Pupil plane analysis on AIMS™ 45-193i for advanced photomasks

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ABSTRACT

Hyper-NA lithography with polarized light illumination is introduced as the solution of 45nm or 32nm node technology. In that case, consideration of new characteristics of mask materials and pellicle films has been required. In order to analyze the influence of mask material's optical characteristics, we have proposed to use the AIMS™ system measuring diffraction intensity balance in previous work *[4]. That was enabled by acquiring pupil plane images using the Bertrand lens in the AIMS™ system to measure selected area's diffracted light.

In this study of mask material evaluation, we used same functionality of AIMS™ system, MonoPole illumination and Bertrand lens, as previous work but other direction's pole is also used on the illumination aperture to cover total diffraction orders of Cross-quad illumination because this illumination is more flexible for x and y patterns. In order to get diffracted light of 45nm half-pitch, hyper-NA e.g. NA=1.35 was applied and the AIMS™ 45-193i Alpha system was used for this evaluation. The examinations were performed with binary and half tone PSM with half pitch 40 to 150nm on a 1x scale and fixed half pitch 45nm with various mask bias. We confirmed the relation between diffractions' intensity balance and wafer printing performance for each material and we compared them to 3D simulation results.

Moreover, by using the same functionality of AIMS™ system, the transmission change by pellicle film was also examined. We have prepared two different thickness pellicles to compare transmission change and printed CD on the wafer. Intensity profile at pupil plane on the clear region of the mask was acquired with Bertrand lens and conventional large sigma setting for both with and without pellicle film on the mask. By comparing transmission distribution change between with and without pellicle, we could calculate transmission loss by pellicle at large incident angles. For this experiment, NA=1.40 was applied and the AIMS™ 45-193i Alpha system was also used. The examinations were performed with half tone PSM at half pitch 45nm and 65nm on a 1x scale on linear polarized DiPole illumination.

As a result, we have confirmed good agreement between AIMS™ measurement data and optical 3D simulations. In conclusion, the AIMS™ system is a valuable tool for analyzing diffraction efficiency or intensity distribution on the pupil plane and comparison to wafer printing performance.

Key words: 45nm, Hyper-NA, polarized illumination, AIMS™, photomask, optical characteristics, pellicle

1. INTRODUCTION

For half pitch 45nm and beyond, hyper NA imaging systems and aggressive off axis illumination will be applied but it involves contrast loss due to vector effects. Vector effects can be reduced effectively by use of polarized illumination. Under such condition of the illumination, Incident light to the mask will be strongly off axis and of course be polarized. Also diffracted light from the mask will also have very large diffraction angle and be polarized. So, following items should be confirmed on the output light from the mask as new issues. To avoid degradation of polarization quality, to keep good diffraction intensity balance to obtain ideal two beam interference and to keep uniformity for these characters. There are three materials on the mask to be analyzed. Quartz substrate's birefringence, mask material including 3D topography and pellicle film have been the key issue to check or optimize for hp45nm mask.

In order to analyze the influence of mask material's characteristics, it had been mainly measured diffracted light using an ellipsometer but we have proposed to use the AIMS™ system for this purpose in previous work *[4]. That was enabled by acquiring pupil plane images using the Bertrand lens in the AIMS™ system to measure selected area's diffracted light. We used off-axis MonoPole illumination in x- and y-polarization which was placed at one side of standard DiPole aperture to evaluate 0th and 1st order diffracted light intensity separately and compared the printing performance using linear polarized DiPole illumination at the same time by AIMS™ system. But DiPole illumination has a good printing performance on only one direction's pattern. So, this illumination is used for very limited pattern or combination of double mask and exposure to print for both directions. Cross-quad with azimuthally polarized illumination has been proposed to achieve good printing performance for both patterns by single mask and single exposure. In this paper, we will use the same MonoPole illumination system as previous work but other direction's pole is also used on the illumination aperture to cover total diffraction orders of Cross-quad illumination.

Moreover, by using the same functionality of AIMS™ system, the transmission change by pellicle film was also examined. Intensity profile at pupil plane on the clear region of the mask was acquired with Bertrand lens and conventional large sigma setting for both with and without pellicle film. By comparing transmission distribution change between with and without pellicle, we could calculate transmission loss by pellicle at large incident angles.

In this study, we analyzed intensity distribution at pupil plane and compared with image contrast or printed CD on the wafer for these two materials, mask material and pellicle thickness, by using AIMS™ 45-19i Alpha system. Item to be discussed is how the optical parameters of these will affect to the wafer print performance.

2. MASK MATERIAL EVALUATION

2-1. Background ; Diffractions intensity balance and image contrast

Theoretically, good image contrast of the two beam interference on wafer is observed by good intensity balance of the two beams. For the quadrupole and azimuthal polarization condition as shown in Fig-1, horizontal two apertures are effective for such two beams and good intensity balance is expected to create the good image contrast. We call these apertures as "x-TE". On the other hand, vertical two apertures are not effective for the vertical patterns because only 0^{th} order's diffraction could enter the pupil and stronger intensity is not expected for the good image contrast. We call these apertures as "y-TE".

So, for the optical characteristics analysis of mask materials, we measured diffraction's intensity for 1^{st} and 2^{nd} orders of x-TE and 0^{th} order of y-TE on this illumination condition.

2-2. Pupil plane analysis for diffractions' intensity measurement

Fig-2 shows the schematic of AIMS™ optics to explain the conjugative relation between Sigma/NA apertures and Mask/CCD positions. (left) is a standard AIMS™ optics condition to analyze intensity profile at wafer. The insertion of Bertrand lens in between projection lenses and CCD enables to measure the intensity at pupil plane on AIMS™ tool. (center) shows this condition. To measure 0^{th} and 1^{st} orders intensity of x-TE separately, MonoPole and linear polarized illumination was used. To measure 0^{th} order of y-TE, other location of MonoPole and other direction's linear polarized illumination was used. Intensity normalization is required for each diffractions by dividing 0^{th} order's intensity at clear region on the mask.

2-3. Experiment-1 ; Diffraction intensity balance in through pitch

To compare the optical characteristics between NTAR7, a Binary Intensity Mask (BIM), and A61A, a 6%

Embedded and Attenuated PSM (6%EAPSM), intensity balance of 0^{th} and 1^{st} of x-TE diffractions in through pitch was confirmed. Each diffractions' intensity was measured by AIMS45-193i Alpha system and was normalized by 0^{th} order's intensity at clear region on the mask. Diffraction intensity of AIMS™ measurement results also compared to 3D simulation results. Evaluated pattern and illumination conditions are common and are shown bellow.

Evaluated pattern ; 1:1 L&S, half pitch = 40 ~ 150nm @1x (5nm step ; 40 ~ 80, 10nm step 90 ~ 150)

Wavelength = 193nm (ArF)

NA=1.35 (Fixed)

Sigma ; MonoPole, c0.784/r0.196, linear polarization (IPS=95%)

3D simulation software : EM-suite Ver.4.01 (Panoramic technology)

Fig-3 (a) shows the A61A with 0 mask bias result and Fig-3 (b) shows the NTAR7 with 0 mask bias result. Firstly, the tendency in through pitch between AIMS™ data and simulation results is well agreed. By comparing these two graphs, intensity balance of x-TE on A61A around hp65nm or larger is relatively good for both simulation and AIMS™ measurement results compared to NTAR7. As going to hp45nm, intensity balance of A61A is getting worse and that of NTAR7 is getting better on the simulation results, but AIMS™ result does not show such tendency because 0^{th} order's intensity is relatively higher than simulation for both A61A and NTAR7 even though the mean target CD error measured by CD-SEM was less than 1nm@1x. Different mask bias conditions were also examined because adding negative bias on A61A or adding positive bias on NTAR7 gets better image contrast which confirmed by simulations and also 0^{th} order's intensity can be controlled by mask bias. Fig-3 (c) shows the result of A61A with negative mask bias. By adding negative mask bias, space CD is larger than line CD on the 1:1 L&S pattern, intensity of 0^{th} order diffraction was successfully increased and balanced to 1^{st} order diffraction on simulations but 0^{th} order's intensity was still higher on AIMS™ result at around hp45nm. Fig-3 (d) shows the result of NTAR7 with positive mask bias. By adding positive mask bias, intensity of 0^{th} order diffraction was successfully decreased and balanced to 1^{st} order diffraction on simulations and AIMS™ results but intensity itself gets smaller and other problem will be expected such as MEEF degradation.

To analyze more detailed performance at hp45nm with cross-quad illumination, we planed and focused on next examination.

2-4. Experiment-2 ; Printing performance at hp45nm with mask bias

Again, to compare the optical characteristics between NTAR7 and A61A at hp45nm, intensity balance of 0^{th} and 1^{st} orders x-TE and 0^{th} order y-TE diffractions were measured in various mask bias conditions. Each diffractions' intensity was measured and normalized in the same way. Diffraction intensity of AIMS™ measurement results was compared to 3D simulation results and also compared to image contrast on the wafer. Evaluated pattern and illumination conditions are shown bellow.

Evaluated pattern ; 1:1 L&S, half pitch = 45nm @1x

Mask bias ; A61A -14 ~ +4nm @1x (2nm step), NTAR7 : -2 ~ +14nm @1x (2nm step)

Wavelength = 193nm (ArF)

NA=1.35

Sigma ; MonoPole, c0.784/r0.196, linear polarization (IPS=95%) for diffraction measurement

C-quad 30deg o0.98 66%opening, Azimuthal Pol. (4 sectors, IPS=95%) for image contrast on wafer

AIMS image measurement ; Scanner mode (Vector effect emulation), IPS=95%, Resist n=1.7,

Immersion n=1.44

3D simulation software : EM-suite Ver.4.01 (Panoramic technology)

Fig-4 (a), (b) and (c) show x-TE diffractions intensity, y-TE diffraction intensity and image contrast at wafer of A61A in various mask bias condition, respectively. In these results, the tendency in various mask bias between AIMS™

data and simulation results is well agreed except for absolute value of image contrast but some constant offsets in mask bias are also recognized. In averaging three graphs, the offset was calculated as -4nm mask bias on AIMS™ data to fit to the simulations. The reason may come from the mask CD model difference between 3D simulation and CD-SEM measurement results because plotted data of mask CD of AIMS™ results were based on CD-SEM results. On Fig-4 (a), the intensity of 0^{th} order diffraction was increased by negative mask bias and there was a cross point to that of 1^{st} order at negative bias region. Intensity of cross points are around 0.17 for both AIMS™ and simulation. Maximum contrast was observed at around +5nm mask bias from the cross point of 0^{th} and 1^{st} orders x-TE diffractions' intensity. That may be caused from smaller 0^{th} diffraction's intensity of y-TE. Maximum image contrast of simulation was around 0.55 and that of AIMS™ was around 0.49.

Fig-4 (d), (e) and (f) have the same format as Fig-4 (a), (b) and (c) respectively but for NTAR7. The tendency between AIMS™ data and simulation results is also well agreed except for absolute value of image contrast and some constant offsets in mask bias are recognized. In averaging three graphs, the offset was calculated as -3nm mask bias on AIMS™ data to fit the simulations. On Fig-4 (d), the intensity of 0^{th} order diffraction was decreased by positive mask bias and was going to get closer to that of 1^{st} order at positive bias region. Intensity of closer points are smaller than 0.1 for both AIMS™ and simulation. The maximum contrast was exceeded at somewhere around positive bias region compared to A61A. Total diffractions' intensity of the exceeded point of image contrast on NTAR7 looks the same as A61A. Although higher contrast was observed at larger positive mask bias regions, other problem, bad MEEF was expected because of smaller total diffractions' intensity.

To clarify such printing performance comparison, Table-1 summarizes contrast and MEEF values at zero mask bias and with adding mask bias structures. The best balance of contrast and MEEF were observed at -10nm mask bias in 1x on A61A and zero bias on NTAR7 by simulation.*[5)] For the AIMS™ data, mask CD model should be discussed. So, both AIMS™ data of mask CD @CD-SEM and @CD shift were summarized on the table. Slice levels @CD shift result show better agreement with simulation ones. In this result, simulation shows equivalent performance between A61A with -10nm mask bias in 1x and NTAR7 with no mask bias. AIMS™ results show good agreement with simulation relatively but AIMS™ result of A61A with -10nm mask bias is slightly better than that of NTAR7 with no mask bias.

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3. PELLICLE THICKNESS EVALUATION

3-1. Background and experimental condition

ArF pellicles are made by single film. So, peak transmission at 193nm wavelength is controlled by its thickness. It is basically targeted at 0degree incident angle. Issues of this single film are that large incident angle causes transmission change and also it causes transmission non-uniformity by thickness distribution. One of the ideas to solve this problem is optimization of film thickness. Thinner film shows better stability performance by the calculation.*[5)] In order to confirm this concept, we have prepared two different pellicle thickness samples to compare the transmission or printed CD change differences by using AIMS™ system. One is targeted 830nm as a standard and other is targeted 560nm as a thinner one.

Fig-5 (a) shows the mask overview and measurement location of pellicle thickness measurement. Table-2 shows the thickness measurement results of two different film thickness. Fig-5 (b) shows AIMS™ measurement locations for transmission distribution at pupil and printed CD on the wafer. Exact the same 9 locations were measured between with and without pellicle using stage navigation on the AIMS™ system.

3-2. Experiment-1 ; Pupil plain analysis for transmission distribution measurement

By using the same methodology to measure diffraction intensity, intensity distribution at pupil plane was measured by AIMS™ system as shown in Fig-2 (right). To measure the transmission change by the pellicle film thickness, large sigma and non-polarization illumination was used and clear region on the mask was selected. NA and sigma was set to 1.4 and conventional 0.98 and non-polarized light illumination was used. With and without pellicle on the mask were measured in this condition to calculate the transmission rate change between these. Fig-6 (b) shows the example of transmission change graph calculated from Fig-6 (a) on standard pellicle at center location. X axis of this graph was calculated by the relation between pupil position and incident light angle because the illumination light came from outer side of the sigma aperture was angled to illuminate the mask. Relation between NA related sigma position and incident angle was calculated from following formula "$\text{Angle} = (180/\pi)\sin^{-1}(\text{sigma\_position} \times NA/4)$". In the example, large transmission change at large incident angle was clearly observed.

Fig-7 (a), (d) show the half side of pupil transmission change result measured by AIMS™ and Fig-7 (b), (e) show the same format of transmission calculation result under the condition of non-polarized light for two different pellicle thickness. n and k of pellicle film for this calculation was 1.4 and 0.0. Fig-7 (c) shows the transmission change at 16 degrees incident angle vs. pellicle thickness plots for both AIMS™ measurement results at 9 locations and calculation and Fig-7 (f) shows the same format as (c) but transmission change at 5 degrees on thinner pellicle because no transmission change was observed around 16 degrees. In these results, the raw transmission curves was well agreed with calculation results and thinner pellicle showed very small transmission change at large incident angle. Although clear thickness effect, transmission change slope, could not be confirmed, the range of transmission change was agreed to calculation results.

3-3. Experiment-2 ; Printed CD on the wafer

In order to confirm the wafer printing effect from the transmission change caused by pellicle film, printed wafer CD was measured by AIMS™ with and without pellicle conditions. Measurement conditions are shown bellow.

Evaluated pattern ; 1:1 L&S, half pitch = 45nm, 65nm @1x (A61A)
Wavelength = 193nm (ArF)
NA ; 1.40 for hp45nm, 0.95 for hp65nm (k1 = 0.32 : constant)
Illumination ; Dipole c0.784, r0.196, Linear polarization (TE)
AIMS image measurement ; Scanner fast mode (Vector effect emulation), IPS=95%, Resist n=1.7,
Immersion n=1.44

Table-3 (a) and (b) show the printed CD results for 9 location measurements with and without standard pellicle on two different pattern pitches. Threshold of AIMS™ data analysis was defined as the space CD to be the target CD at center location pattern under without pellicle condition. And the same threshold was used for CD analysis in each one table. In these results, printed CD difference between with and without pellicle of hp45nm was quite large, -3.2nm@1x in average, compared to that of hp65nm. It was also expected from transmission results. The large CD difference is not important because exposure dose with pellicle is defined with pellicle. So, important thing is that large CD/transmission difference would magnify CD uniformity error by pellicle thickness non-uniformity. In the result, CD uniformity degradation caused from pellicle was seen on the result of hp45nm but not on the result of hp65nm because hp65nm has much less CD/transmission difference between with and without pellicle.

Table-3 (c) and (d) have the same format as Table-3 (a) and (b) respectively but for thinner pellicle. CD uniformity degradation caused from pellicle was not seen for both hp45nm and hp65nm because they have few CD/transmission difference. Fig-8 (a) and (b) show CD difference vs. pellicle thickness. In these results, no clear relation was observed.

4. CONCLUSION

We have successfully analyzed pupil image by AIMS^{TM} system and the data showed good agreement with 3D simulation results. So that, AIMS^{TM} system is valuable to analyze mask material's optical characteristics. From two major mask materials' analysis results,

1. Mask material (BIM vs. 6%EAPSM) ; A61A shows better diffraction intensity balance on x-TE in though pitch. Image contrast on the wafer can be optimized by controlling intensity balance of diffractions by optimizing mask bias. Although almost equivalent contrast and MEEF performance was expected by 3D simulation results at hp45nm, AIMS results suggested that the actual performance of NTAR7 was slightly worse than A61A.
2. Pellicle film thickness ; Pellicle apodization effect on the wafer printing performance of 2 different pellicle thickness was demonstrated. Thinner pellicle shows better characteristics than conventional one as follows, (1) Smaller transmission error at large incident angle, (2) Smaller effect on maximum intensity and CD on wafer, (3) CD non-uniformity was not magnified by the thinner pellicle.

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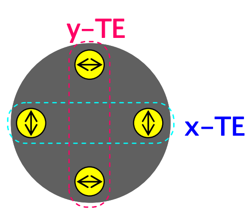
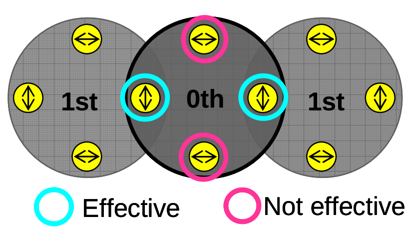


(a) Sigma shape



(b) Diffracted light at pupil plane

Fig-1 ; Schematic image of the (a) sigma shape of Quadorupole with polarized illumination and the (b) diffracted light positions at pupil plane which describes the effective or not effective component to the image contrast for y-direction's pattern.

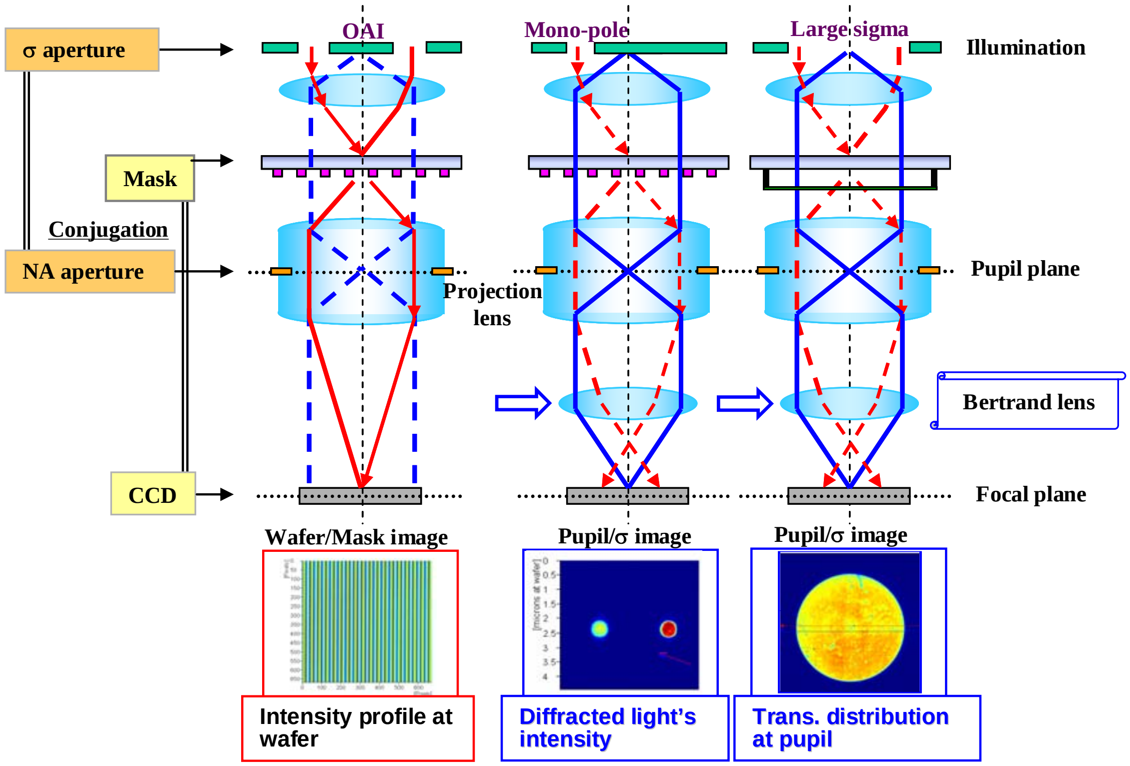
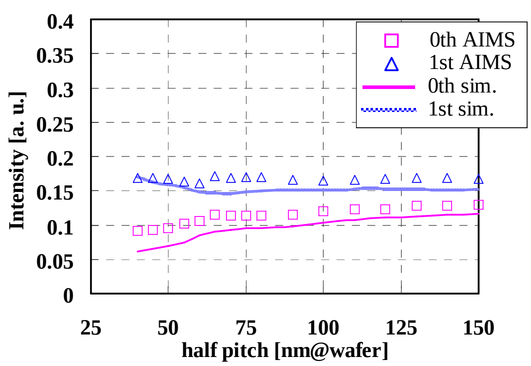
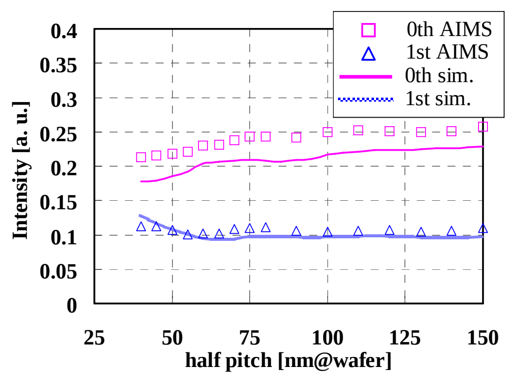


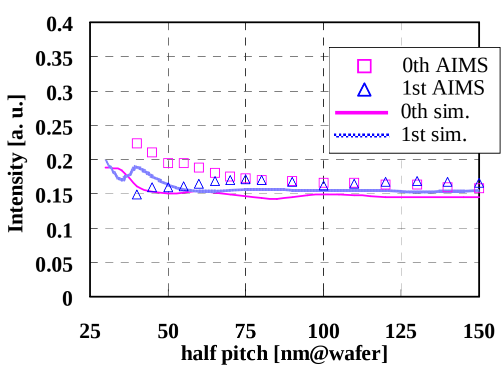
Fig-2 ; Optical diagram of AIMS™ for showing pupil plane analysis methodology. Each 3 settings are showing, (left) standard AIMS™ mode, (center) diffraction intensity analysis and (right) pellicle apodization analysis.



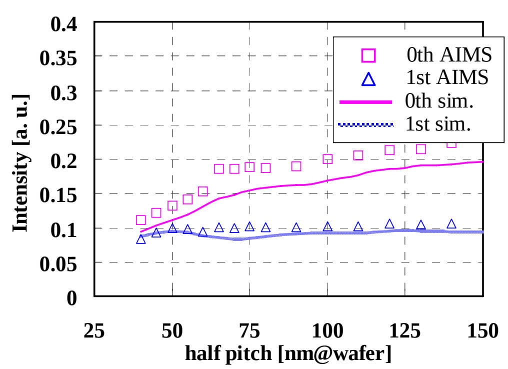
(a) A61A with no mask bias



(b) NTAR7 with no mask bias

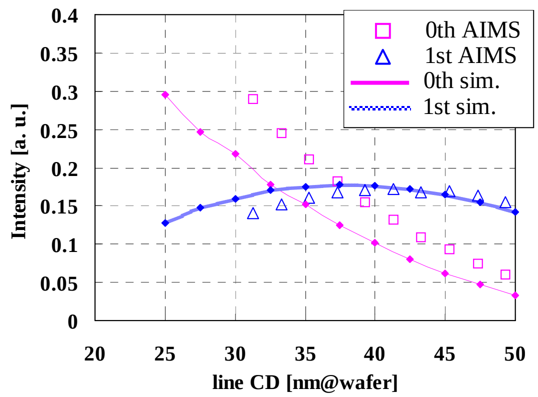


(c) A61A with -10nm@1x mask bias

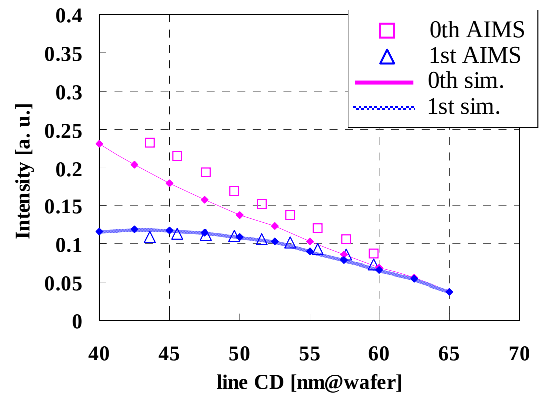


(d) NTAR7 with +10nm@1x mask bias

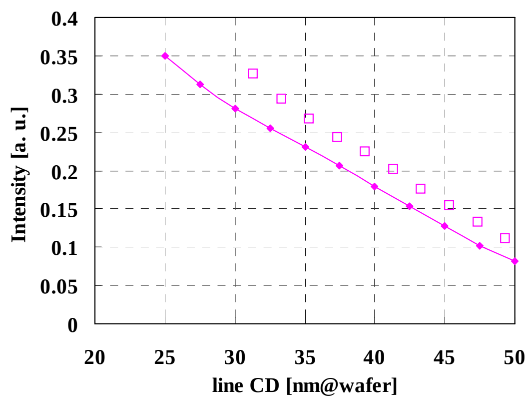
Fig-3 ; 0^{th} and 1^{st} order's diffraction intensity of x-TE components in trough pitch 1:1 patterns



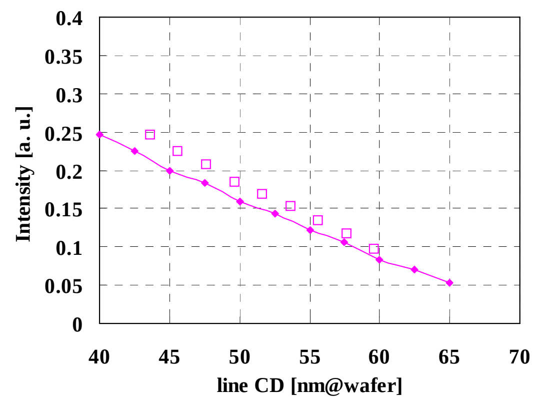
(a) Diffraction intensity of x-TE on A61A



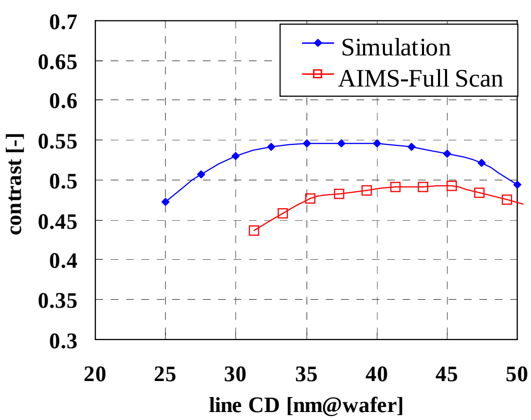
(d) Diffraction intensity of x-TE on NTAR7



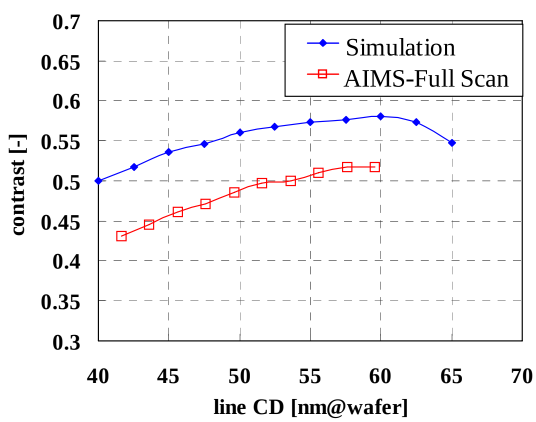
(b) Diffraction intensity of y-TE on A61A



(e) Diffraction intensity of y-TE on NTAR7



(c) Image contrast on A61A



(f) Image contrast on NTAR7

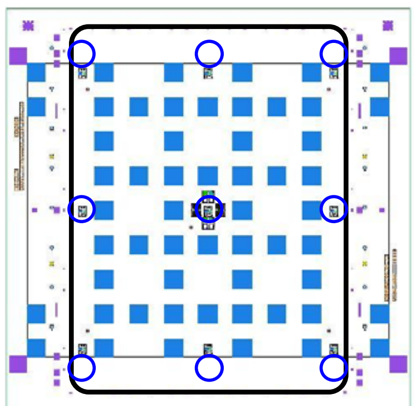
Fig-4 ; Diffraction intensity and image contrast on A61A and NTAR7 at hp45nm in various mask bias

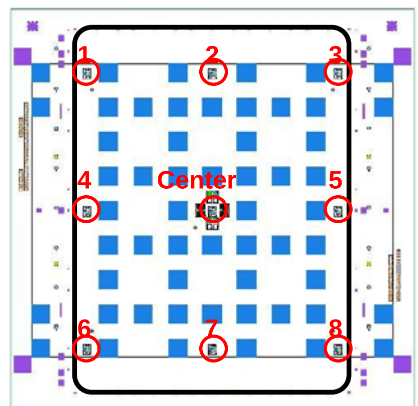
Table-1 ; Summary of image contrast and MEEF on A61A and NTAR7 at hp45nm in different mask bias

		6%HT-PSM(A61A)			Binary(NTAR7)		
		contrast	**MEEF**	slice	contrast	**MEEF**	slice
Simulation	no BIAS	0.534	3.01	0.183	0.536	**1.84**	0.242
	w/ BIAS	**0.546**	**1.80**	0.286	0.580	2.68	0.157
AIMS @CD-SEM	no BIAS	0.493	3.29	0.197	**0.460**	**2.20**	0.298
	w/ BIAS	**0.486**	**2.26**	0.310	0.509	3.24	0.194
AIMS @CD shift (4nmHT, 3nmBIM)	no BIAS	0.475	3.77	0.173	**0.471**	**2.47**	0.268
	w/ BIAS	**0.487**	**2.26**	0.290	0.517	3.92	0.163

Table-2 ; Film thickness measurement results of two different pellicle thickness at 9 locations

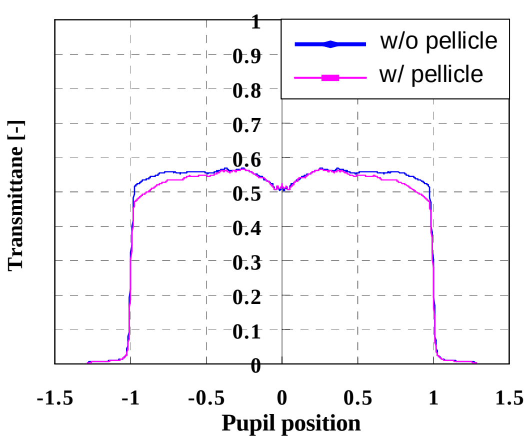
	Pel-1	Pel-2
Ave	830.0	563.3
Max	831.4	564.9
Min	828.1	562.5
Range	3.3	2.4
3sigma	3.5	2.2

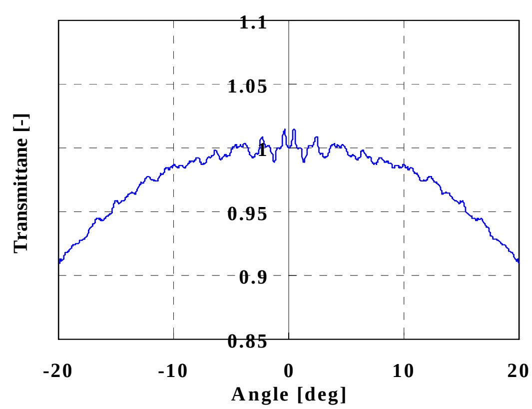




(a) Pellicle film thickness measurement (b) AIMS™ measurement

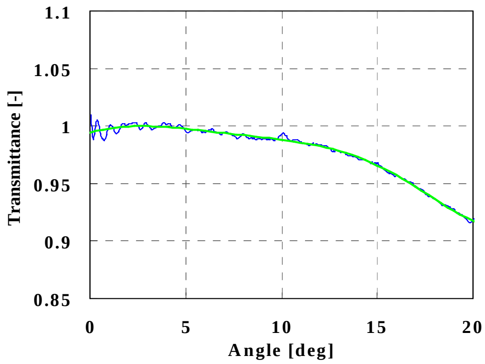
Fig-5 ; Test mask overview and measurement locations for experiments



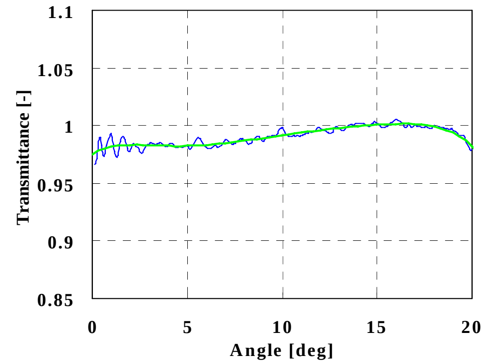


(a) Intensity distribution profile at pupil plane (b) Transmission change by pellicle

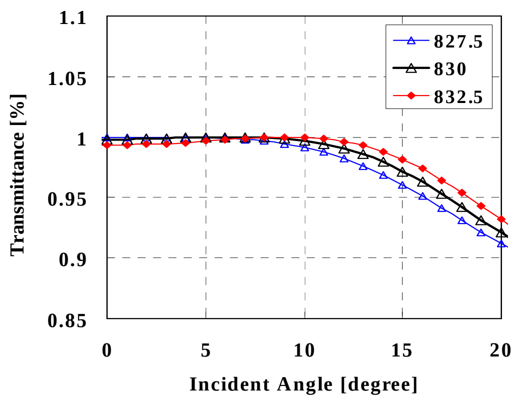
Fig-6 ; Example of transmission change by standard pellicle thickness



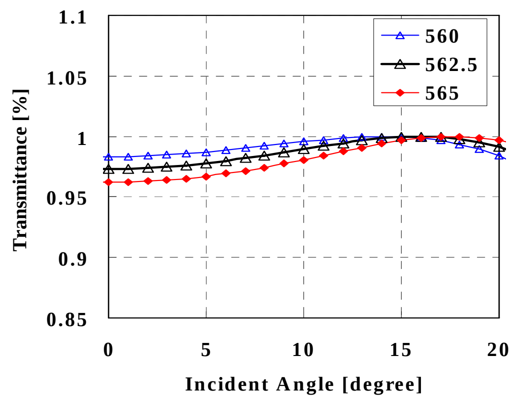
(a) Raw data of transmission change (standard)



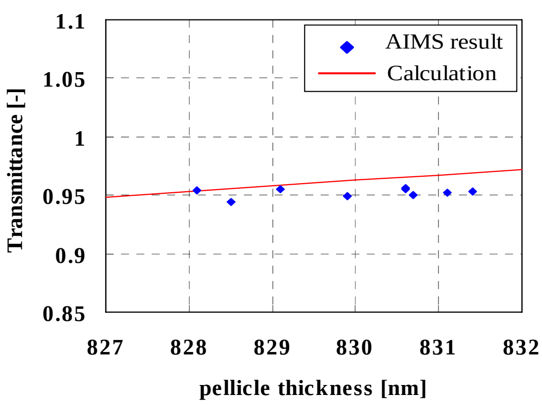
(d) Raw data of transmission change (thinner)



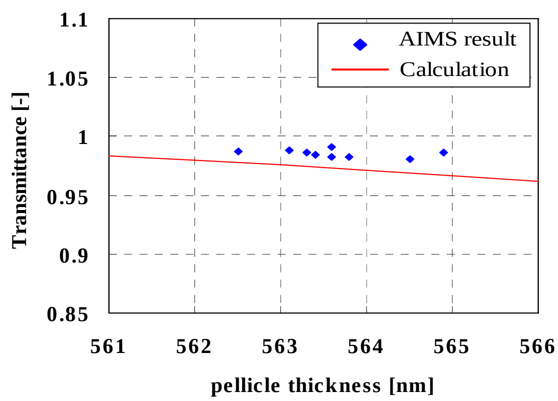
(b) Calculation data of transmission change (standard)



(e) Calculation data of transmission change (thinner)



(c) Trans. at 16deg vs. pellicle thickness (standard)



(f) Trans. at 5deg vs. pellicle thickness (thinner)

Fig-7 ; Transmission change by pellicle and relation to film thickness

Table-3 ; Printed CD measurement results by AIMS™ at hp45nm and hp65nm on with and without pellicle conditions

(a) hp45nm/NA1.40 (standard)

	w/o pellicle	w/ pellicle	Difference
Center	45.0	41.3	-3.7
1	45.9	42.7	-3.2
2	45.7	43.0	-2.7
3	45.7	43.0	-2.7
4	44.7	41.4	-3.3
5	44.8	42.1	-2.7
6	44.4	40.4	-4.0
7	44.1	40.6	-3.5
8	43.8	41.1	-2.7
Average	**44.9**	**41.7**	**-3.2**
3Sigma	**2.2**	**3.0**	-

(b) hp65nm/NA0.95 (standard)

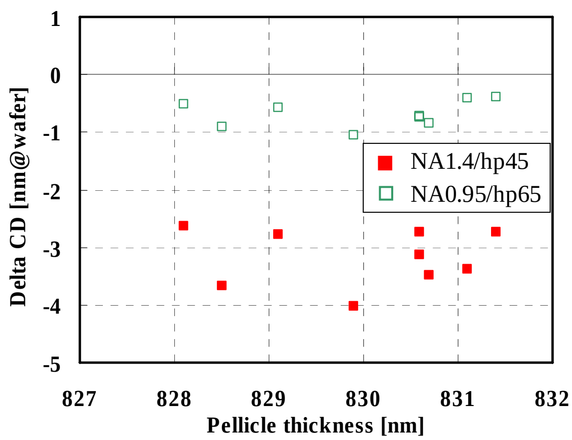
	w/o pellicle	w/ pellicle	Difference
Center	65.0	64.1	-0.9
1	65.5	64.7	-0.8
2	66.0	65.4	-0.6
3	65.1	64.6	-0.5
4	64.5	64.1	-0.4
5	64.9	64.1	-0.8
6	64.0	62.9	-1.1
7	64.4	63.5	-0.9
8	63.8	63.4	-0.4
Average	**64.8**	**64.1**	**-0.7**
3Sigma	**2.1**	**2.3**	-

(c) hp45nm/NA1.40 (thinner)

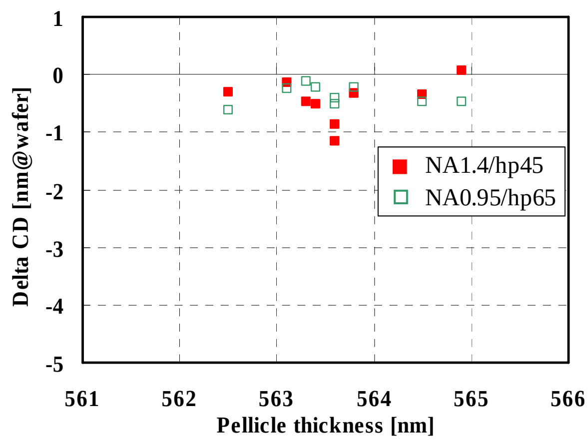
	w/o pellicle	w/ pellicle	Difference
Center	45.0	44.1	-0.9
1	43.4	43.0	-0.4
2	44.3	43.7	-0.6
3	43.5	43.6	+0.1
4	44.3	44.2	-0.1
5	45.1	44.0	-1.1
6	43.0	42.7	-0.3
7	44.1	43.8	-0.3
8	44.6	44.0	-0.6
Average	**44.1**	**43.7**	**-0.4**
3Sigma	**2.2**	**1.6**	-

(d) hp65nm/NA0.95 (thinner)

	w/o pellicle	w/ pellicle	Difference
Center	65.0	64.5	-0.5
1	64.2	63.7	-0.5
2	64.2	63.9	-0.3
3	63.3	63.3	0
4	63.8	64.2	+0.4
5	64.4	64.5	-0.1
6	63.4	63.2	-0.2
7	64.4	63.8	-0.6
8	64.3	64.2	-0.1
Average	**64.2**	**63.9**	**-0.3**
3Sigma	**1.4**	**1.4**	-



(a) CD difference vs. thickness (standard)



(b) CD difference vs. thickness (thinner)

Fig-8 ; Printed CD difference measured by AIMS™ between with and without pellicle vs. film thickness