Programmed Defects Study on masks for 45nm Immersion Lithography using the novel AIMS™45- 193i

Thomas Scherübl[2], Arndt C. Dürr[1], Klaus Böhm[2], Robert Birkner[2], Rigo Richter[2], Ulrich Strößner[2]
[1]Advanced Mask Technology Center GmbH & Co. KG,
[2]Carl Zeiss SMS GmbH,

ABSTRACT

Mask manufacturing for the 45nm node for hyper NA lithography requires tight defect and printability control at small features sizes. The AIMS™[1] technology is a well established methodology to analyze printability of mask defects, repairs and critical features by scanner emulation. With the step towards hyper NA imaging by immersion lithography the AIMS™ technology has been faced with new challenges like vector effects, polarized illumination and tighter specs for repeatability and tool stability.

These requirements pushed the development of an entirely new AIMS™ generation. The AIMS™ 45-193i has been designed and developed by Carl Zeiss to address these challenges. A new mechanical platform with a thermal and environmental control unit enables high tool stability. Thus a new class of specification becomes available. The 193nm optical beam path together with an improved beam homogenizer is dedicated to emulate scanners up to 1.4 NA. New features like polarized illumination and vector effect emulation make the AIMS™ 45- 193i a powerful tool for defect disposition and scanner emulation for 45nm immersion lithography.

In this paper results from one of the first production tools will be presented. Aerial images from phase shifting and binary masks with different immersion relevant settings will be discussed. Also, data from a long term repeatability study performed on masks with programmed defects will be shown. This study demonstrates the tool's ability to perform defect disposition with high repeatability. It is found that the tool will fulfill the 45nm node requirements to perform mask qualification for production use.

INTRODUCTION

THE NEW AIMS™45 – 193i TOOL

For more than 10 years[2] AIMS™ has been a well established methodology in the mask shop as a quasi industry standard. With an AIMS™ system the mask can be analyzed under scanner relevant conditions (Fig. 1). A portion of the mask is illuminated under the same conditions (NA, sigma settings) as scanner does. The light diffracted by the mask is gathered by an objective lens which magnifies the image on a CCD camera. Thus, the CCD camera sees the same aerial image as the wafer does and defects can be evaluated concerning their printability. The main applications for the AIMS™ systems are repair qualification, process development and process control.

The insertion of immersion lithography for the 45nm node required a completely new set of specifications for AIMS™. Higher higher NA and sophisticated polarized (azithmutal) illumination schemes are used in immersion scanners[3]. These parameters as well as higher tool stability due to smaller feature sizes, have driven the development of a new AIMS™ tool for the 45nm node in cooperation between Zeiss SMS and Sematech.

The AIMS™ 45 – 193i tool[4] has been developed on a new mechanical platform which together with a thermal controlled measurement chamber provides extremely stable conditions for measurements which result in good longterm repeatability values which will be shown in this paper. Besides the tool has new designed 193nm optical beamline, consisting of objective lens, imaging unit and illumination unit. The illumination unit supports various kinds of off-axis illumination schemes used in immersion scanners which can be combined with linear (x, y direction) or azimuthal polarization in order to enhance contrast. Finally, the tool is equipped with the new Zeiss proprietary vector effect emulator which allows to emulate the contrast of aerial images in resist which are formed under high angles.

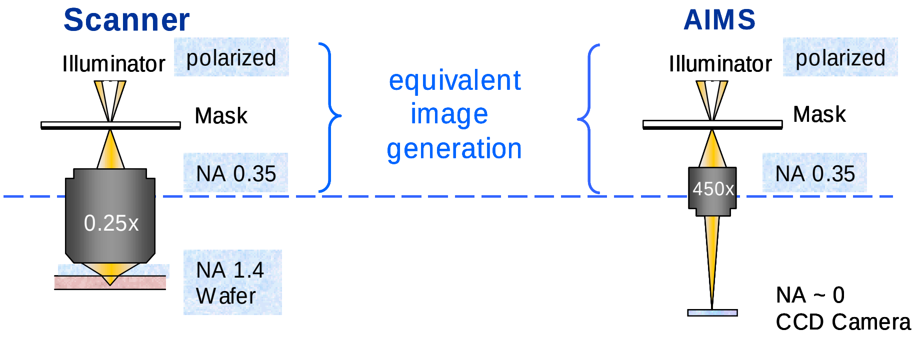


Fig 1.: Comparison AIMS™ versus Scanner

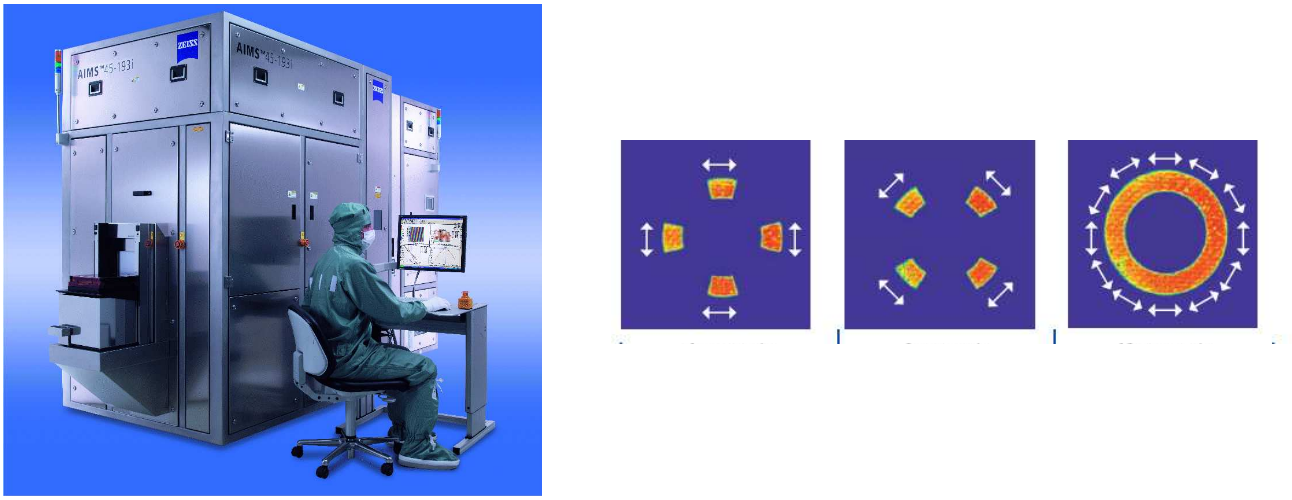


Fig. 2. The new AIMS™45- 193i (left) with examples of polarized off-axis illumination setting (right).

The scope of this paper was to investigate the stability and repeatability of one of the first AIMS™45-193i tools which has been shipped and installed at the AMTC mask shop in Dresden. By using different test masks which were representative for the 45nn node, first the tool stability has been studied by monitoring the contrast. Then the long term repeatability study of defect analysis by a transmission criterion has been analyzed and, finally, an estimation has been made about the minimum detectable defect size on mask level.

LONGTERM REPEATIBILTY STUDY

For the long-term repeatability study AMTC prepared three different mask with a 1:1 lines and spaces pattern (see Table 1). Two of the masks have been a MoSi type, one of them has been a APSM. Each of the masks has been measured with a certain setting except the MoSi 1 mask has been analyzed under two different settings.

	MoSi 1	**MoSi 1**	**APSM**	**MoSi 2**
hp @ wafer	75nm	75nm	75nm	45nm
Duty cycle	1:1 l/s	1:1 l/s	1:1 l/s	1:1 l/s
NA	0.8	0.75	>0.8	1.2
Sigma setting	off-axis 2-poles unpol	off-axis 4-poles unpol	on-axis unpol	off-axis 2-poles pol
Defect	real	real	real	programmed 33nm x 11nm (1x)

Table 1: Mask types investigated in this study

The log term repeatability study has been made by 3 times load/unload the mask per day for 5-6 consecutive days. As metrics the contrast of defect free areas (reference area) as used. An example of a measured aerial image containing a defect is shown in Figure 3. For the study of defect evaluation the normalized transmission loss has been recorded and analysed by using a profile plot (Figure 3 left .

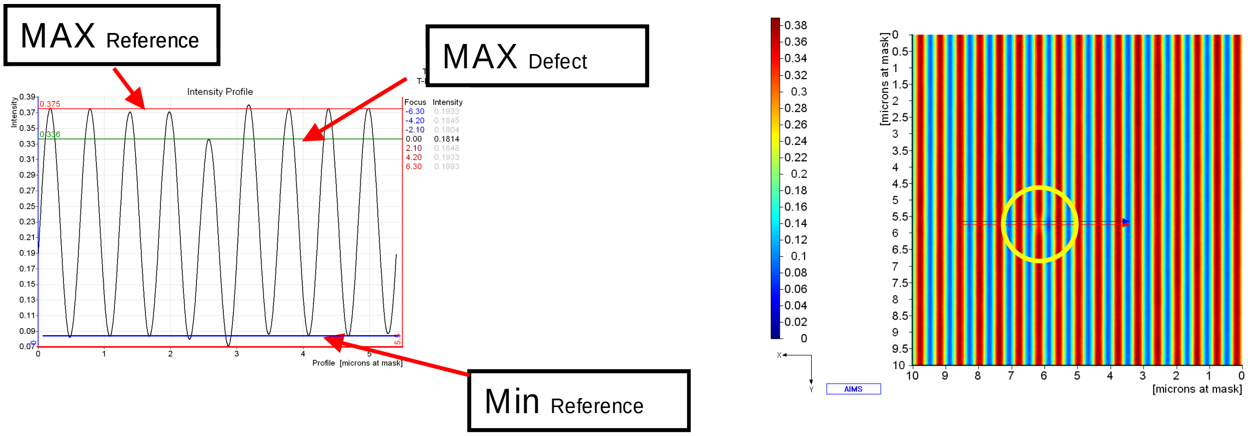


Fig.3: Metrics used for the repeatability study

The following formulas have been used for calculating contrast and transmission loss from the profile plot:

1. Monitor Contrast of reference:

$$C = \frac{Max_{\mathrm{Re}\,f} - Min_{\mathrm{Re}\,f}}{Max_{\mathrm{Re}\,f} + Min_{\mathrm{Re}\,f}}$$

2.Characterize Defect by norm. Transmission Loss:

$$T_{Loss} = \frac{Max_{Defect} - Max_{\mathrm{Re}\,f}}{Max_{\mathrm{Re}\,f}}$$

Contrast stabilty

The results of the contrast stability study in table 2 show that the depending of the setting and mask type, the contrast values of 63.1 % for MoSi 1 (4-pole) and 95% (2-pole) can be reached. The long term behavior of the contrast is very stable as the 3 sigma values vary from 1.3% to 0.38%. For the high contrast settings (contrast larger than 80%) the long term repeatability is even below 1%. From table 2 also shows that the MoSi 2 mask with 45nm features shows the best contrast stability. These results confirm the good stability of the new AIMS™45 – 193i tool due to the new tool concept.
In order to analyse the optical performance of the AIMS™ - 193i tool the measured data have been compared to simulated data. The simulations have been performed using the rigorous simulator “Microsim” assuming a perfect optical system. In figure 4 the simulated and the measured contrast are compared. The simulated data and the measured data are in very good agreement. For the 2-pole settings of MoSi 1 and MoSi 2 the measured data show even a higher contrast as the simulations. The exact reason for that behavior is currently not fully understood and requires further investigations. One reason can be that the input parameter in the optical simulator like optical constants n and k for the MoSi layer or the MoSi film thickness do not represent well the real world values. Therefore, the simulator can predict different contrast compared to the AIMS™ values depending on the settings.

	MoSi 1 75nm off-axis 4-poles	**MoSi 1 75nm off-axis 2-poles**	**APSM 75nm on-axis**	**MoSi 2 45nm off-axis 2-poles**
Contrast mean	**63.1%**	**95%**	**87.8%**	**86.4%**
Contrast 3σ	**1.3 %**	**0.66%**	**0.7%**	**0.38%**

Table 2: Results of the contrast stability study

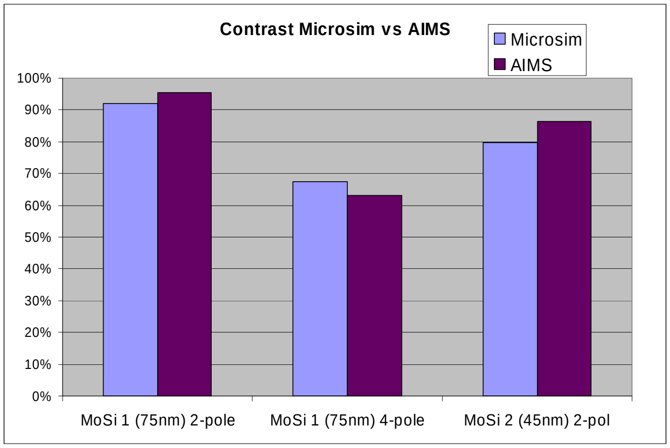


Figure 4: Comparison between measurements and rigorous simulations by Microsim

Long Term Repeatability of Transmission loss

Next the long term repeatability of the transmission loss of mask defects has been analyzed. The calculation of the transmission loss has been performed as described in Fig. 3. For analysis we plotted the contrast values and the repeatability results in one plot (Fig. 5). The long term repeatability of the transmission loss varies from 1.2% to 0.85% depending on the mask. Figure 5 also indicates that the transmission loss repeatability is inversely correlated to the contrast. Settings with high contrast lead to a very good repeatability below 1 %. This is in good agreement with the contrast stability results in Table 2 where higher contrast settings also show better contrast stability. The transmission loss values for the different masks and defects (see table 1) are plotted in Table 2. It can be seen that except for the APSM the transmission loss values are in the range of 9% - 14%. The APSM defect shows a quite large transmission loss of 25%. For all cases the long term repeatability is less than one tenth of the transmission loss value. Therefore, these defects can be easily detected and evaluated by the AIMS™ 45 – 193i with high repeatability.

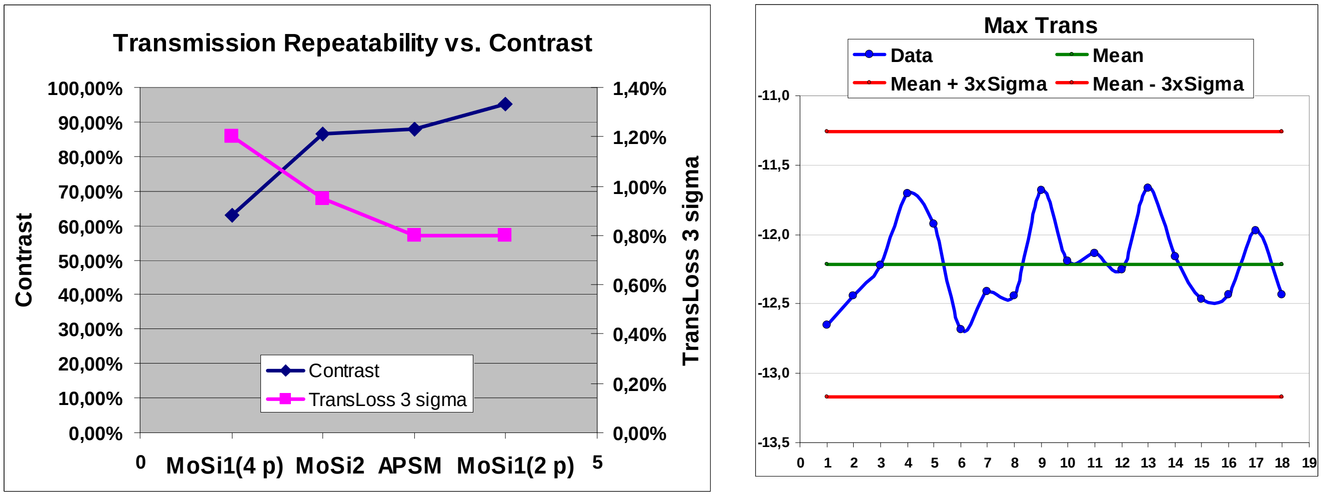


Figure 5: Result of the long term repeatability of transmission loss (right axis) compared to the contrast (left axis) for different masks. The right graph shows the results of the MoSi2 mask (45nm hp) over 6 days with a mean transmission loss of 12.25%.

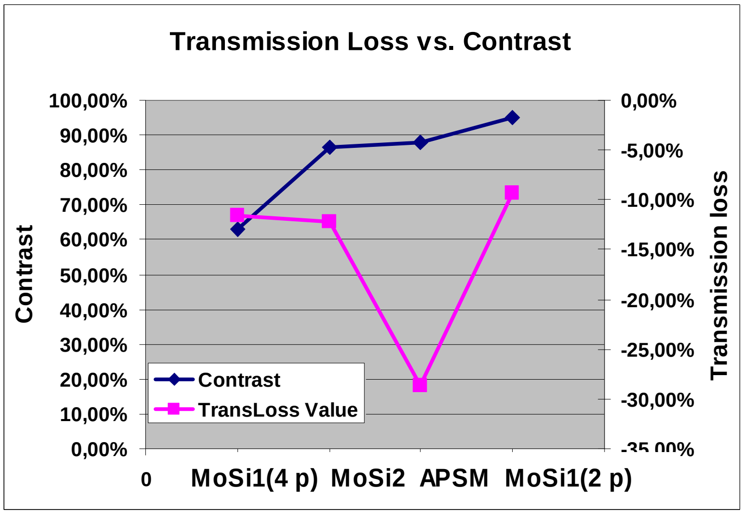
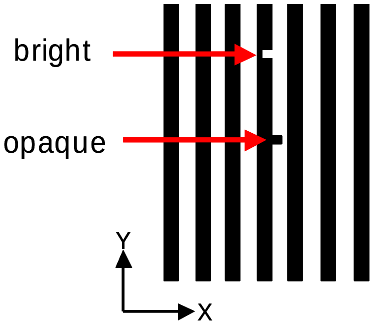


Figure 6: Transmission loss values (right axis) compared to the contrast (left axis) for different masks.

Estimation of minimal detectable defect size

Having measured a long term transmission loss repeatability of 1%, in a next step we estimated the minimal detectable defect size on 45nm masks by using the transmission loss criteria. For that purpose we prepared a CoG glass mask with programmed defects (see Fig. 7) . We used 4 programmed defects with areas of 6441 nm^2 and 3400 nm^2 for both opaque and bright defects. The aspect ratio of the y-axis to the x-axis of the defects was 2:1. The mask has been measured at the AIMS™ 45 – 193i tool using the following settings:

Disar 35° (63%) NA=1.4 (0.35 mask level) Sigma=0,96.
The measured contrast in the aerial image was around 82 % (see figure 8)



	Bright 2	Bright 1	Opaque 1	Opaque 2
X	-57nm	- 40 nm	40 nm	57nm
Y = 2X	113 nm	80 nm	80 nm	113 nm
A (nm*nm)	6441	3400	3400	6441

Fig. 7: CoG mask (half pitch 180nm at mask, l/s 1:1) with programmed defects of different sizes

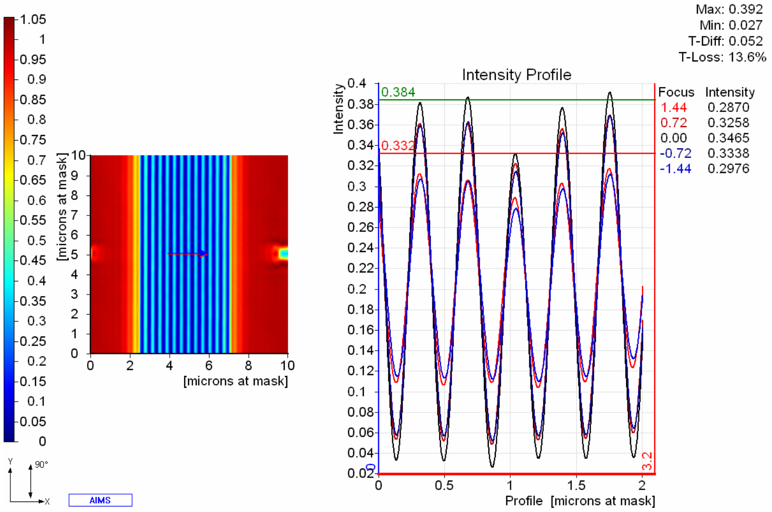


Fig. 8: AIMS™ images and intensitiy profile plot of a programmed defect on a CoG mask (half pitch 180nm at mask, l/s 1:1)

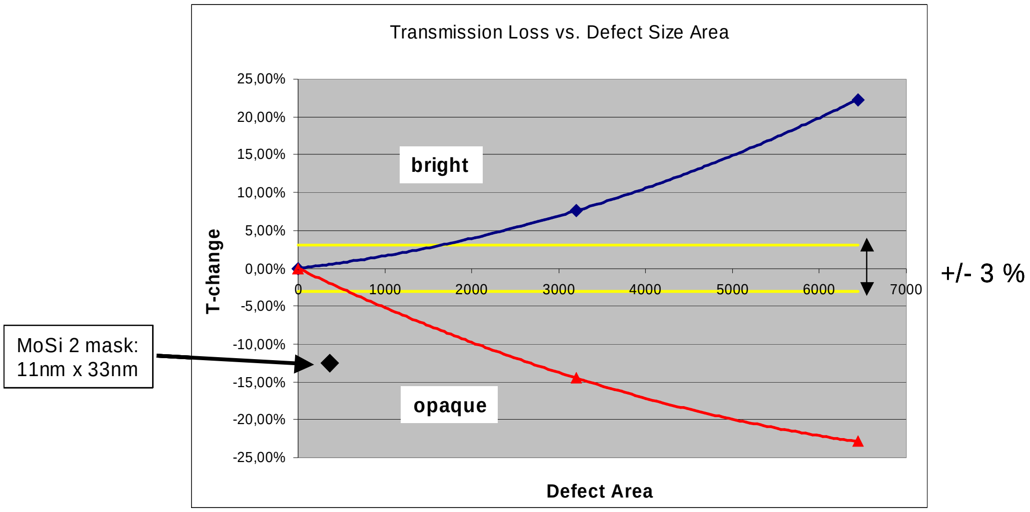


Fig. 9: Transmission change of programmed defects on CoG mask (half pitch 180nm at mask, l/s 1:1) as a function of defect area

Figure 8 shows an aerial image of opaque defect which leads to a transmission loss. Bright defects will lead to a transmission gain. These transmission changes as a function of the defect area have been plotted in Fig.9.
The transmission change data have be fitted with a quadratic function for both bright and opaque defects. The transmission change repeatability has been measured to be less than 1 % (see figure 5). A save detection of the transmission loss or change is possible if the transmission change is 3 times the repeatability which means +/- 3%. Using this value, the minimum detectable defect size for a CoG mask is below 17nm x 34 nm for opaque and below 26 nm x 57 nm for a bright defect at mask level. For this estimation a defect aspect ratio y to x of 2:1 has been assumed. However, this value holds for the CoG mask. In figure 9 we also plotted the transmission loss value of the programmed defect on the MoSi 2 mask (180hp at mask) with a defect size of 11nm x 33nm. The resultant defect area of this defect is 366nm, but shoes a large transmission loss of 12.5 % compared to the CoG area. This indicates that the transmission loss depends strongly on the mask type.

Conclusion

The AIMS™ 45 – 193i has been developed by Carl Zeiss together with Sematech. In this work the tool stability has been demonstrated by a long term repeatability study at the AMTC mask shop in Dresden. The tool showed an excellent contrast and transmission loss repeatability which both were below 1% over 5-6 days. The comparison of measured AIMS™ images to simulated images by Microsim showed a very good agreement. This indicates that the new tool has a low aberration 193nm optics. The minimal detectable defect size depends strongly on the mask type and setting and is well below 11nm x 33nm for a 45nm MoSi mask.

Acknowledgements

AMTC is a joint venture of Infineon, AMD and Toppan Photomasks and gratefully acknowledges the financial support by the German Federal Ministry of Education and Research (BMBF) under Contract No. 01M3154A “Abbildungs-methodiken für nanoelektronische Bauelemente").

The authors would also like to thank Oliver Kienzle of Carl Zeiss for his support and contributions during this project.

References

1. TM: Trademark of Carl Zeiss
2. R.A. Budd et al. 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. W. Conley et al. 45nm imaging capability of various PSM technologies using polarization. Proceedings of SPIE Vol. 6152 2006
4. A. Zibold et al. First results for hyper NA scanner emulation from AIMS™45 – 193i