Printability study with polarization based AIMS™ fab 193i to investigate mask polarization effects

Axel Zibold[a], Ulrich Stroessner, Eric Poortinga*, Rainer Schmid, Thomas Scherübl,
Norbert Rosenkranz, Wolfgang Harnisch

Carl Zeiss SMS GmbH, Carl Zeiss Promenade 10, 07745 Jena, Germany
* Carl Zeiss SMT Inc., Thornwood, 10594 NY, USA

ABSTRACT

Immersion lithography offers the semiconductor industry the chance to extend the current ArF processes to smaller nodes before switching to a shorter wavelength. The move to immersion will require increased attention to the photomask along with new effects influencing the aerial image formation as the numerical apertures (NA) of scanners move up to at least 0.93 and even higher. Feature sizes on the photomask become comparable or even smaller than the wavelength and hence act more like wire grid polarisers which lead to polarisation effects. As of today AIMS™ fab tools are in operation worldwide. The novel AIMS™ fab 193i tool with a maximum NA of 0.93 is the latest aerial image measurement system for ArF-lithography emulation down to the 65nm node. Common adjustments are numerical aperture, illumination type and partial illumination coherence to match the conditions in 193nm scanners. In addition to non-polarized illumination, the AIMS™ fab 193i allows the user to select linear x and y polarised light for different settings and types, e.g. off-axis annular, quadrupole or dipole illumination. In this paper the polarisation effects of different photomask features are explored by comparing measurement results using linear polarised illumination parallel and perpendicular to line and space patterns and non-polarised illumination. Different MoSiON embedded phase shift masks have been investigated at the highest possible NA=0.93 and for different half-pitches from 500nm to 260nm, the latter corresponding to the 65nm node at the wafer level.
Keywords: aerial image, AIMS, immersion, polarization, numerical aperture, hyper NA

1. INTRODUCTION

The AIMS™ is an optical system for evaluating reticles under the specific stepper or scanner settings of wavelength, numerical aperture (NA), partial coherence of illumination (sigma: σ) and illumination type such as annular, quadrupole or dipole.[2,3,4,5] The latest AIMS™ tool is the AIMS™ fab 193i which offers advanced capabilities to emulate dry and immersion scanners for NA up to 0.93. Figure 1 shows a picture of the AIMS™ fab 193i plus which is equipped with mini-environment, mask handler and SMIF mask loader.

Fig. 1: Picture of an AIMS™ fab 193 plus, an automated AIMS™ system including mask handling.

[a] zibold@smt.zeiss.com

This second generation tool has undergone a series of major system improvements. An increased system stability, new beam homogenisation and energy monitoring provide new performance parameters such as long-term illumination stability with drifts less than 2.5%/h and CD repeatability in the 1nm range at the wafer level.[6,7,8] Table 1 shows measurement results on a binary test mask with static line width/CD repeatability (10 times repeated) based on isolated and dense lines of 100nm and 80nm at wafer level (sample 1) and results on a MoSi test mask for 100nm at wafer level (sample 2). Profile plots have been extracted for the center line of a line and space test pattern and line width was determined using the threshold model. The 3σ values show very good performance of 0.7nm and 0.6nm for the binary mask (sample 1). It can be seen as contrast drops significantly due to closer vicinity to the resolution limit (80nm pattern of sample 1) or the 100nm pattern of the MoSi mask that the 3σ value increases by a factor of two.

static CD repeatability			
		Sample 1	Sample 2
100 nm isolated	<CD>	99.9nm	
	3*sigma	0.7nm	
	contrast%	82%	
100 nm l&s dense	<CD>	100nm	100nm
	3*sigma	0.6nm	1.4nm
	contrast%	63%	42%
80 nm l&s dense	<CD>	80nm	
	3*sigma	1.3nm	
	contrast%	36%	

Table 1: Static CD repeatability results (10x) on two masks, NA0.8, off-axis illumination, measured on AIMS™ fab 193i.

With these specifications the tool enables wafer level printability analysis for 65nm node masks with appropriate high numerical aperture (NA0.9x) and contrast. In addition to these improvements the systems takes into account that scanners using an immersion liquid provide an extended depth-of-focus and thus increase the process window. Optionally the process window or process latitude analysis can be shown for dry and immersion conditions. This is discussed in detail in a previous paper.[7]

With printable feature sizes becoming so small on the wafer, scanners are required to use numerical apertures approaching 1 and with use of immersion liquid achieving even values above 1 (hyper NA). It is generally known that polarisation effects from imaging will occur. They result in a loss of contrast for the p-type (TM) polarised light contribution whereas s-type (TE) contributions are imaged without contrast loss.[9] To optimize the printing process it matters for scanners to work with s-type polarization such as dipole off-axis illumination combined with linear polarization vector perpendicular to the dipole axis or with tangential polarization schemes. In addition photomask induced polarisation can even enlarge p-type polarized light contribution since photomasks can act like wire grid polarisers[10,11] and enhance the contrast loss in the resist. Therefore it is important for mask inspection and evaluation that the mask has to be observed with the right polarization. In this paper the focus is on a study of polarisation effects from masks with different polarization directions in the illumination setting.

2. MEASUREMENTS AND DISCUSSION

Measurements were taken at NA=0.93 on a MoSiON reticle with 1:1 260nm (75nm) half-pitch on mask (wafer).

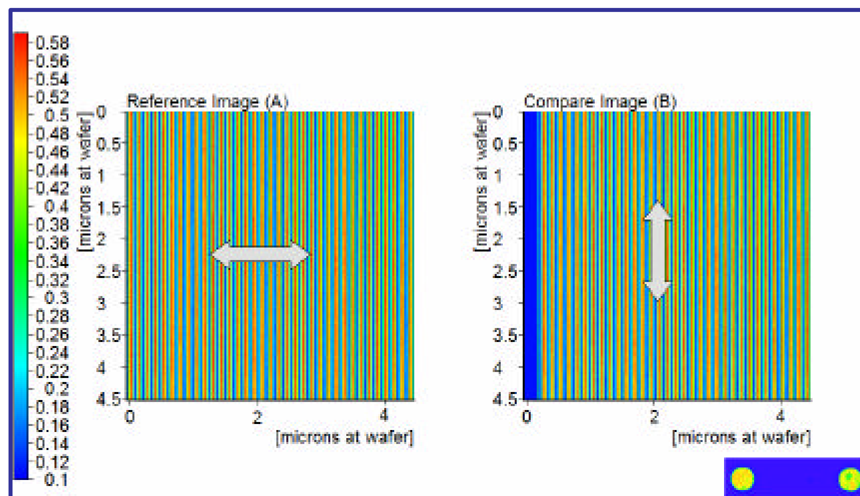

Fig. 2: Investigation of mask polarisation effects based on lines and spaces MoSiON 1:1 260nm ½ pitch. Settings: λ=193nm, NA=0.93, σ=0.98, dipole 15%. Polarisation in illumination was selected perpendicular (left image) and parallel (right image) to lines and spaces. The inset shows the applied dipole illumination in the pupil.

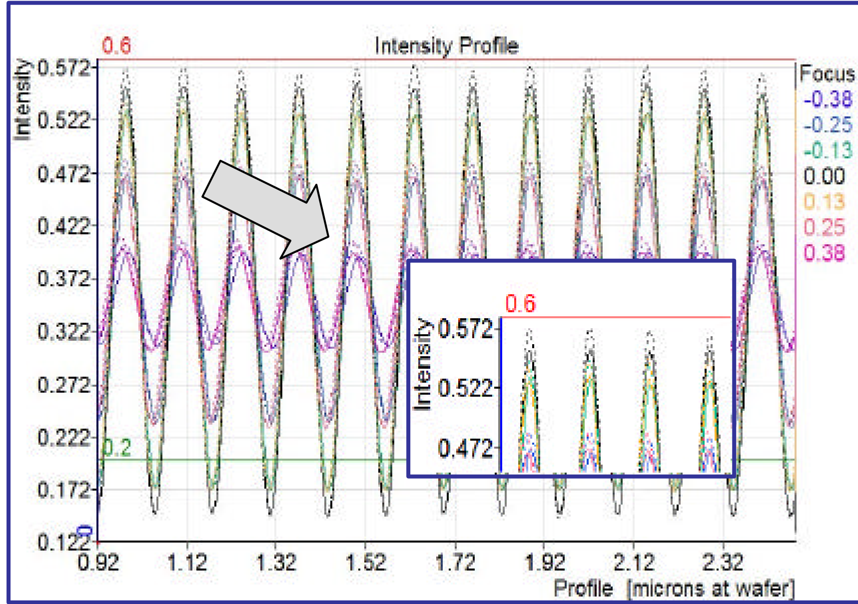

Fig. 3: Investigation of mask polarisation effects based on lines and spaces MoSiON 1:1 260nm ½ pitch. Profile plots were taken on images in Fig 2 and overlaid. Polarisation perpendicular (solid line) and parallel (dashed line) to lines and spaces is shown. Result for each the 7 planes of the through focus measurement is shown.

The lines and spaces (l&s) are oriented in the vertical direction, the dipole was applied in the horizontal direction and polarised illumination was either parallel or perpendicular to the lines and spaces. Fig. 2 displays the measurement results. Through focus AIMS™ measurements were taken and the aerial images displayed for the (best) focus plane in the two polarization directions. In order to analyse the effect of polarisation coming from the reticle intensity profiles were selected perpendicular to the l&s and overlaid for the two different directions of polarisation. From figure 3 we can see that the direction with polarisation parallel to the lines and spaces shows an increase of peak intensities whereas the minima are only slightly affected. Relative changes of the intensities or the diffraction limited transmittance are in the order of 4% to 5% which is safely in the sensitivity range of the AIMS™ fab 193i (limit <2%). Comparison of non-polarised and linear polarised light illumination parallel to the l&s (parallel polarisation) have shown about 2% to 3% change in transmittance to higher values in the polarised case. Whereas effects are seen for the transmittances calculation of contrast differences between parallel and perpendicular polarised linear illumination have shown negligible results. Defining a Principal Transmittance Ratio (PTR) at the mask level based on

$$PTR = \frac{k_1}{k_2} \qquad \text{where} \qquad k_1 = \frac{T_{TM_{OUT}}}{T_{TM_{IN}}}\ ,\ k_2 = \frac{T_{TE_{OUT}}}{T_{TE_{IN}}}$$

we can find with the approximation $T_{TM_{IN}} \cong T_{TE_{IN}}$ a value of PTR of 0.96.

PTR describes the polarisation efficiency or contrast of the polarising element. A mask that induces polarisation would show a PTR value less or greater than 1.0. An optical element that does not polarise incident light would have a PTR value of 1.0. Greater than 1 means the transmission efficiency of incident TM polarization is greater than that of TE. A perfect polarizer that passes 100% of the TM incident light and blocks 100% of TE incident light would have a PTR value of 8. In case for our example which shows a value less than 1 (0.96) we find a polarization effect of the mask in favour of the desired scanner illumination.

In a further investigation we have analysed a MoSiON reticle with test features showing different half pitches between 260nm and 500nm. The lines and spaces (l&s) were all oriented in vertical direction, the dipole was applied in horizontal direction and polarised illumination was either parallel (x) or perpendicular (y) to lines and spaces. Through focus AIMS™ measurements were taken and for each profile plot an averaged intensity value in best focus was determined for the different polarization directions (x,y) and non-polarized (u). In addition from determining the averaged minimum value for each profile plot a contrast was calculated based on

$$C_{x,y,u} = (T_{max} - T_{min} / T_{max} + T_{min})_{x,y,u}$$

The results are shown in figures 4 and 5.

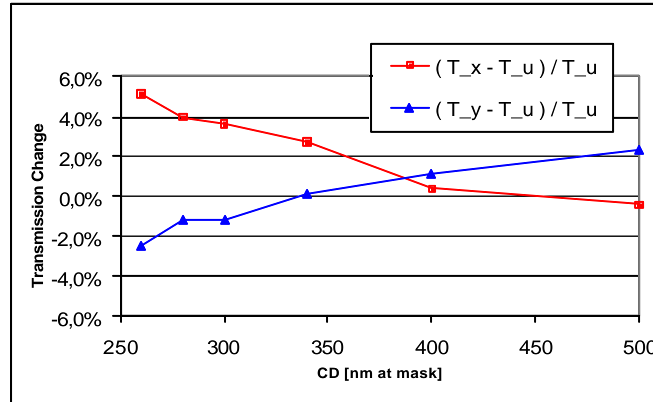

Fig. 4: Investigation of mask polarisation effects based on lines and spaces MoSiON 1:1 260nm to 500nm ½ pitch. Settings: λ=193nm, NA=0.93, σ=0.98, dipole 15%. Display of change in transmittance. Polarisation in illumination was selected parallel (x) and perpendicular (y) to lines and spaces and non-polarised (u).

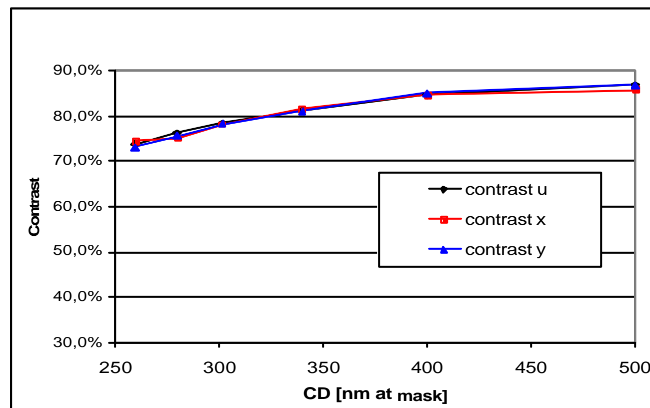

Fig. 5: Investigation of mask polarisation effects based on lines and spaces MoSiON 1:1 260nm to 500nm ½ pitch. Settings: λ=193nm, NA=0.93, σ=0.98, dipole 15%. Display of contrast for polarisation in illumination parallel (x) and perpendicular (y) to lines and spaces and non-polarised (u).

The results show a distinct increase in transmission indicating the increase of polarisation of the reticle towards smaller feature sizes. Again effects are in the range of about 5% for transmission change down to 260nm half-pitch on the reticle. The contrast is dropping towards smaller feature sizes as it is expected under scanner equivalent imaging of decreasing pitch. The contrast behaviour for the different polarization states is found to be similar.

3. CONCLUSION

MoSiON embedded phase shift masks have been investigated at highest possible NA=0.93 and for different half-pitches from 500nm to 260nm for reticle polarisation effects. Polarisation effects on transmission of the features are found to increase with smaller feature size towards the 65nm node. The effects on these materials are in the order of less than 5%. From the investigation we can see that the AIMS™ fab 193i with its linear polarised illumination for the vertical and horizontal mask direction allows to separate and investigate polarisation effects from the reticle itself taking into account real world mask effects. The application of the polarisation capability allows to judge on the suitability of the reticle for wafer printing in accordance with the correct polarization illumination that matters for the wafer printing in high NA approaching 1. Large peak intensities for different polarisation states or large Principal Transmittance ratio indicate that the reticle is significantly contributing towards printability properties and vector effects based on the scanner optics being enlarged. With the increase of

the transmittance change towards smaller half-pitches it is expected to have significant larger effects towards 45nm node as mask features reduce to 180nm.
Other materials and masks with sub-resolution mask features act strongly as wire grid polarizers and can be analysed with the polarisation function of the AIMS™ and their results valuably used as input for further analysis. It is especially helpful that AIMS™ as a scanner emulator catches the real world mask effects such as line edge roughness, sidewall angle effects and material tolerances that lead to different optical properties in a first place.

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REFERENCES

1. TM: trademark of Carl Zeiss
2. R.A. Budd, D.B. Dove, J.L. Staples, R.M. Martino, R.A. Furguson, J.T. Weed. Development and application of a new tool for lithographic mask evaluation, the stepper equivalent Aerial Image Measurement System, AIMS. IBM J. Res. Develop. Vol 41 No.1,2 January/ March, 1997.
3. R.A. Budd, J. Staples and D. B. Dove. A New Tool for Phase Shift Mask Evaluation, the Stepper Equivalent Aerial Image Measurement System AIMS. Proceedings of SPIE Vol. 2087, 1993.
4. A.M. Zibold, T. Scherübl, A. Menck, R. Brunner, J. Greif. Aerial Image Measurement Technique for Today's and Future 193nm Lithography Mask Requirements. Proceedings of 20th EMC Conference, 2004.
5. A.M. Zibold, R. Schmid, B. Stegemann, T. Scheruebl, W. Harnisch, Y. Kobiyama. Aerial image measurement technique for Automated Reticle Defect Disposition (ARDD) in wafer fabs. Proceedings of SPIE Vol. 5446-117, 2004.
6. A.M. Zibold, R. Schmid, A. Seyfarth, M. Wächter, W. Harnisch, H.v. Doornmalen. Advances in hardware, software and automation for 193nm aerial image measurement systems. Proceedings of SPIE Vol. 5752-114, 2004.
7. A. Zibold, W. Harnisch, T. Scherübl, N. Rosenkranz, J. Greif. Using the aerial image measurement technique to speed up mask development for 193nm immersion and polarization lithography. Proceedings of SPIE Vol. 5645-30, 2004.
8. A. M. Zibold, E. Poortinga, H.v. Doornmalen, R. Schmid, T. Scherübl, W. Harnisch. Advances with the new AIMS™ fab 193 2nd generation: A system for the 65 nm node including immersion. Proceedings of SPIE Vol. 5853-131, 2005.
9. C.A. Mack and J.D. Byers. Exploring the Capabilities of Immersion Lithography Through Simulation. Proceedings of SPIE Vol. 5377, 2004.
10. R. W. Wood, ``On a remarkable case of uneven distribution of light in a diffraction grating spectrum'', *Phil. Mag*. 4, 1902.
11. Karsten Bubke, Silvio Teuber, Ingo Hoellein, Hans Becker, Holger Seitz, Ute Buttgereit. Investigation of Polarization Effects on new Mask Materials. Proceedings of SPIE Vol. 5754-55, 2005.