Challenging to meet 1nm Iso- Dense Bias (IDB) by controlling Laser Spectrum

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Abstract

According to the ITRS Roadmap, for 45nm Node (as 65nm Half Pitch), the requirement of Gate CD Control is defined as 2.6nm. One of the most challenging CD errors is Iso-Dense Bias (IDB). Assuming 40% of CD errors are dominated by IDB, IDB should be less than 1nm. In general, the majority of IDB is due to: primarily, exposure tool-related factors such as aberrations, flare, and sigma fluctuation, and secondly, the change in photoresist characteristics. However, due to the rapidly increasing usage of ArF exposure tools, Band Width (BW) characteristics of the laser source is an additional factor whose contribution is becoming more critical.

Ideally, BW is monochromatic, thereby not affected by chromatic aberration change. However, in reality, the BW exhibits a shape of spectral distribution with a finite width.

This study describes experimental and simulation results for E95%, and how performance of both CDs and Laser is dependent on E95% in order to meet 1nm of IDB towards 45nm Node.

-IDB vs. E95%

-CD at through pitch vs. E95%

-Process Latitude vs. E95%

-DOF

-EL

-Pattern shortening vs. E95%

1. Introduction

Transistor performance is dependent upon CD Uniformity, however the challenge for lithography CDU is that, while in past CDU was dominated by exposure tool factors, now there are multiple factors affecting CDU. For example, reticle and resist factors are now non-negligible in terms of overall budget. However, after fixing processing conditions, such as the exposure tool, reticle, resist, etc., and then basing OPE characteristics on the aforementioned fixed conditions, there still is CD instability. This CD instability is contributed by the variability associated with each individual factor, such as exposure tool, resist, reticle, etc., however, chromatic aberration variability due to the

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exposure laser light source can now not be ignored as a factor affecting CDU. Chromatic aberration variability is defined as the fluctuation in the laser spectral bandwidth (E95%). The sensitivity of printing performance to spectral bandwidth fluctuation is obtained and from this, the required E95% is determined. In particular, focusing on Iso-Dense Bias (IDB), which is highly dependent on OPE, we investigated the required E95% performance and the dependence of other factors on E95% fluctuation.

2. E95% Definition and Evaluation Condition

2.1E95% Definition

The laser has a monochromatic ideally, but exhibits a spectral behavior that is a shape of spectral distribution with a finite width. Different wavelengths, arising from the varying spectral bandwidths, exhibit different chromatic aberration characteristics, leading to variations in best focus values. The combination of these best focus values is chromatic aberration (Fig. 1).

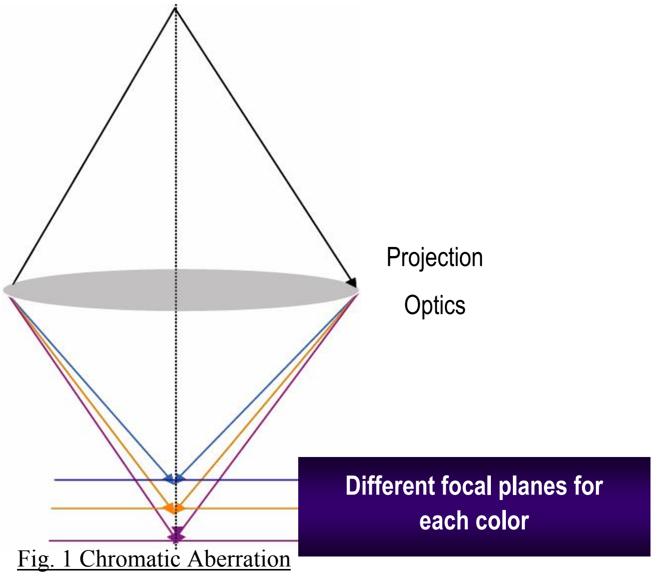


Fig. 1 Chromatic Aberration

Specifically, small spectral bandwidth (E95%) is advantageous to chromatic aberration, whereas large spectral bandwidth leads to defocus, and contributes to loss in contrast. E95% is defined as 95% of the integrated area of the entire spectral distribution.

2.2 Experimental Condition

The current evaluations conditions are presented in Table 1. The evaluation investigated (a) the sensitivity of each CD to E95%, (b) process margin and (c) laser performance. Our evaluation was performed using both simulation and actual exposure experiments for Line CD, Trench CD and Through-pitch patterns. The exposure condition used a Nikon NSR S308F, with illumination condition of NA=0.92, 1/2 Annular σ outer=0.95; E95% was set to a nominal of 0.36pm, and varied for 0.3pm, 0.5pm, 0.6pm and 0.7pm. Printing performance experiments used Cymer XLA-145 laser, while stability experiments utilized Cymer XLA-240 laser integrated with a Nikon NSR S609B

Table 1 Experiment Condition .

Test Features	**CD Characteristics**	Dense=(Line 70nm/ Space=90nm), Iso= 120nm on Reticle, Fat Line= (L=200/ S=100)
	Line (Through Pitch)	L=70nm/ S=90nm through L=70nm/ S=3000nm (Experiment), L=70nm/ S=90nm through L=70nm/ S=2000nm (Simulation)
	Iso Dense Bias (IDB)	L=70nm/ S=90nm and Iso=120nm on Reticle, Iso=70nm on wafer as target
	Trench	Dense=(Line 70nm/ Space=90nm), Trench=(L=2000/ S=110nm), Trench w/ SRAF (S=94nm)
	Line End Shortening	Described at Data Page
	Focus/ Exposure Latitude	Line Pitch 160= (L=70nm/ S=90nm), P200= (L=70nm/ S=130nm), Iso w/ SRAF= (L=90nm/ S=100), Trench w/SRAF= (S=94nm/ L=100nm)
Scanner/ NA & σ	Nikon NSR-S308F NA=0.92, σ=0.95 1/2Annular	
Substrate	ArF Resist (200nm) on BARC (82nm) on Bare Silicon	
CD/ Dose Determination	For Simulations, Light Intensity Threshold at Line=70nm/ Space=90nm Foe Experiment, Line=70nm/ Space=90nm on reticle should be L=70nm/ S=90nm on wafer	
E95% Laser Setting	For Simulations, E95%= 0.30, 0.38, 0.50, 0.60, 0.70, 0.80pm respectively	
	For Experiment, E95% value as described at Data Page	
Laser Model	For Experiment of Wafer Patterning; Cymer XLA 105	
	For Long Term Stability; Cymer XLA 240 integrated to Nikon NSR-S609B	

3. Correlation between E95% and each CD

3.1 Line CD Sensitivity to E95%

Fig. 2 presents exposure results for E95% sensitivity for three types of Line CDs.

- Line CD plot for Dense Pattern consisting of Line CD=70nm and Space CD of 80nm
- Iso CD plot for Iso Pattern of 120nm Line on-reticle, and approximately 70nm on-wafer
- CD plot for Fat Line Pattern of Line CD=200nm, Space=100nm on-reticle, and approximately 225nm on-wafer

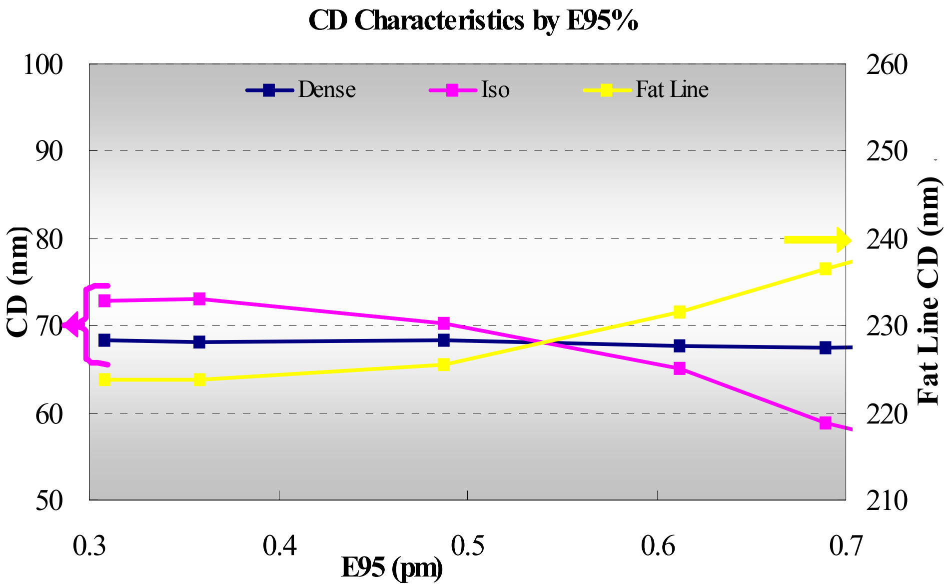


Fig. 2 Sensitivity of Line CD vs. E95%

Results show that as E95% increases, there is no change in Dense Line, a decrease in Iso, and an increase in Fat Line. For these three CD types, Iso exhibits the greatest sensitivity to E95% fluctuation. We verified simulation results for Iso CD and Fat Line, as shown in Fig. 3 and Fig. 4 respectively.

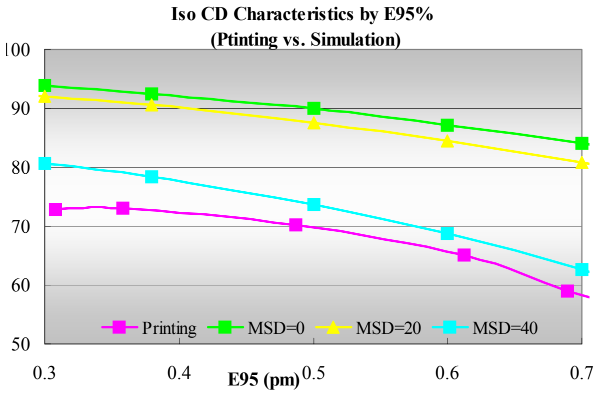


Fig. 3 Iso CD vs. E95%

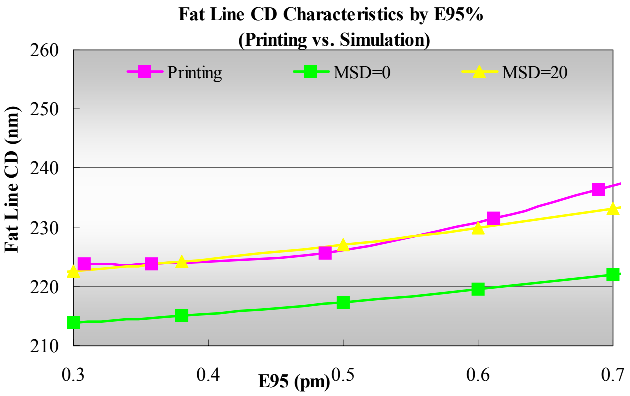


Fig.4 Fat Line CD vs. E95%

The simulation methodology added an additional parameter, Acid Diffusion Length (MSD) that represents the resist characteristics effect on the optical intensity distribution. In other words, simulation with MSD=40 parameter represents a condition with long acid diffusion length and generally high resolution, whereas MSD=0 parameter indicates a purely optical simulation with no influence from acid diffusion. From the results we know that for Iso CD, as the MSD increases, sensitivity to E95% also increases. Additionally, for both Iso CD and Fat Line, although there is a delta between the absolute CD values for simulation and exposure results, they both exhibit the same behavior. Therefore we can say that the simulation and experimental results are well matched.

In particular, targeting the Iso Line because it is the most sensitive, we establish the following definition:

Iso Dense Bias (IDB) = Iso CD - Dense CD

and show the sensitivity to E95% in Fig. 5.

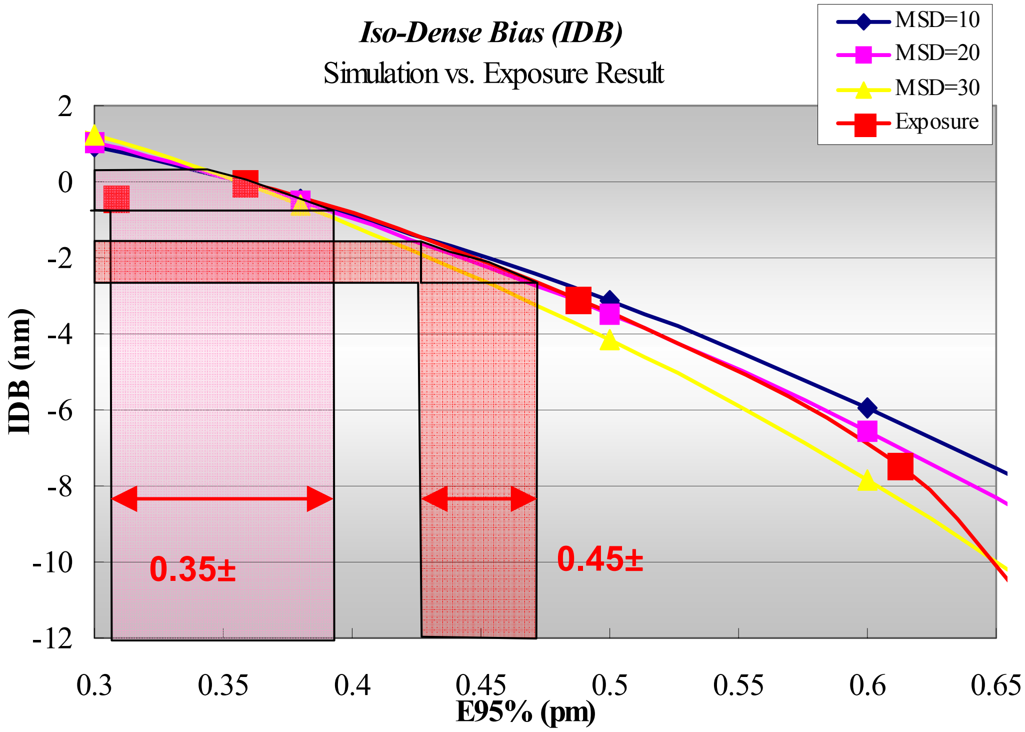
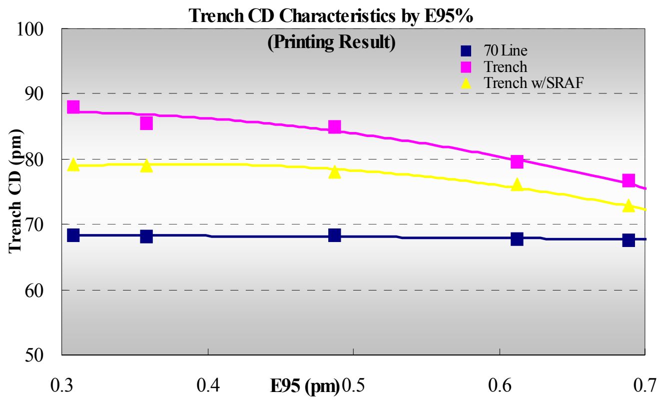


Fig. 5 IDB Sensitivity

The results show that the correlation between IDB and E95% is not linear, but displays a parabolic characteristic similar to 4th order curve fitting. If E95% is small, the effect on IDB is minimal, however, if E95% is large, it presents a large IDB fluctuation due to the steep slope. In order to maintain IDB to within 1nm, experimental results show that for E95 center value of 0.35pm, stability within ±0.041pm is required. Moreover, for the case of E95 center value of 0.45pm, stability within ±0.022pm is required.

3.2 Trench Line Sensitivity to E95%

Fig. 6 shows the correlation obtained from exposure results between E95% and both on-reticle 110nm trench patterns, and the same 110nm trench pattern with 94nm Sub-Resolution Assist Features (SRAF). As a reference, Dense Line results are also plotted.



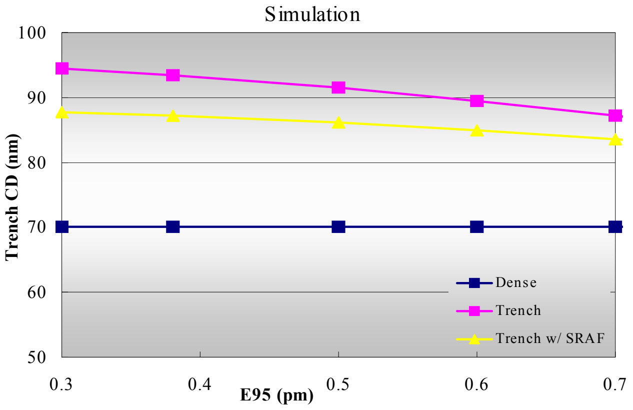


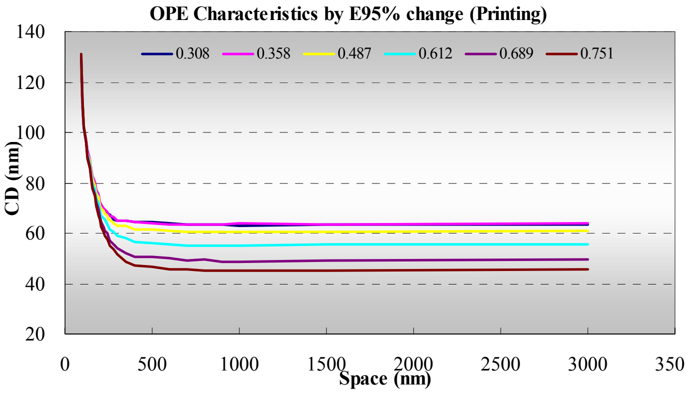
Fig. 6 Trench CD vs. E95% by Printing

Fig. 7 Trench vs. E95% by Simulation

Similarly, Fig. 7 shows simulation results. Both simulation and experimental results show that as E95% increases, the Trench CD becomes smaller. Furthermore, the Trench pattern without SRAF exhibited greater sensitivity to E95% than that with SRAF. The actual sensitivity is 2.5nm/Δ0.1pm.

3.3 Through Pitch Characteristics

OPE characteristics due to Through-pitch when varying E95% from 0.3pm to 0.75pm (exposure) and to 0.8pm (simulation) are shown in Fig. 8 and Fig. 9, respectively. Varying E95% from 0.3pm to 0.7pm leads to Iso CD variation of 20nm.



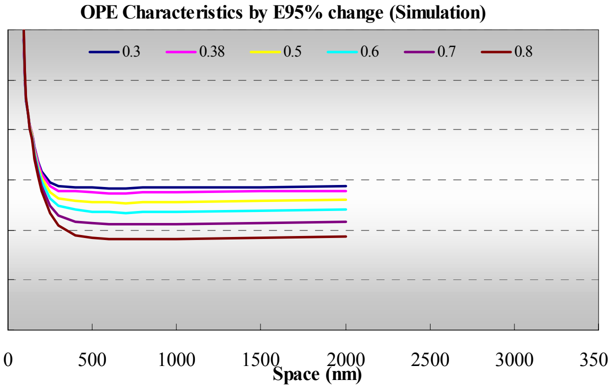


Fig. 8 Through-Pitch by Printing

Fig. 9 Through-Pitch by Simulation

4. Other effect of E95%: Process Margin and Laser Performance Dependency

4.1 Line End Shortening

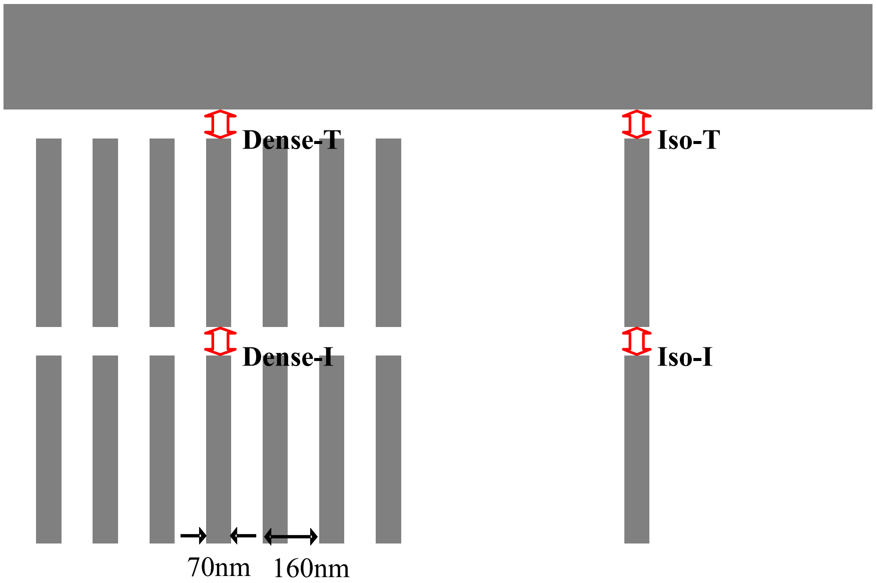


Fig. 10 Test Features for Line End Shortening

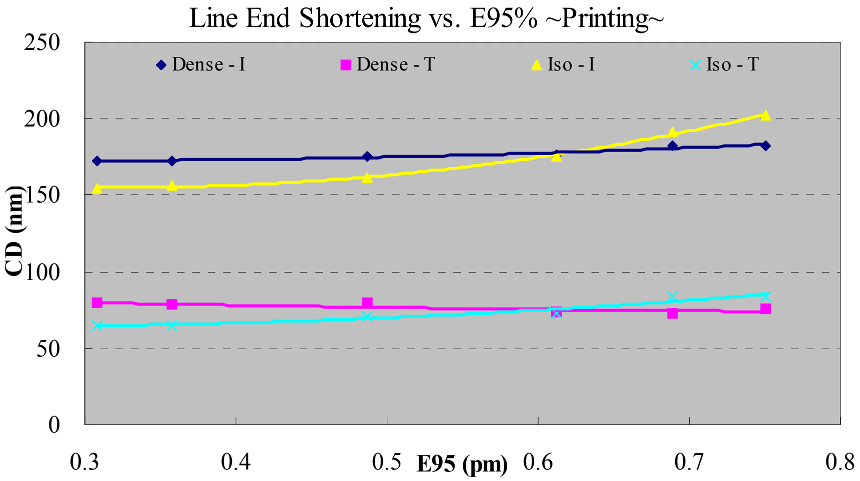


Fig. 11 Line End Shortening

We investigated E95% fluctuation on Line End Shortening as another effect aside from CD variation. The test pattern consisted of 70nm Line/ 90nm Space, measuring and defining Dense-I as the Line End Shortening amount between two adjacent Dense features, and Dense-T as the distance between the Dense feature and the pad structure. Similarly, for isolated features, Iso-I is defined as the Line End Shortening between two adjacent Iso features, while Iso-T is that between the Iso feature and the pad structure. Fig. 10 figuratively shows the test patterns.

Fig. 11 presents the results. Line End Shortening for Dense features shows minimal sensitivity to E95%, while it is quite evident for Iso features, with the pull back between Iso lines (Iso-I) exhibiting the greatest sensitivity. This sensitivity shows a parabolic tendency similar to that of IDB. For E95% center values of 0.4pm and 0.7pm, the sensitivities are 5nm/Δ0.1pm and 20nm/Δ0.1pm, respectively.

4.2 Process Margin due to E95% Variability

We invested both Focus Margin and Exposure Latitude. Test features included (a) Pitch=160nm, (b) Pitch=200nm, (c) Iso patterns with SRAF and (d) Trench patterns with SRAF. Focus Margin and Exposure Latitude are presented in Fig. 12 and Fig. 13, respectively. Results show that the impact on Iso CD focus margin and exposure latitude due to E95% fluctuation is small and as such, is considered negligible.

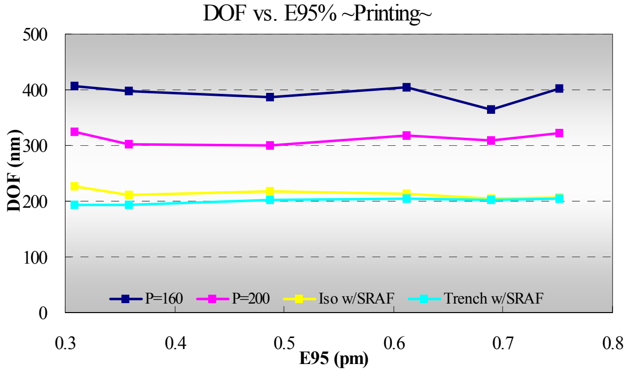


Fig. 12 Focus Margin by E95% Change

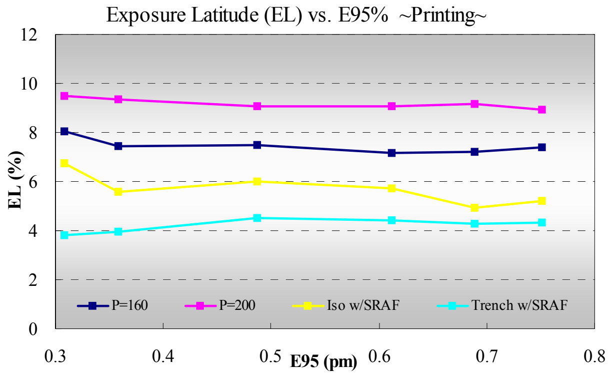


Fig. 13 Exposure Latitude by E95% Change

In addition, we evaluated the ED-Window for Iso CD. Results are presented in Fig. 14. As reported above for focus margin and exposure latitude, the impact of E95% variation on process margin is similarly negligible.

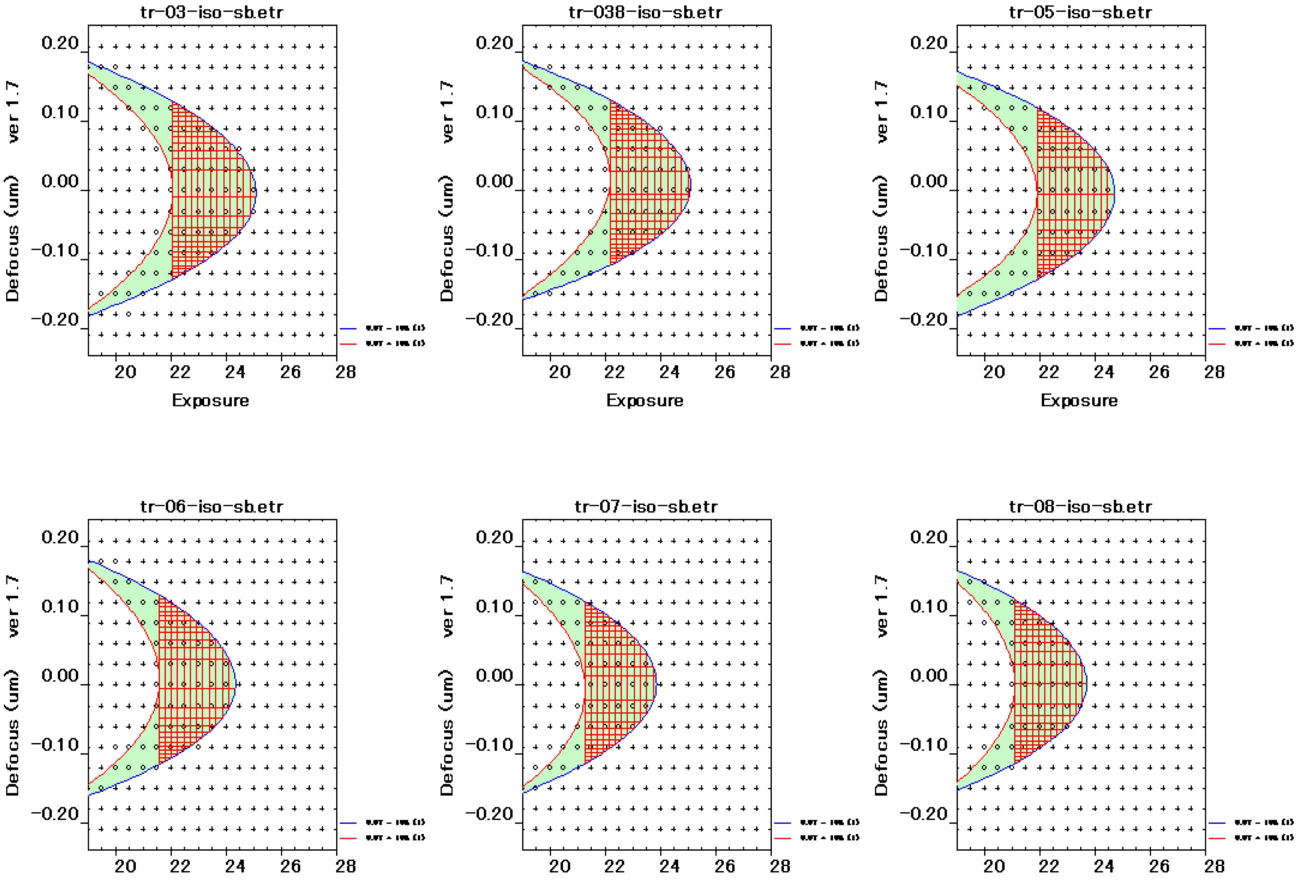
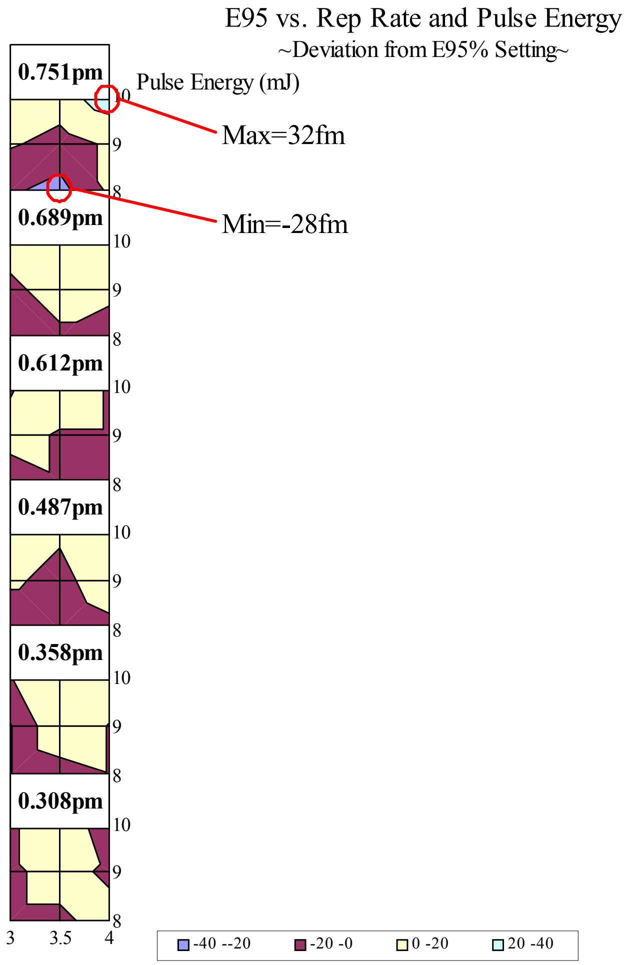


Fig. 14 Iso CD Process Margin

4.3 E95% Stability



E95 vs. Rep Rate and Pulse Energy

~Deviation from E95% Setting~

Max=32fm

Min=-28fm

Fig. 15 Rep. Rate & Pulse Energy Dependency

Beginning with IDB, continuing with the impact on Line End Shortening for Iso and Trench patterns, E95% stability is understood. Now, we investigate the actual performance of the laser itself. First, for each E95% setting, we vary the laser Repetition Rate and Pulse Energy in a matrix to cover Rep Rates of 3kHz, 3.5kHz, 4kHz, and Energy of 8mJ, 9mJ and 10mJ. Fig. 15 shows the E95% difference obtained. The dependency on differing laser operation environments, from low to high duty, and the thermal and acoustic characteristics due to differing duty conditions with respect to each module were considered. Therefore, the E95% stability can be estimated through the root-mean-square (RMS) of the E95% measurement error component and the repeatability (R) of laser itself, when the characteristic delta is defined as Deviation (D).

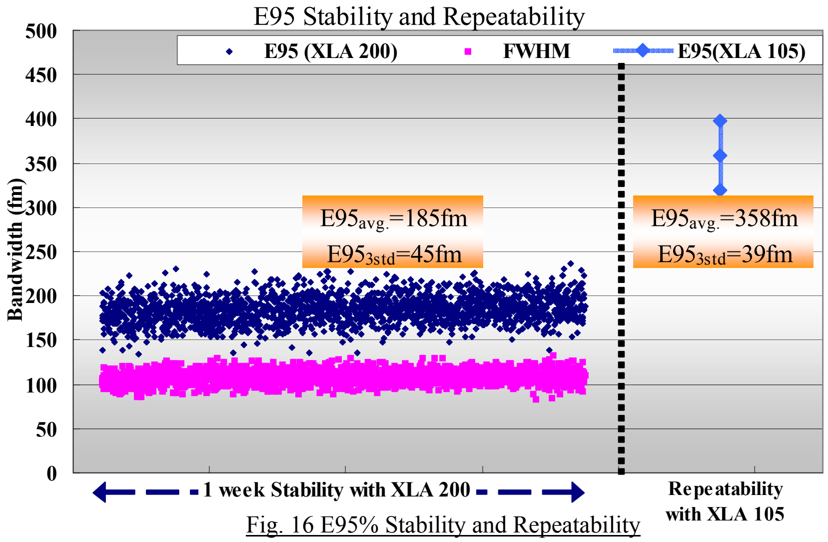


Fig. 16 E95% Stability and Repeatability

Repeatability measurement results are shown on the right hand side of Fig. 16. This repeatability is shown to be 39nm 3σ for Cymer XLA-145 at E95% nominal conditions. In other words, Stability (S) is defined as:

$$\text{Stability (S)} = \sqrt{D^2 + R^2}$$

With Repeatability of 39fm, and previously indicated Deviation of 32fm, Stability of 50fm is obtained. E95% stability covering one week for the Cymer's 45nm Node Laser, the XLA-240, is displayed on the left hand side of Fig. 16. This covered Maximum to Minimum Duty conditions, as well as multiple Pulse Energy conditions. These results satisfy the stability (3σ) requirements for the 45nm Node, and demonstrate improvement compared to XLA-145 E95% stability performance.

When considering the E95% requirements as obtained from IDB sensitivity, if stability performance of ±0.041pm is conditionally set for a center value of 0.35pm, the current performance of ±0.050pm or ±0.045pm for both XLA-145 and XLA-240 is slightly unsatisfactory, however, with minimal performance improvements, we estimate being able to achieve acceptable performance. Cymer plans to improve E95% stability performance through usage of Active Control function.

5. Conclusion

For the 45nm Node, we have confirmed the influence of E95% on CD performance through the following:

- Isolated Feature reduction as E95% increases
- Fat Line becomes wider by increasing E95%
- Line End Shortening of Iso features increases with larger E95%
- However, Dense features are not sensitive to E95%
- Focus Margin and Exposure Latitude not affected by E95%

However, there is a strong relationship between Iso sensitivity and both Acid Diffusion Length and reticle bias amount. IDB increases with large acid diffusion lengths and large reticle bias. From the experimental conditions, we determined that in order to maintain IDB to within 1nm, E95% stability of 0.35pm±0.041pm or 0.45pm±0.022pm is required.

Further stability performance improvements are anticipated to satisfy current requirements, and with minimal improvements to current ±0.045nm performance levels, the ±0.041nm requirement will be met thus enabling IDB within 1nm. We have therefore demonstrated the laser spectral bandwidth effect on IDB for the 45nm Node and can state that it is at a controllable level.

References

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