45nm Node Logic Device OPE Matching between Exposure Tools Through Laser Bandwidth Tuning

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ABSTRACT

For 45 nm Node logic devices, we have investigated the impact of laser bandwidth fluctuation on Optical Proximity Effect (OPE) by evaluating variation in through-pitch critical dimension (CD) performance. In addition, from these results we have calculated the Iso-Dense Bias (IDB), and determined the sensitivity to laser bandwidth fluctuation. These IDB results also enable us to present the laser bandwidth stability that is required to maintain a constant OPE. And finally, we introduce results from an investigation into OPE-matching between different generations of exposure tools, whereby in addition to laser bandwidth control, tilt-scan methodology was employed.

Keywords: Iso-Dense Bias, IDB, laser bandwidth, E95, OPE

1. INTRODUCTION

With the development of 45 nm Node Devices and the device shrinkage that accompanies it, the requirements for tighter process control become increasingly more demanding. This is seen nowhere more acutely than in the need to maintain tight Iso-Dense Bias (IDB) control as part of the overall Optical Proximity Effect (OPE) portion of the Critical Dimension (CD) Budget.

IDB performance can be attributed to numerous factors that generate changes in image contrast or induce focus blur. To date, conventional methods have primarily focused on adjustment of exposure illumination condition in order to optimize IDB. One additional contributor to IDB is the laser light source and its spectral bandwidth, E95%, in particular. With overall CD budget requirements becoming more stringent at the 45 nm Node and beyond, there is now even more demand for very stable bandwidth control and the added ability to set spectral bandwidth with both high accuracy, and greater flexibility. [1]-[5]

By studying through-pitch performance of various 45 nm Node Device patterns on a Hyper NA immersion exposure tool, we will determine the IDB sensitivity to changes in laser bandwidth performance.

In addition, we will investigate the ability to execute an OPE matching strategy for 45 nm Node Devices. This will incorporate both simulations and experimental testing to verify IDB matching between different immersion exposure tools through the adjustment of spectral bandwidth.

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2. ISO-DENSE BIAS STUDY AT 45NM DEVICE

2.1 Evaluation conditions

Our initial investigation, which included both simulation and actual exposure testing, evaluated the laser bandwidth dependency of through-pitch CD for 45 nm Node device, using a 65 nm pattern. For both line and trench evaluation patterns, the optimal mask bias was defined as that which produced printed CD equal to 65 nm. Additionally, we investigated both annular and conventional illumination in order to evaluate the dependency on illumination condition. Using the Active Bandwidth Stabilization Line Narrowing Module (ABS-LNM), we performed the evaluation under the following three E95% laser bandwidth conditions: 240 fm, 360 fm, 500 fm. Laser spectra used for simulations were calculated using spectral data from an actual laser, and set equivalent to the above three E95% laser bandwidth conditions. Experimental condition details are shown in Table 1.

Table 1 Evaluation conditions for IDB study

Item	Conditions
Exposure tool	ArF Immersion with MAX NA 1.2 + ArF Excimer laser XLA 300
Pattern	65 nm Line : pitch = 121 nm ~ 1100 nm, 44 steps, with mask bias 65 nm Space : pitch = 125 nm ~ 1500 nm, 31 steps, with mask bias
Illumination	Annular : NA = 1.2, $\sigma_{outer} = 0.80$, $\sigma_{inner} = 0.50$ Conventional : NA = 1.2, $\sigma = 0.93$
E95%	240 fm, 360 fm, 500 fm
Process	Same resist process for both line and trench
Dose	Under E95% = 240 fm Bandwidth condition, dose under which printed CD at 130 nm pitch equaled 65 nm
Simulation model	Full resist model

Next we will elaborate in more detail on the laser bandwidth adjustment. Laser bandwidth adjustment was performed using a proto-type ABS-LNM. The ABS-LNM enables the laser bandwidth to be automatically controlled to a set E95% value. However, the unit also enables adjustment of the laser bandwidth set point to specific target values. This function is called Tunable ABS. The current experiment adjusted the laser bandwidth over a wide range of E95% values, from 225 fm to 525 fm. Results of this testing are shown in Fig. 1.

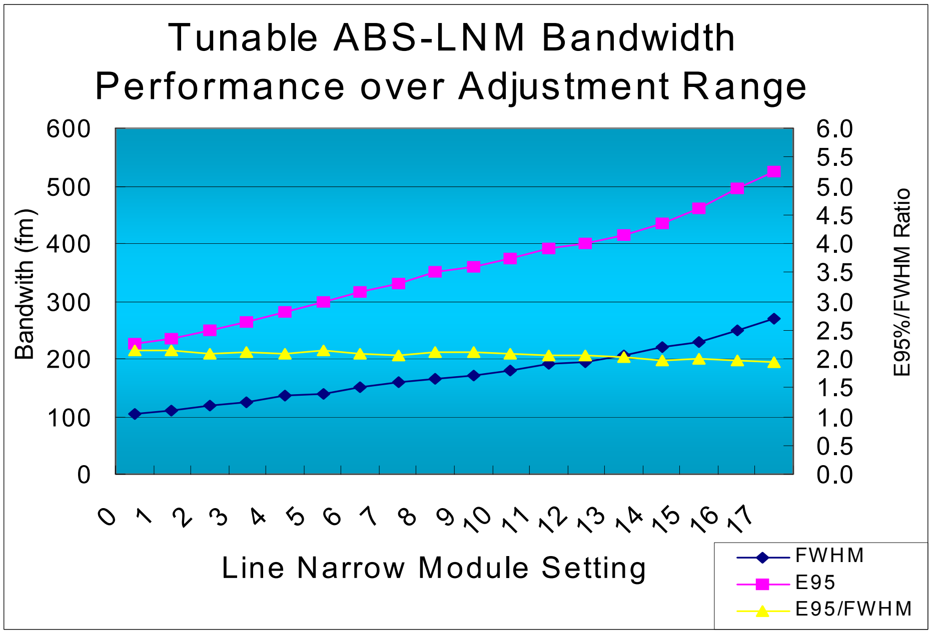


Fig. 1 E95% laser bandwidth adjustability with ABS

Based on these results, we determined the reference E95% laser bandwidth for this experiment to be 240 fm, 360 fm and 500 fm. Moreover, we also verified that the ratio of E95% to Full-Width Half-Max (FWHM) was extremely stable, varying only between 1.94~2.15, indicating very stable spectral shape. This in turn led us to determine that because the laser spectral shape does not vary greatly with ABS-LNM, laser bandwidth adjustment across a wide range was possible. Therefore, based on this understanding, we modified the original spectral data to produced spectra for the same three E95% conditions to be used for input into the simulation. This spectral data used in the simulation is shown in Fig.2. [6]

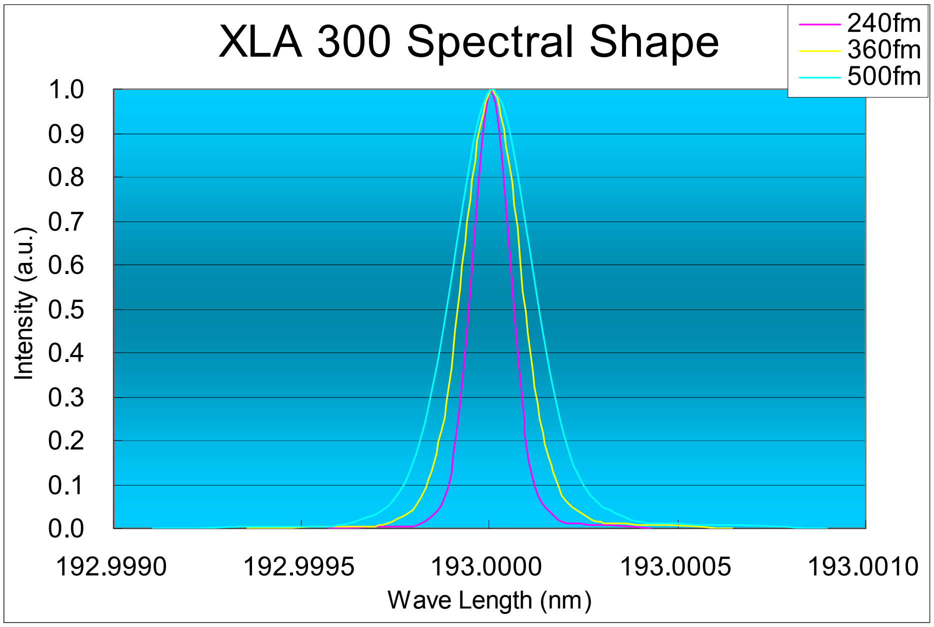


Fig. 2 Laser spectra data for simulation

2.2 Through-pitch CD Behavior for Line Pattern

We next present the through-pitch CD results for the line pattern obtained from both simulation and exposure.

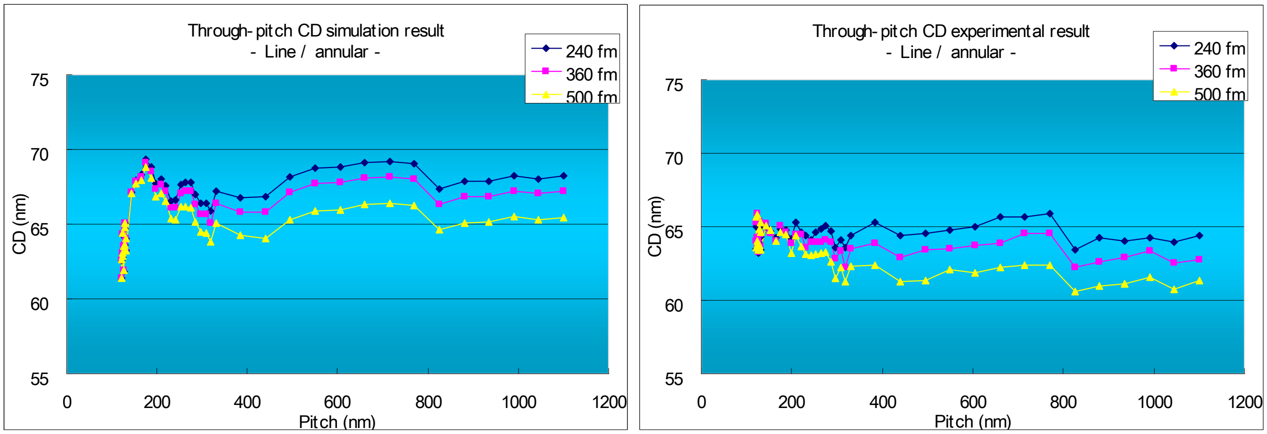


Fig. 3 Simulation and experimental result of through-pitch CD (line / annular)

Simulation and experimental results for line pattern using annular illumination condition are presented in Fig. 3. We can observe from these results that both simulation and experimental results exhibit a similar trend.

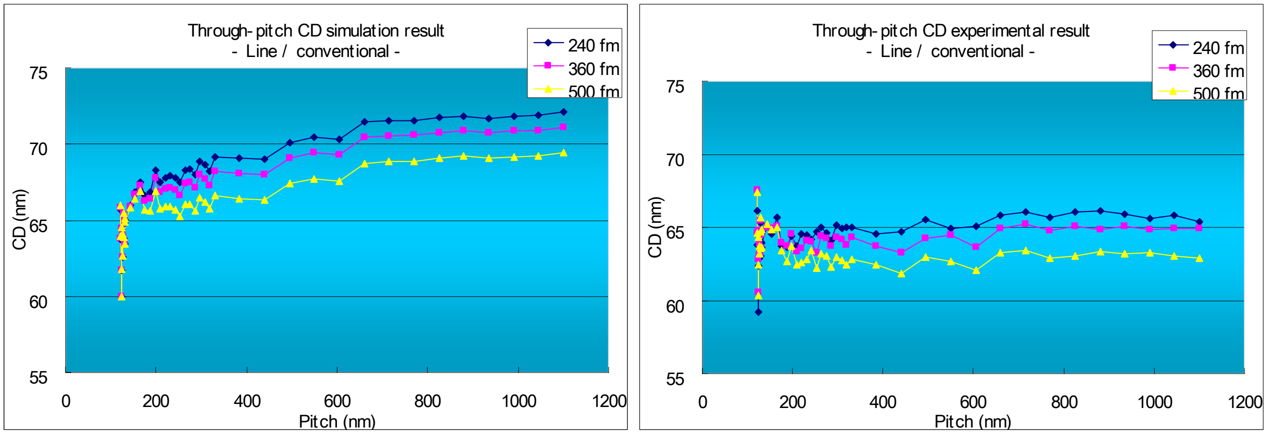


Fig. 4 Simulation and experimental result of through-pitch CD (line / conventional)

Similarly, Fig. 4 shows both simulation and experimental results for the line pattern under conventional illumination. There is also similarity between both simulation and exposure behavior. However, for simulation results, there is a tendency for the CD to become larger as the pattern becomes more isolate, which occurs when bias from experimental results is applied.

Fig. 5 presents the through-pitch ΔCD, as defined as the difference in CD between the E95% 240 fm case and that of 360 fm and 500 fm, respectively.

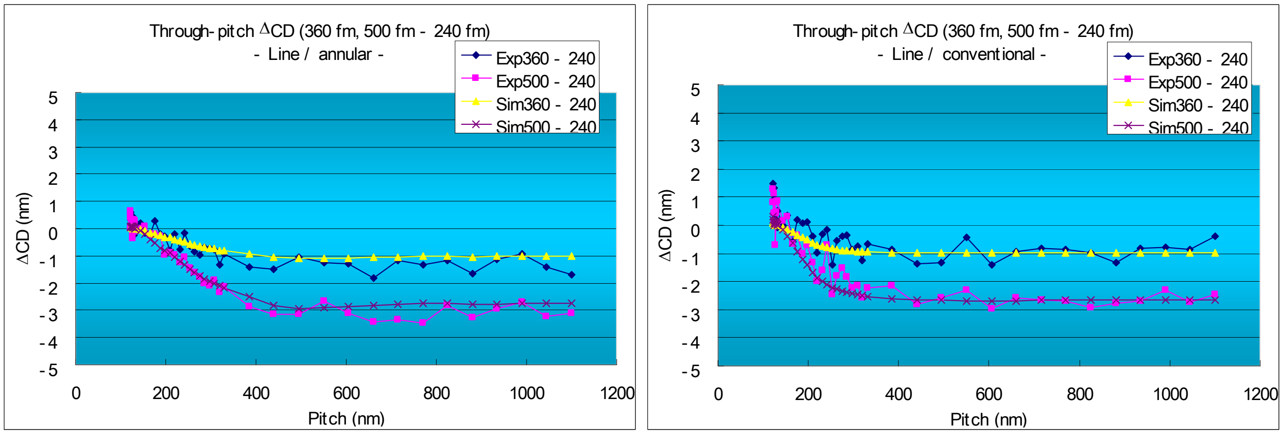


Fig. 5 Through-pitch ΔCD (line)

We can see from these results that there is a high correlation between the simulation experimental results for the line pattern. Furthermore, since the ΔCD due to fluctuation in E95% laser bandwidth is constant beyond a pitch of 500 nm, we can consider 65nm line pattern of 500 nm pitch and greater to be equivalent to isolate condition.

2.3 Through-pitch CD Behavior for Trench Pattern

Next, we present in Fig. 6 both simulation and experimental results for trench pattern under annular illumination condition.

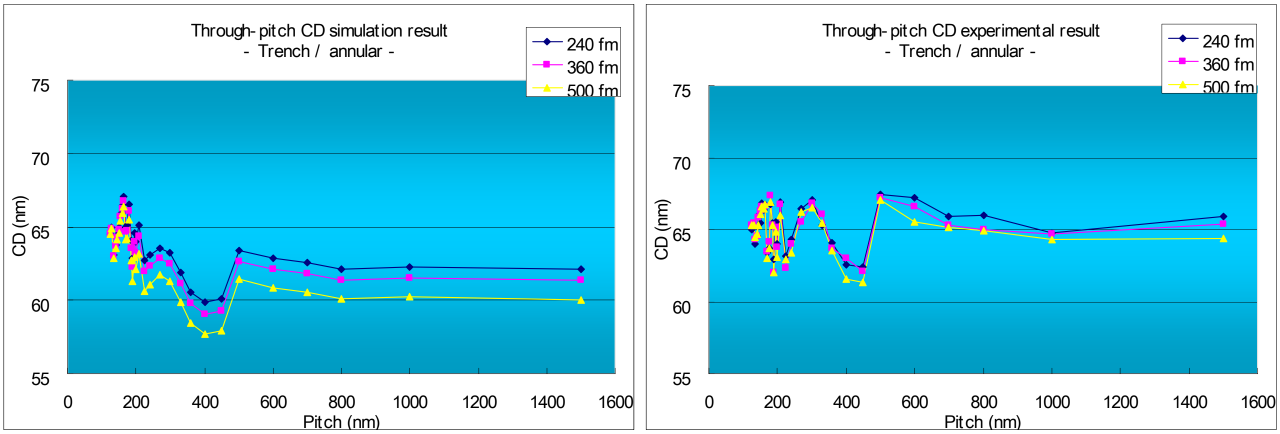


Fig. 6 Simulation and experimental result of through-pitch CD (trench / annular)

These results also exhibit a high degree of correlation between simulation and exposure. The simulation results also show a tendency for the CD to become smaller as the pattern becomes more isolate, again as a result of applying the bias from experimental results.

In Fig. 7 we show simulation and experimental results for trench pattern using conventional illumination.

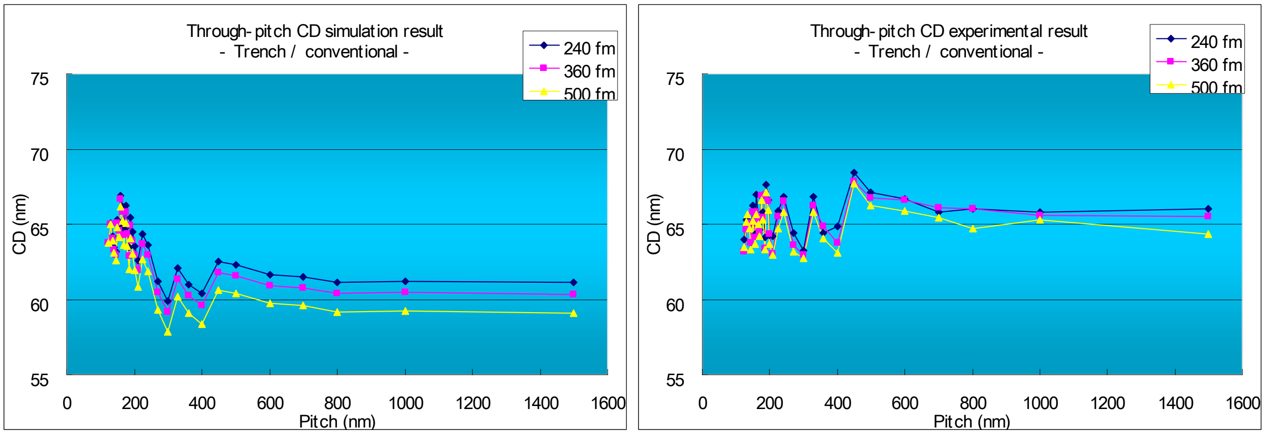


Fig. 7 Simulation and experimental result of through-pitch CD (trench / conventional)

These results also possess a high level of correlation. The tendency for the pattern to become smaller as this pitch is increased is more pronounced that in annular case.

Similar to the line pattern, Fig. 8 shows the through-pitch ΔCD for the trench pattern between E95% of 240 fm and 360 fm, 500 fm, respectively.

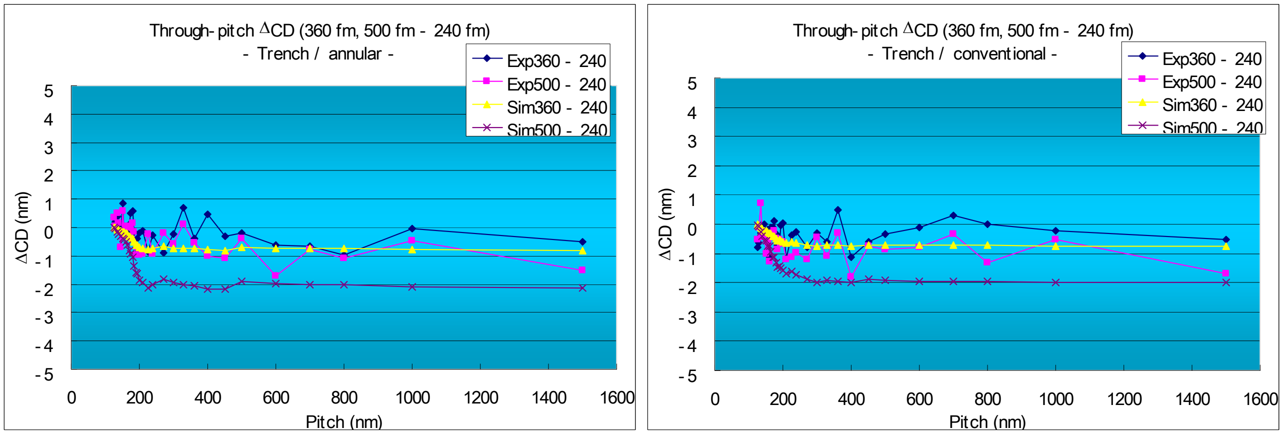


Fig. 8 Through-pitch CD delta (trench)

For the trench pattern, the change in CD when the E95% laser bandwidth is varied greatly is smaller for the experimental results than for simulation. Also, the ΔCD due to change in E95% laser bandwidth is constant beyond a pitch of 300 nm. We can therefore consider 65nm trench pattern of 300 nm pitch and greater to be equivalent to isolate condition.

2.4 IDB sensitivity

We calculated IDB from the through-pitch CD data obtained for both line and trench patterns. Defined as the CD difference between dense and isolate patterns, IDB for the line pattern was calculated using a pitch of 121 nm for dense and 1100 nm for isolate, while for the trench pattern, pitches of 125 nm and 1500 nm, respectively, were used. IDB results for line and trench patterns under both annular and conventional illumination conditions are shown in Fig. 9.

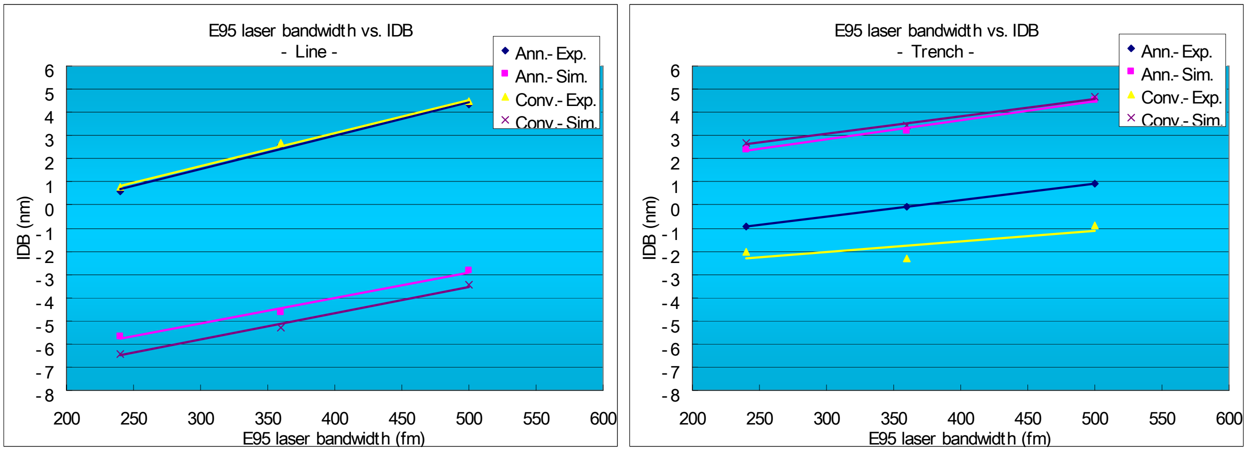


Fig. 9 E95% laser bandwidth vs. IDB

These results also show a good correlation between simulation and experimental results. The current results show that compared to the trench pattern, the line pattern exhibits a greater sensitivity to variation in E95% laser bandwidth. Furthermore, for the above two evaluated illumination conditions, there is minimal difference in the IDB sensitivity as a function of illumination condition. We have determined the allowable E95% laser bandwidth fluctuation for each condition that is required to maintain the change in IDB, in other words, OPE variation, to less than 1 nm. These results are shown in Table 2.

Table 2 Acceptable E95% laser bandwidth variation

	acceptable variation (fm/nm)
Line(Ann.)-Exp.	69.0
Line(Ann.)-Sim.	90.5
Line(Conv.)-Exp.	69.6
Line(Conv.)-Sim.	86.6
Trench(Ann.)-Exp.	141.4
Trench(Ann.)-Sim.	119.7
Trench(Conv.)-Exp.	137.7
Trench(Conv.)-Sim.	130.5

For the line pattern evaluated in this investigation, E95% laser bandwidth stability of within 70 fm is required to maintain OPE variation to less than 1 nm. E95% control methodologies to achieve this level of stability need to be considered.

2.5 MEEF sensitivity

Fig. 10 shows the change in MEEF when E95% laser bandwidth is varied. The measurement patterns are listed in Table 3.

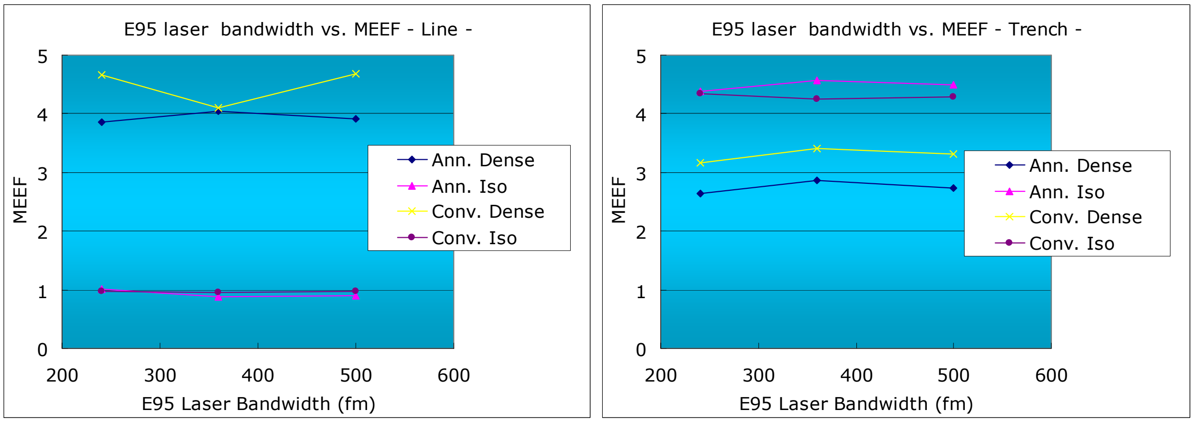


Fig. 10 Experimental result of E95% laser bandwidth vs. MEEF

Table 3 Patterns for MEEF measurement (line / trench)

Line

		Pattern CD	Pitch
Annular	Dense	60 nm	121 nm
	Iso	98 nm	1100 nm
Conventional	Dense	60 nm	121 nm
	Iso	93 nm	1100 nm

Trench

		Pattern CD	Pitch
Annular	Dense	64 nm	125 nm
	Iso	80 nm	1500 nm
Conventional	Dense	64 nm	125 nm
	Iso	72 nm	1500 nm

The experimental results indicate that even with E95% laser bandwidth variation, there is virtually no impact on MEEF for the two evaluated illumination conditions. In addition, MEEF results showed essentially no dependency on illumination condition.

Fig. 11 shows the simulation results confirming the NILS variation under the above conditions. From these results we can see that the change in NILS is extremely small when E95% laser bandwidth is varied. In addition, the variation due to illumination condition is minimal. This correlates well with the current MEEF experimental results.

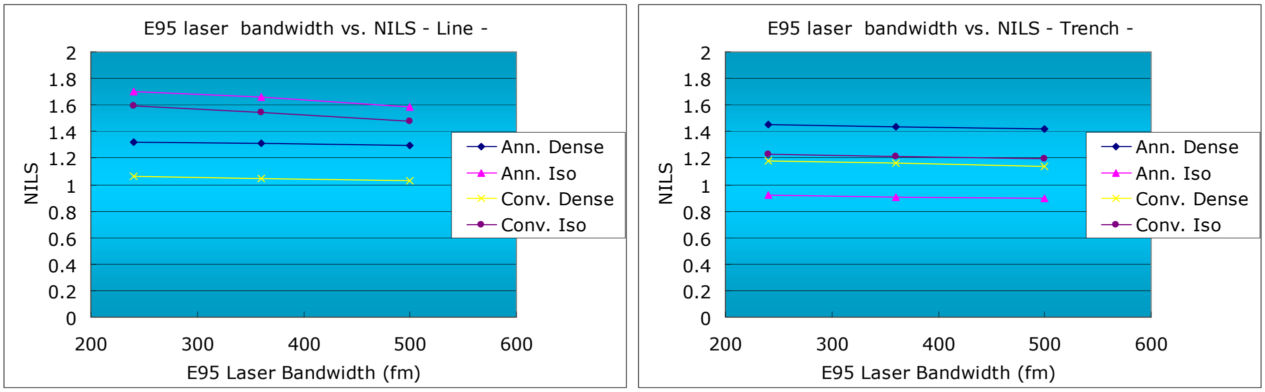
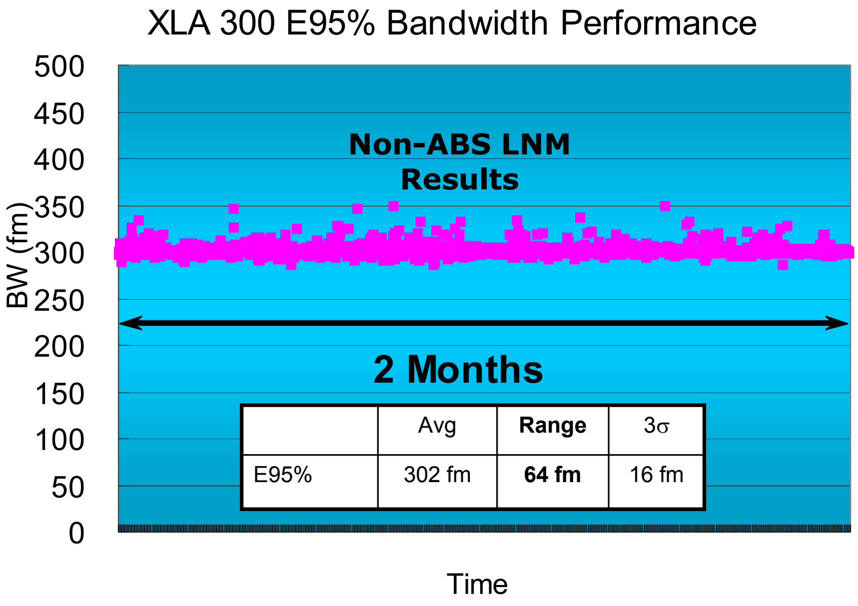


Fig. 11 Simulation result of E95% laser bandwidth vs. NILS

2.6 Laser performance

We next validate the performance of the XLA 300 laser used in this investigation with respect to the E95% laser bandwidth stability requirements as determined from the experimental results. Fig. 12 shows E95% laser stability results for XLA 300 over a two month period.



	Avg	**Range**	3σ
E95%	302 fm	**64 fm**	16 fm

Fig. 12 XLA 300 E95% bandwidth performance

We can see that the current XLA 300 performance – without active laser bandwidth control – satisfies the E95% laser stability requirement of 70 fm. With each successive technology generation, we also estimate that the stability requirements for laser bandwidth will become increasingly more severe. Consequently, active E95% laser bandwidth control technologies, such as ABS to achieve the required stability and Tunable-ABS for adjustment flexibilty, will also be required.

3. OPE MATCHING BETWEEN EXPOSURE TOOLS

Here we investigate OPE matching between different generation exposure tools. OPE differences that arise from different generation exposure tools occur due to the following:

Projection lens design, Illumination design, Chromatic aberration, Laser bandwidth

Differences in projection lens design are particularly great between all-refractive type and catadioptric type. This difference can be expressed as an effective NA delta. Illumination design differences can also be described as effective σ delta. The impact from these differences is determined by the combination of chromatic aberration and laser bandwidth.

Using laser bandwidth adjustment to compensate for these differences is extremely important. However, when the chromatic aberration difference between exposure tools of different generations is large, the required bandwidth may exceed the allowable tolerance setting, and laser bandwidth adjustment alone is insufficient. In this case, another method of adjustment is required, such as contrast adjustment through focus blur by tilt scan exposure. Tilt scan exposure overview and OPE adjustment are explained in Fig. 13. [7]

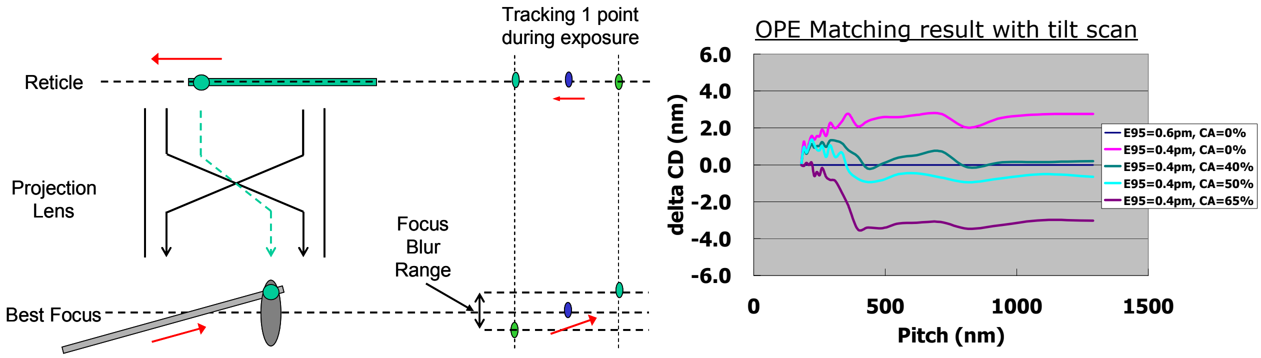


Fig. 13 Contrast adjustment with tilt scan and OPE matching result with tilt scan [7]

Even when applying an adjustment method other than laser bandwidth to achieve OPE matching, a high level of laser bandwidth stability is still required.

Next we report on the OPE matching results between exposure tools of different generations when tilt scan exposure was applied. For both line and trench patterns, we evaluated the ability to match the OPE of max NA 1.2 immersion exposure tool to that of max NA 0.93 immersion exposure tool. Detailed conditions from this investigation are presented in Table 4.

Table 4 OPE matching between exposure tools evaluation conditions

Item	Conditions		
Exposure tool	Tool A	ArF immersion, Max NA=1.2 (Catadioptric), E95% laser bandwidth = 250 fm	
	Tool B	ArF immersion, Max NA=0.93 (All refractive), E95% laser bandwidth = 400 fm	
Target Patterns	Line	CD = 90nm, pitch=121 nm ~ 1100 nm, 44 steps, with mask bias	
	Space	CD = 90nm, pitch=125 nm ~ 1500 nm, 31 steps, with mask bias	
Exposure conditions	Line	Tool A	Optimized NA & illumination (annular), with tilt scan (defocus range 190 nm)
		Tool B	Fixed NA & illumination (annular)
	Space	Tool A	Optimized NA & illumination (Conventional), with tilt scan (defocus range 190 nm)
		Tool B	Fixed NA & illumination (Conventional)

Fig. 14 shows the experimental results after optimization of the Tool A exposure conditions for OPE matching with Tool B.

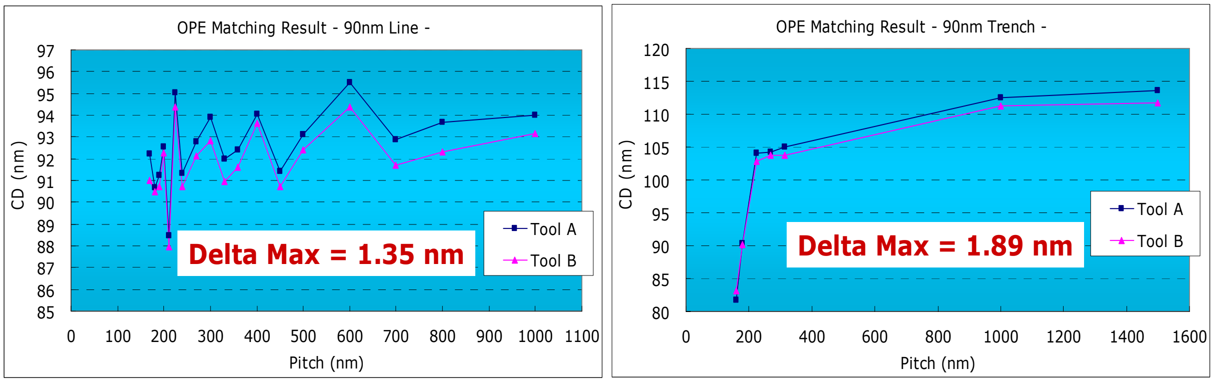


Fig. 14 OPE matching result (line, trench)

We have verified that even when the difference in chromatic aberration is large between exposure tools of different generations, it is possible to achieve OPE matching within 2 nm for both line and trench patterns through the usage of tilt scan and illumination condition optimization.

4. CONCLUSION

We have shown that there is a high correlation between simulation and experimental results for line and trench patterns, and both annular and conventional illumination conditions.

Through both simulation and experimental results, IDB sensitivity to E95% is shown to be greater for the line pattern than the trench pattern.

We have also shown, through simulation and exposure, that IDB sensitivity differences between illumination conditions are minimal for the two investigated illumination conditions.

MEEF sensitivity to E95% due to pattern and illumination condition is shown to be small, and assumptions validated by NILS simulation results.

In order to maintain OPE variation to within 1 nm, we have shown that E95% Laser Bandwidth Stability of less than 70 fm is required. Depending on process and exposure conditions, the change in CD at interim pitches may be larger than at completely isolate condition, thereby requiring tighter laser bandwidth stability.

Current XLA 300 ArF Laser light source bandwidth performance satisfies the target requirements for stability at the 45 nm Node device.

However, as bandwidth requirements become more severe with each successive node, bandwidth technologies – ABS for stability and Tunable-ABS for flexible control & adjustment – will become necessary to satisfy the required performance

Through exposure conditions optimization and implement of tilt scan, OPE matching of max NA=1.2 immersion exposure tool to that of max NA=0.93 immersion exposure tool can be achieved to within 2 nm

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