Effects of Laser Bandwidth on Tool to Tool CD matching

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ABSTRACT

According to the ITRS roadmap, low k1 imaging requires extremely tight control of Critical Dimension (CD). Maintaining the same performance from one exposure to another for new imaging requirements has become increasingly important, particularly for matching dry and wet systems. Tool to tool CD matching depends on many factors, for example, lens aberrations, partial coherence, laser spectral bandwidth and short range flare.

We have performed a detailed study of laser bandwidth effects on tool CD matching for typical 65nm node structures exposed on immersion ArF scanners . A high accuracy on-board spectrometer was used to characterize the lithography

Laser bandwidth, allowing measurements of both the FWHM and E95 parameters of the laser spectrum. Spectral bandwidth was adjusted over a larger range than normally experienced during wafer exposures using Cymer's Tunable Advanced Bandwidth Stabilization device (T-ABS) to provide controlled changes in bandwidth while maintaining all other laser performance parameters within specification.

Measurements of both Lines and Contact Holes on 65nm node structures through all pitches were made and correlated with bandwidth to determine the sensitivity of IDB and C/H to bandwidth variation. We demonstrated that bandwidth can be adjusted for CD matching on different tool using the T-ABS function.

KEYWORDS

Laser bandwidth, E95, Iso Dense Bias, FWHM, T-ABS, CD matching

INTRODUCTION

According to the 2007 lithography roadmap of the International Technology Roadmap for Semiconductors (ITRS), shown in Table 1, low k1 imaging requires extremely tight control of Critical Dimension (CD). Maintaining the same performance from one exposure to another for new imaging requirements has become increasingly important. One of the keys for CD matching is correction of optical proximity effects.

To control proximity effect for tool matching, tool parameters such as CDSEM performance, illumination partial coherence, lens numerical aperture, laser bandwidth and

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focus need to be well controlled. Partial coherence is very popular method for isolated and dense line CD matching. Laser bandwidth also is one of the critical factors. Variations in laser bandwidth will cause defocus errors because of chromatic aberration in the projection lens, resulting in contrast loss and optical proximity error.

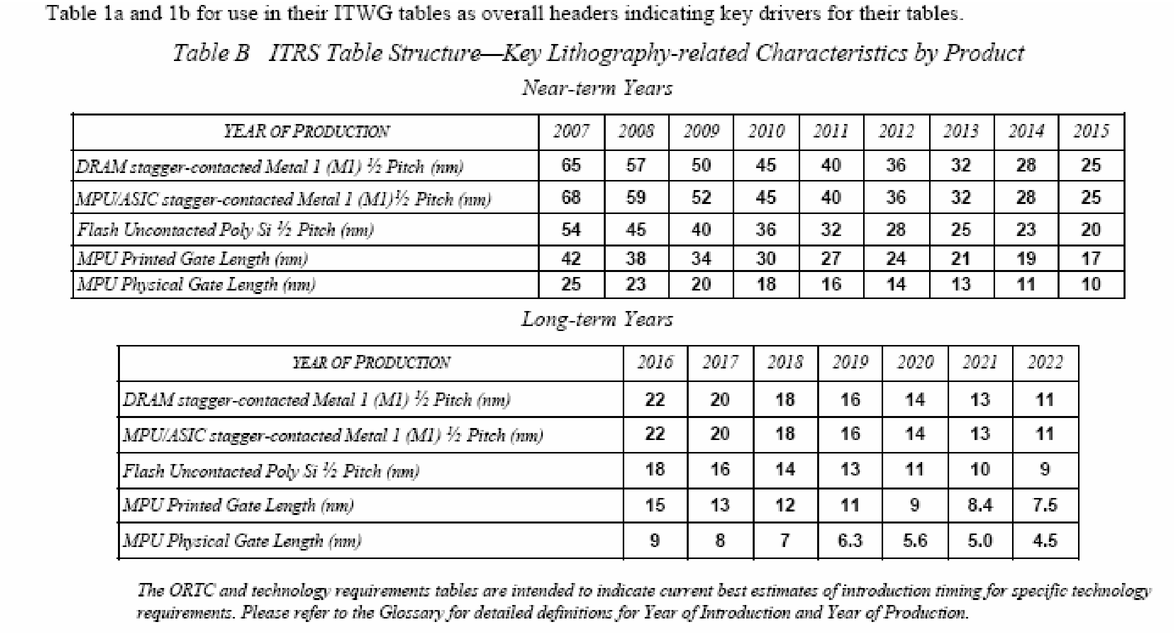


Table 1a and 1b for use in their ITWG tables as overall headers indicating key drivers for their tables.

Table B ITRS Table Structure—Key Lithography-related Characteristics by Product

Near-term Years

YEAR OF PRODUCTION	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
DRAM stagger-contacted Metal 1 (M1) ½ Pitch (nm)	65	57	50	45	40	36	32	28	25
MPU/ASIC stagger-contacted Metal 1 (M1)½ Pitch (nm)	68	59	52	45	40	36	32	28	25
Flash Uncontacted Poly Si ½ Pitch (nm)	54	45	40	36	32	28	25	23	20
MPU Printed Gate Length (nm)	42	38	34	30	27	24	21	19	17
MPU Physical Gate Length (nm)	25	23	20	18	16	14	13	11	10

Long-term Years

YEAR OF PRODUCTION	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*
DRAM stagger-contacted Metal 1 (M1) ½ Pitch (nm)	22	20	18	16	14	13	11
MPU/ASIC stagger-contacted Metal 1 (M1) ½ Pitch (nm)	22	20	18	16	14	13	11
Flash Uncontacted Poly Si ½ Pitch (nm)	18	16	14	13	11	10	9
MPU Printed Gate Length (nm)	15	13	12	11	9	8.4	7.5
MPU Physical Gate Length (nm)	9	8	7	6.3	5.6	5.0	4.5

The ORTC and technology requirements tables are intended to indicate current best estimates of introduction timing for specific technology requirements. Please refer to the Glossary for detailed definitions for Year of Introduction and Year of Production.

Experimental and simulation work on the effects of laser bandwidth has been carried out in the past [1][2][3]. The effects of the bandwidth metrics, Full Width at Half Maximum (FWHM) and E95, have been clearly defined. One-dimensional optical proximity performance and CD sensitivity to laser bandwidth changes for a 80-nm technology node were recently reported. [3]. For 45nm node BW sensitivity , R.C Peng has report at last year[4]. The effects of laser bandwidth for tool matching is unknown. This paper will provide a detailed study of laser bandwidth and partial coherence effects on tool CD matching for typical 65nm node structures exposed on both immersion scanners. A high accuracy on-board spectrometer was used to characterize the lithography.

Laser bandwidth, allowing measurements of both the FWHM and E95 parameters of the laser spectrum. Spectral bandwidth was adjusted over a larger range than normally experienced during wafer exposures using a Tunable Advanced Bandwidth Stabilization device (T-ABS) to provide controlled changes in bandwidth while maintaining all other laser performance parameters within specification.

Measurements of both Lines and Contact Holes on 65nm node structures through all pitches were made and correlated with bandwidth to determine the sensitivity of IDB and C/H to bandwidth variation. We demonstrated that bandwidth can be adjusted for CD matching on different tool using the T-ABS function.

TUNABLE ADVANCED BANDWIDTH STABILIZATION FUNCTION AND EXPERIMENTAL CONDITIONS

2.1 Tunable Advanced Bandwidth Stabilization

In a typical excimer laser, narrow bandwidths are attained using a grating-based line narrowing module (LNM). The grating acts as a wavelength narrow-pass filter, effectively limiting the spectral characteristics to a narrow regime.

Cymer has developed a means to add modulation within this device, which can provide Active Bandwidth Stabilization (ABS) and which is tunable, to allow compensation for bandwidth variations over the life of the laser consumable,

thereby improving stability of the light source. The ABS feature enables closed loop Active Bandwidth Stabilization, and results in significantly improved stability compared to a non-stabilized configuration [5].

This same method can be used to change the bandwidth target within the same lithography tool for tool matching. This application is named “Tunable” Active Bandwidth Stabilization (Tunable ABS).

In this study, the illumination source is a Cymer XLA 360 laser, which is a dual chamber MOPA design with a Master Oscillator (MO) and Power Amplifier (PA). To change the bandwidth, we used the T-ABS device to achieve different E95 targets. Three settings were used in this experiment, as shown in Table-1.

	E95	FWHM	Ratio
Setting 1	302	146	2.07
Setting 2	392	185	2.12
Setting 3	504	236	2.14

Table 1 Laser bandwidth setting

2.2 Lithography Experimental Conditions

To study the Optical Proximity performance for tool matching, we used an OPC monitor pattern to check L/S and C/H through all pitches. The layout included vertical and horizontal lines. The experimental conditions are listed in Table 2 at each bandwidth condition, 3 sets of different illumination conditions were used to study the OPE response to these variables.

All conditions were exposed with an 0.93NA immersion scanner. For CD measurements, we used a Scanning Electron Microscope (SEM) to measure both lines and contact holes. Scanner and laser parameters were recorded and controlled within specifications during all bandwidth adjustments to reduce experimental noise. At each exposure condition, 3 wafers were measured for L/S and Contact Hole CD.

Bandwidth	Illumination type	Na	s-out	s-in
Setting 1	Annular	0.93	0.9	0.6
			0.9	0.7
			0.8	0.6
Setting 2	Annular	0.93	0.9	0.6
			0.9	0.7
			0.8	0.6
Setting 3	Annular	0.93	0.9	0.6
			0.9	0.7
			0.8	0.6

Table 2a: L/S experiment split table

Partial Coherence

Bandwidth	Illumination type	na	s-out	s-in
Setting 1	Quasar (Dense)	0.93	0.9	0.7
	Annular (ISO)		0.7	0.3
	Quasar (Dense)	0.93	0.9	0.6
	Annular (ISO)		0.7	0.4
	Quasar (Dense)	0.93	0.8	0.6
	Annular (ISO)		0.8	0.4
Setting 2	Quasar (Dense)	0.93	0.9	0.7
	Annular (ISO)		0.7	0.3
	Quasar (Dense)	0.93	0.9	0.6
	Annular (ISO)		0.7	0.4
	Quasar (Dense)	0.93	0.8	0.6
	Annular (ISO)		0.8	0.4
Setting 3	Quasar (Dense)	0.93	0.9	0.7
	Annular (ISO)		0.7	0.3
	Quasar (Dense)	0.93	0.9	0.6
	Annular (ISO)		0.7	0.4
	Quasar (Dense)	0.93	0.8	0.6
	Annular (ISO)		0.8	0.4

Table 2b: C/H experiment split table

EXPERIMENTAL RESULTS

3.1 Bandwidth data

When T-ABS was used to set different E95 targets (Figure 1) streaming laser data was collected by an on-board bandwidth metrology unit, called the Bandwidth Analysis Module (BAM).The bandwidth control 3 sigma of the lowest bandwidth, setting 1, (E95 target is 302fm) is below 10 fm. The bandwidth control 3 sigma of the highest bandwidth, setting 3, is slightly higher at 17 fm. The bandwidth was observed to be very stable during the wafer exposure process.

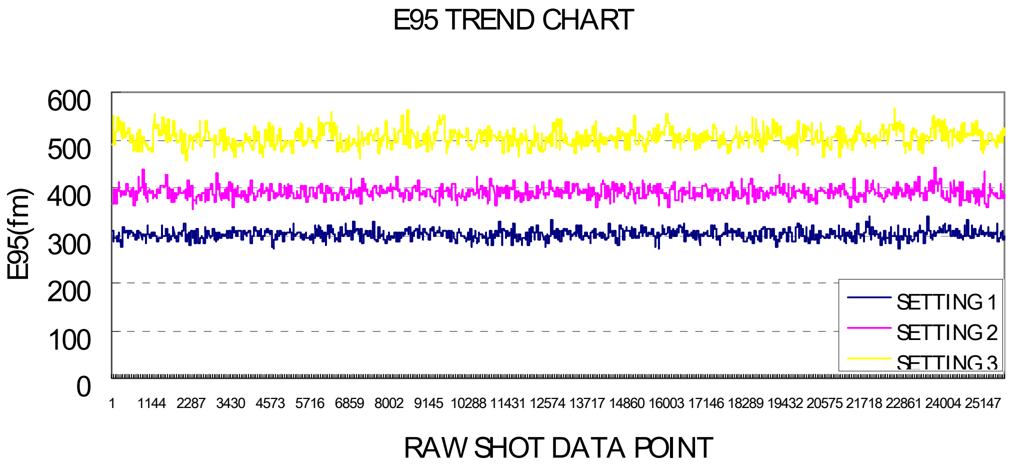


Figure-1: E95 bandwidth control trend chart at 3 bandwidth settings.

3.2 L/S OPE performance

Linewidth was measured at eighteen pitches between dense (1:1) and isolated. The results for 3 types of illumination condition are shown in Figure 2/3/4, for each bandwidth setting.

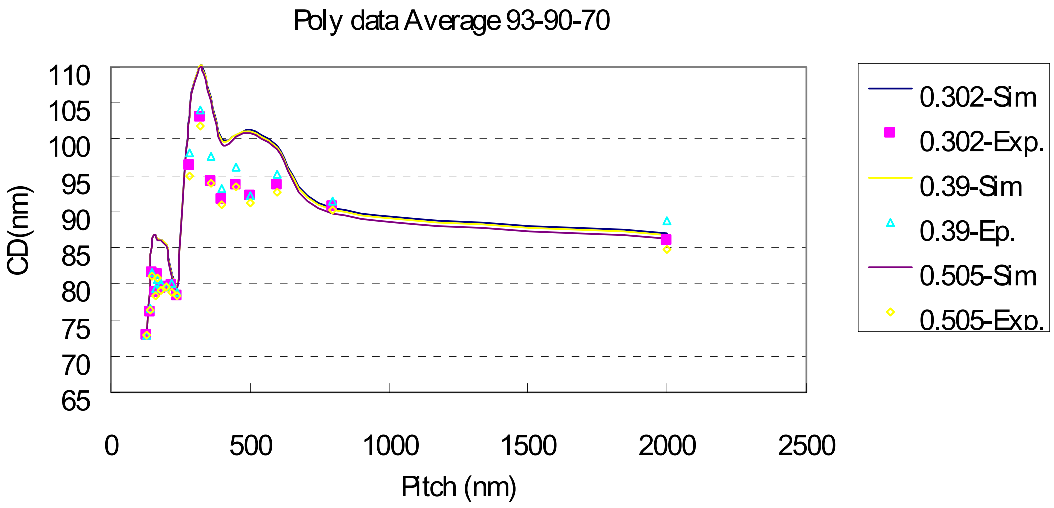


Figure 2 : Experiment data for NA 0.93 ,Outer coherence 0.9 , Inner coherence 0.70 with different E95 BW condition.(0.302pm / 0,39pm /0.505pm)

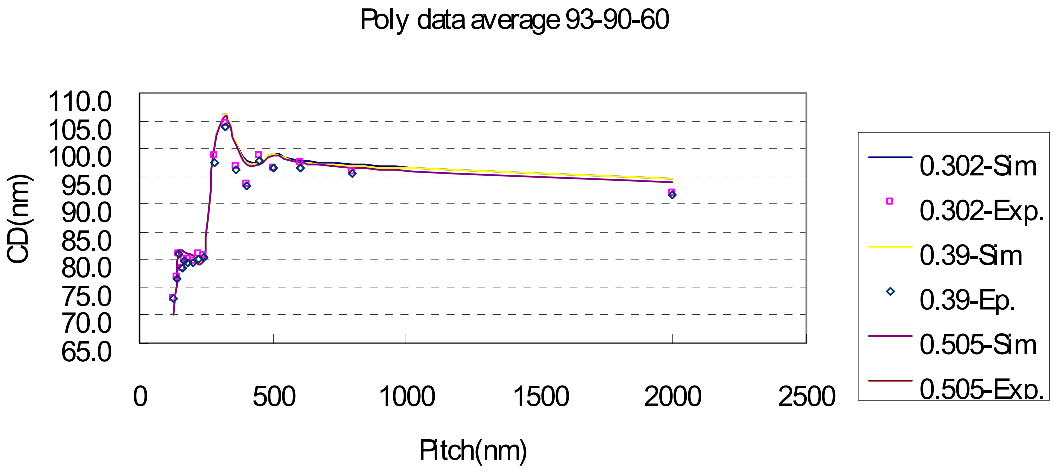


Figure 3 : Experiment data for NA 0.93 ,Outer coherence 0.90 , Inner coherence 0.60 with different E95 BW condition.(0.302pm / 0.39pm)

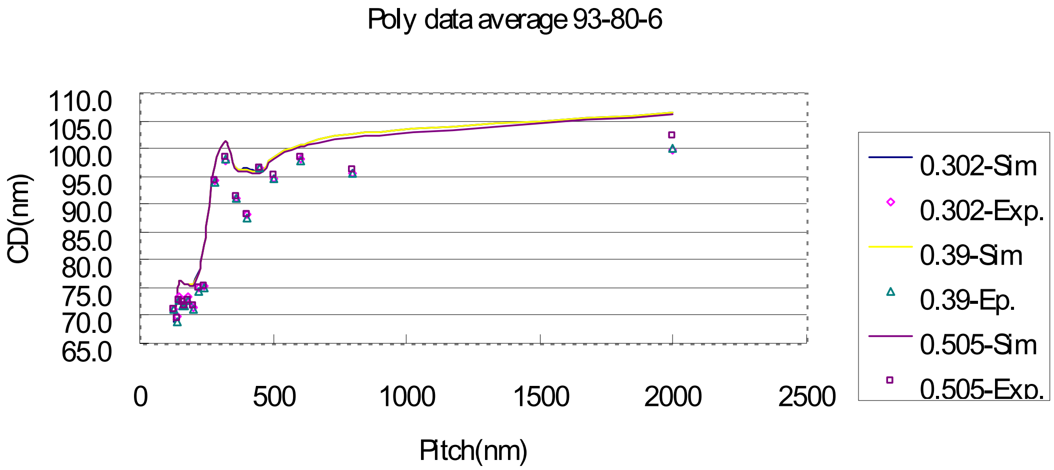


Figure 4 : Experiment data for NA 0.93 ,Outer coherence 0.80 , Inner coherence 0.60 with different E95 BW condition.(0.302pm / 0,39pm /0.505pm)

The OPE curves are shown at the three bandwidth settings, the lowest bandwidth being closest to the nominal imaging conditions. As expected , the change in CD was larger for the isolated features, which is well known to be more sensitive to changes in contrast. IDB, the difference between the CD of dense lines and isolated lines is often used to characterize optical proximity performance. For all E95 BW condition, the CD sensitivity to BW is around 0.5nm to 1.2nm per 0.1 pm BW. The three illumination conditions showed little difference in the shapes of the curves at each bandwidth conditions, as shown in Figure 5/6/7.

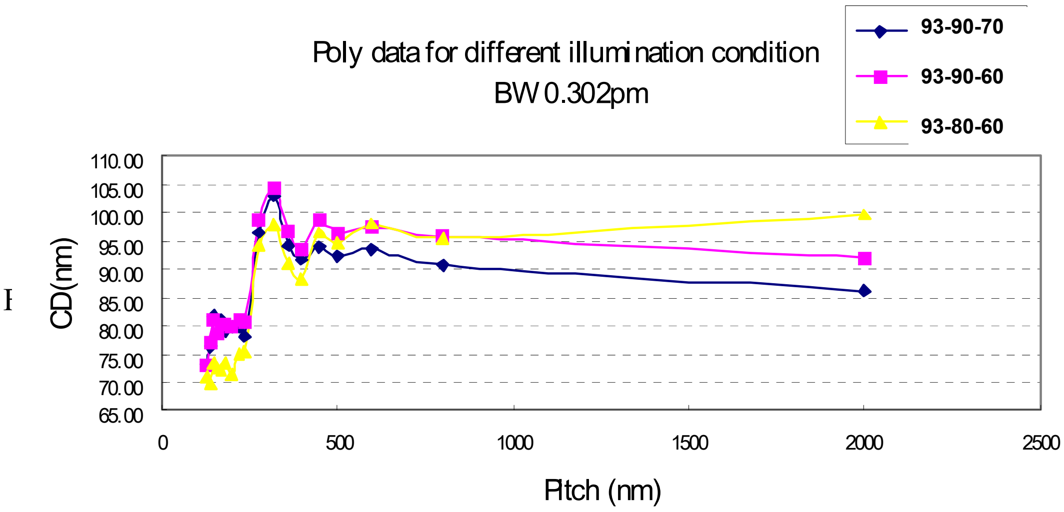


Figure-5: Experiment data for E95 BW 0.302 pm with different illumination condition.

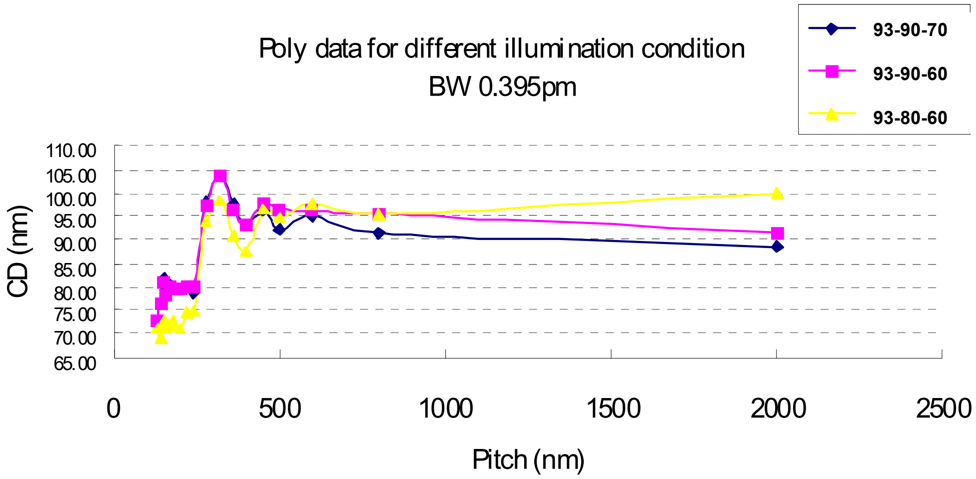


Figure-6: Experiment data for E95 BW 0.395 pm with different illumination condition.

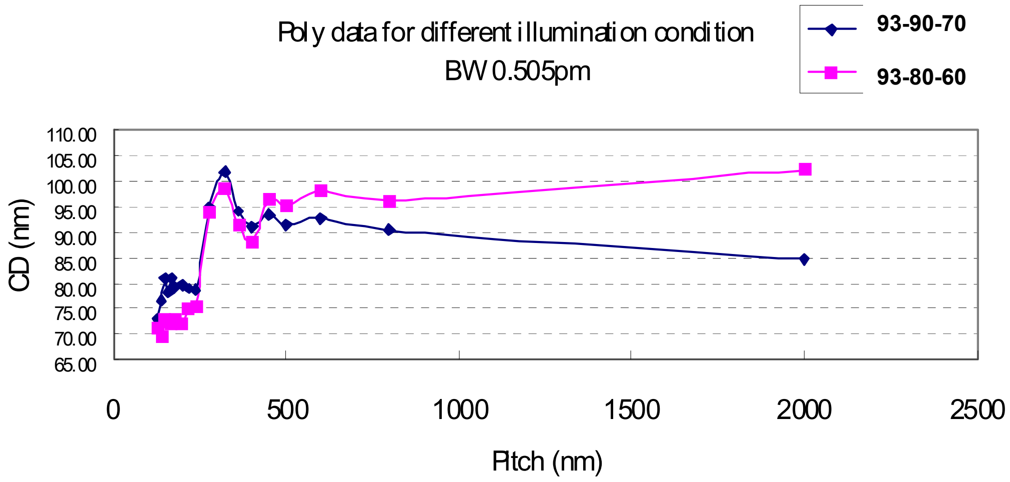


Figure-7: Experiment data for E95 BW 0.505 pm with different illumination condition.

The CD sensitivity to coherence change is greater than the sensitivity to BW. The inner coherence CD sensitivity is 4.9nm per 0.1 inner coherence. Different outer sigma produce different OPE shapes, but only slight changes in the inner sigma can be used to compensate for IDB. For tool matching , we can use illumination conditions to match the OPE behavior between different scanner tools. BW primarily influences isolate line CD and not all OPE features.

3.3 C/H OPE performance

Contact holes were measured at twelve pitches between dense hole(1:1) and isolated hole. The results for 3 types of illumination condition are shown in Figure 8/9.

Due to resolution issues, we used 2 types of illumination condition for dense hole and isolated hole; annular for isolated holes and quasar for dense holes.

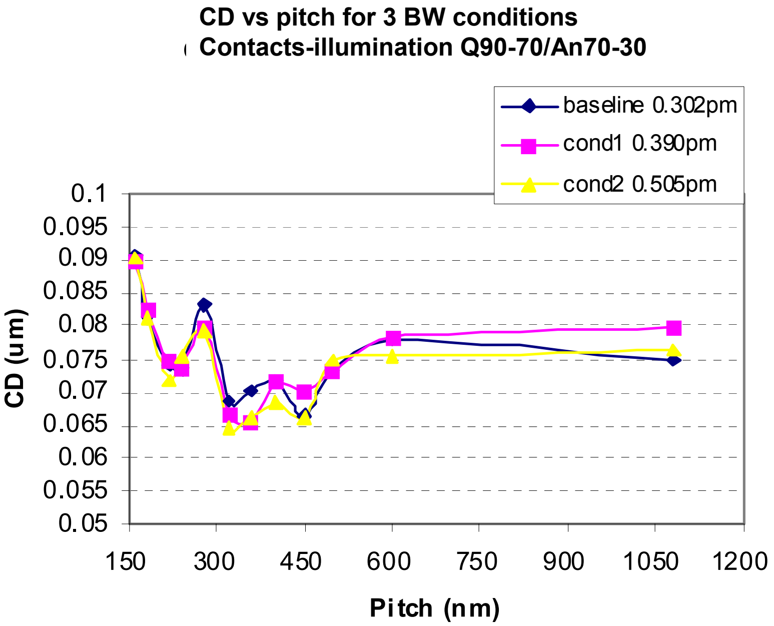


Figure 8 : C/H Experiment data for NA 0.93 Quasar outer sigma 0.90 , Inner sigma 0.70 , Annular outer sigma 0.70 ,inner sigma 0.30 with different E95 BW condition.(0.302pm / 0,39pm /0.505pm)

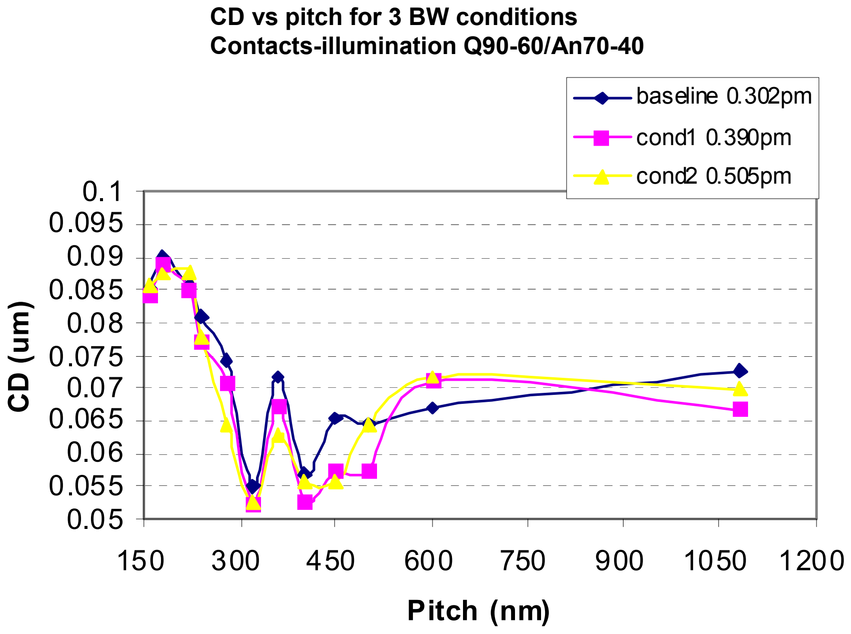


Figure 9 : C/H Experiment data for NA 0.93 Quasar outer sigma 0.90 , Inner sigma 0.60 , Annular outer sigma 0.70 ,inner sigma 0.40 with different E95 BW condition.(0.302pm / 0,39pm /0.505pm)

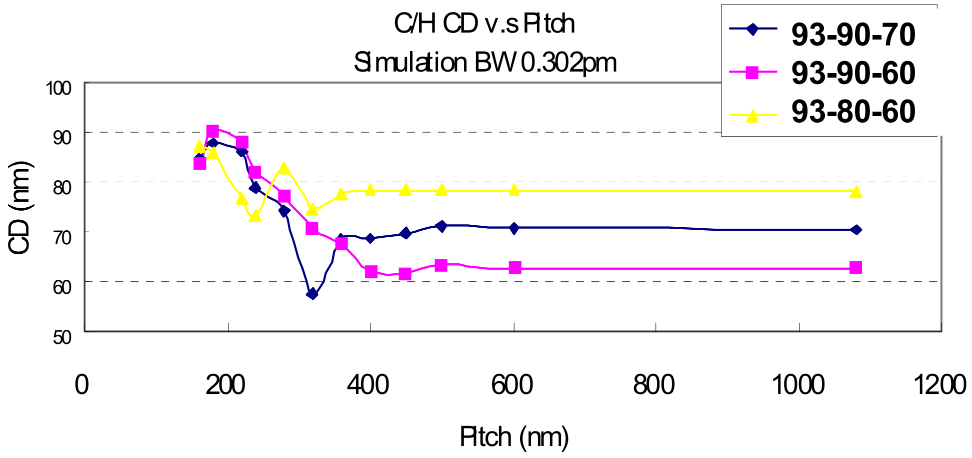


Figure 10 : C/H simulation for NA 0.93 BW 0.302pm with different illumination condition.

Figure 10 show C/H CD is very sensitive to illumination condition. The C/H CD sensitivity to coherence is smaller than the sensitivity to BW. The inner coherence CD sensitivity is1.3 ~ 5.1 nm per 0.1 inner coherence. Different outer sigma produce different OPE shapes, but only slight changes in the inner sigma can be used to compensate for IDB.We get the same conclusion as with L/S; illumination will change the OPE feature, bandwidth only influences isolated line CD. For tool matching, if the OPE curve is different, we need to adjust the illumination condition, but on the production line, we suggest adjusting the laser bandwidth for IDB matching, since this is safer for the production environment. T-ABS is a very useful technique for changing bandwidth for different lasers and provides very powerful tool matching.

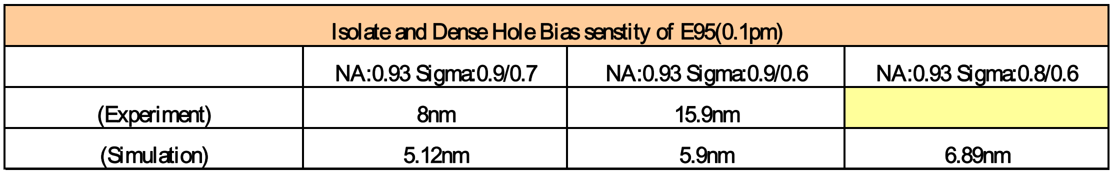
DISCUSSION AND CONCLUSIONS

In this paper, we checked the OPE and IDB sensitivity to laser bandwidth and illumination condition. A summary of the CD sensitivity results is shown in Table-3. Based on these results, BW only influences isolated line CD and will not influence other OPE features. If we can provide stable BW, it also improves the isolated line CD stability. For different tools, we can use the Cymer T-ABS function to adjust the BW for tool matching. ABS can also overcome the bandwidth drift due to laser module aging to provide more stable CD.

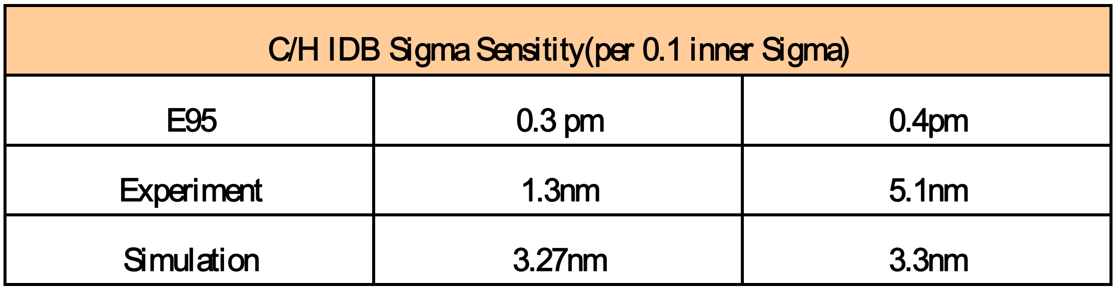
IDB senstity of E95(0.1pm)			
	NA:0.93 Sigma:0.9/0.8	NA:0.93 Sigma:0.9/0.6	NA:0.93 Sigma:0.8/0.6
(Experiment)	0.65nm	0.5nm	1.2nm
(Simulation)	0.39nm	0.31nm	0.27nm

Sigma Sensitity(per 0.1 inner Sigma)		
E95	0.3 pm	0.4pm
Poly	4.8nm	4.6nm
Simulation	9.3nm	9.3nm

Table-3a . Summary for line



Isolate and Dense Hole Bias senstity of E95(0.1pm)			
	NA:0.93 Sigma:0.9/0.7	NA:0.93 Sigma:0.9/0.6	NA:0.93 Sigma:0.8/0.6
(Experiment)	8nm	15.9nm	
(Simulation)	5.12nm	5.9nm	6.89nm



C/H IDB Sigma Sensitity(per 0.1 inner Sigma)		
E95	0.3 pm	0.4pm
Experiment	1.3nm	5.1nm
Simulation	3.27nm	3.3nm

Table 3b. Summary for Hole

*:

ACKNOWLEDGEMENTS

Thanks to Joe Bendik at Dynamic Intelligence Inc. for the simulation work.

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