly beneficial for the mask maker.

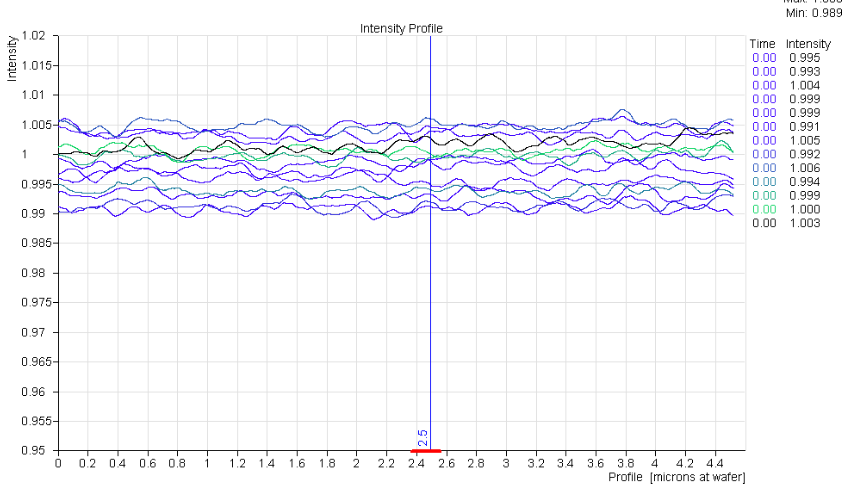

Fig. 2: Profile plots of normalized clear images repeated every 5 min over 1h on the AIMS™ fab 193 2nd generation. The settings are numerical aperture NA = 0.69 and pupil filling σ = 0.6 circular.

2. HIGH RESOLUTION MODE

The high resolution mode is realized by an objective which is a hybrid objective combining diffractive and refractive lens elements that allow a very compact lens design despite of the complexity of the short wavelength, material selection and the requirement for cement-free design [8]. The hybrid objective works at wavelength λ = 193 nm and is made for use on the AIMS™ fab 193 in transmission mode. It has a magnification of 50x, a numerical aperture NA = 0.65 and a working distance > 7.8 mm. The use of the same wavelength as the exposure tool is beneficial since the contrast depends on the optical properties of the mask material which are optimized for their use at that specific wavelength. The high resolution is given by the fact that the smallest separation between two object points that will allow them to be resolved is scaling with λ/ NA. Various measurements have proven that lines and spaces down to 150 nm half pitch on mask can be resolved [8]. Figure 3 shows two lines and spaces pattern of 200 nm and 150 nm on the mask. The working distance of 7.8 mm allows the investigation of masks with and without a pellicle.

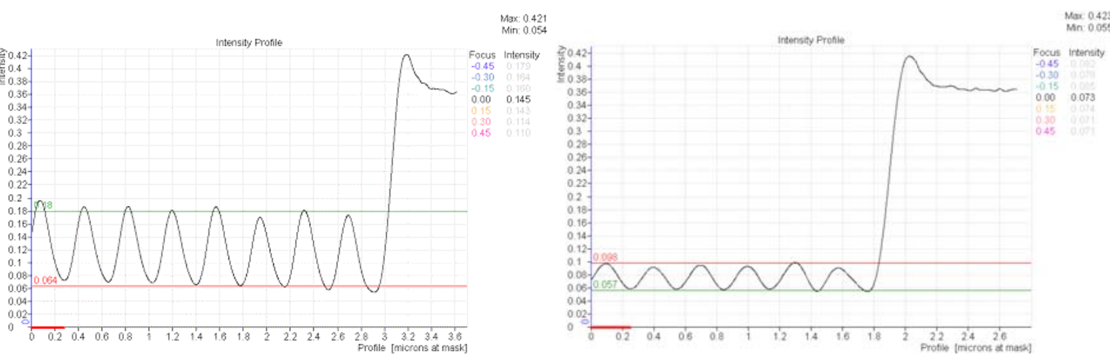

Fig. 3: Intensity profiles of 200 nm (left side) and 150 nm (right side) lines and spaces patterns on a binary mask. The measurements are done in high resolution mode on AIMS™ fab 193.

3. MEASUREMENTS AND DISCUSSION

Measurements have been performed on various samples in order to show both aerial image and high resolution images for specific features. We have investigated:

- Contact hole pattern of a MoSi phase shift mask
- A printing chrome defect on a binary mask
- Assist features and serifs of two different sizes on a binary mask

Figure 4 shows the normalized aerial image of a 400 nm line and space contact hole pattern on an attenuated phase shift mask on the left side. On the right side we see the high resolution image. The contacts are clearly displayed with an upper and lower end showing enlargement due to OPC and higher transmission. Assist features can be seen between the contacts.

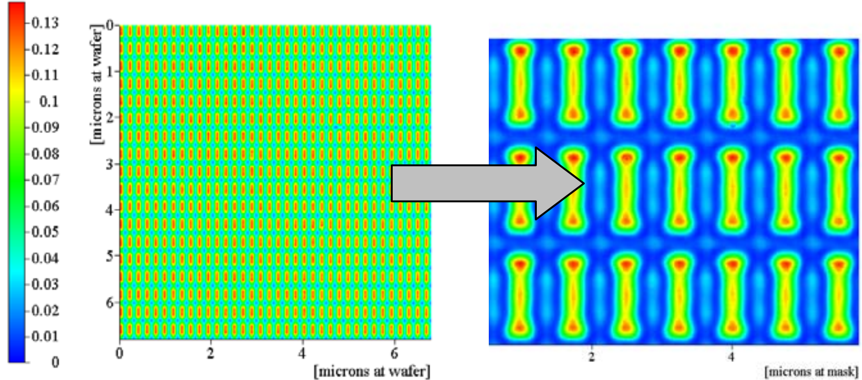

Fig. 4: Image comparison of 193 nm aerial image at wafer level (λ = 193 nm, NA = 0.8, sigma = 0.8 circular) and high resolution review at mask level of an active layer

Figure 5 shows the high resolution image of a chrome pattern. In the center part of the image we can see a chrome extrusion which causes a defect. From such images area calculation can be made. We have calculated a defect size of 0.15 μm^2. Such defects can also be viewed and accessed on masks which have multiple write steps before an aerial image formation will be applicable.

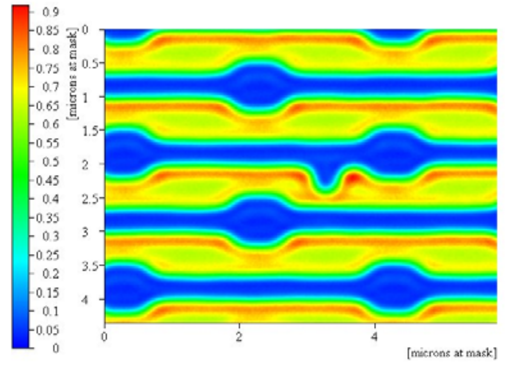

Fig. 5: Defect review of chrome extrusion with high resolution mode at 193 nm wavelength.

Figure 6 shows the layout of chrome test patter with binary mask features. The structures are shown as a positive image. Figure 7 displays the corresponding high resolution image derived from it. We have measured various positive and negative (bright) features on a test reticle in order to investigate the high resolution capability. Below we will discuss two different negative features of different main feature sizes, assist feature sizes and serif sizes:

- 600 nm main features, scatterbars 200 nm on the left side / 160 nm on the right side and 160 nm serifs
- 400 nm main features, scatterbars 120 nm on the left side / 100 nm on the right side with 100 nm serifs

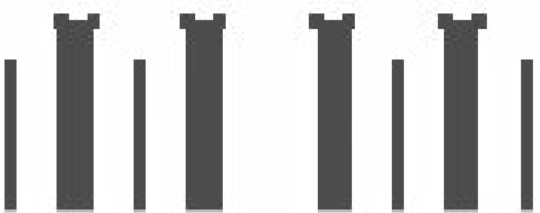

Fig. 6: Layout of chrome test patterns on clear area to investigate serifs of main structures and assist features in high resolution mode.

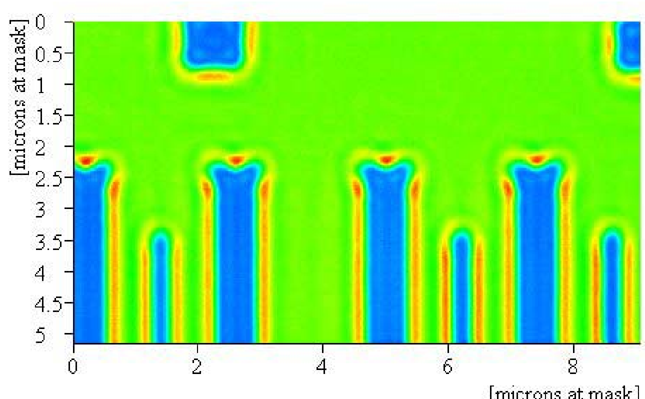

Fig. 7: High resolution image of chrome pattern on clear area. Main structure size is 600 nm on mask.

In the table of figure 8 the comparison of aerial image measurements and high resolution mode is made. For further visualization contour plots are also generated. Applied to the high resolution mode the contour plot provides a simplified view how the mask pattern looks. Applied to the aerial image the contour plot provides a simplified view of how the latent image will later print on the wafer.

For both feature sizes, 600 nm and 400 nm on mask, the aerial image shows four distinct lines which are printable. In the spaces transmission of assist features can be seen, however their transmission is below the printing threshold which was selected at 0.6. This fact can be seen in the contour plot. Applying the high resolution mode the assist features become visible between the main structures. For the 600 nm feature the line ends show clearly the serifs at the left and right corner. They can be seen at the ends of all lines as it is expected for a defect free pattern. For the 400 nm structures the serifs are not fully resolved anymore as they are having a size of 120 nm. However, due to the diffraction effects of the serifs an optical proximity effect is still visible and the line ends are distinctly visible in the contour plot. The corners are slightly domed to the outside displaying the feature with a flat line end. Thus from the high resolution contour plot it is obvious that there are no defects in either the left or right corners which would make the corner rounding worse especially in the aerial image formation.

	Measurement @ 193nm	Contour Plot
Structure: 600nm Scatterbar: 160nm/ 200nm Serif: 160nm	Aerial Image	
	High Resolution Mode	
Structure: 400nm Scatterbar: 100nm/ 120nm Serif: 100nm	Aerial Image	
	High Resolution Mode	

Fig. 8: Comparison of aerial image measurements and high resolution mode.
The AIMS™ settings are λ = 193 nm, NA = 0.92 and σ = 0.6 circular.

SUMMARY

The AIMS™ fab 193 2nd generation systems for stepper or scanner emulation up to NA of 0.92 have been introduced to the market. These systems fulfill the requirements of the 65nm node for dry and immersion lithography emulation. Extended depth-of-focus software will allow the emulation of the effects from the immersion liquid and a linear polarized illumination capability is under development to become available with an upgrade of the illumination unit. This will be of benefit to allow early mask R&D work in regards of polarization effects.
Supplementary to the aerial image capability a high resolution mode is available to review structures, defects and defect repairs, both printing and non-printing, in more detail. Due to the increased resolving power a fast and cost saving alternative to SEM imaging is now available, but under the exact lithographic wavelength in any given field of view. Finally, it is shown in this work that serifs and assist features can distinctly be visualized in contour plots and assessed on quality.

ACKNOWLEDGEMENT

The authors would like to thank Oliver Kienzle, Mark Joyner, Wolfgang Harnisch, Thomas Scherübl and Peter Schaeffer for their discussions related to the topics.

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