Proximity Matching for ArF and KrF Scanners

Young Ki Kim, Lua Pohling, Ng Teng Hwee, Jeong Soo Kim, Peter Benyon
FAB7 Operations Lithography , Chartered Semiconductor Manufacturing Ltd
60 Woodlands Industrial Park D Street 2, Singapore 738406

Jerome Depre*, Jongkyun Hong, Alexander Serebriakov
ASML Netherlands B.V, De Run 6501, 5504 DR Veldhoven, The Netherlands

ABSTRACT

There are many IC-manufacturers over the world that use various exposure systems and work with very high requirements in order to establish and maintain stable lithographic processes of 65 nm, 45 nm and below. Once the process is established, manufacturer desires to be able to run it on different tools that are available. This is why the proximity matching plays a key role to maximize tools utilization in terms of productivity for different types of exposure tools.

In this paper, we investigate the source of errors that cause optical proximity mismatch and evaluate several approaches for proximity matching of different types of 193 nm and 248 nm scanner systems such as set-get sigma calibration, contrast adjustment, and, finally, tuning imaging parameters by optimization with Manual Scanner Matcher.

First, to monitor the proximity mismatch, we collect CD measurement data for the reference tool and for the tool-to-be-matched. Normally, the measurement is performed for a set of line or space through pitch structures.

Secondly, by simulation or experiment, we determine the sensitivity of the critical structures with respect to small adjustment of exposure settings such as NA, sigma inner, sigma outer, dose, focus scan range etc. that are called 'proximity tuning knobs'.

Then, with the help of special optimization software, we compute the proximity knob adjustment that has to be applied to the tool-to-be-matched to match the reference tool.

Finally, we verify successful matching by exposing on the tool-to-be-matched with tuned exposure settings.

This procedure is applicable for inter- and intra scanner type matching, but possibly also for process transfers to the design targets.

In order to illustrate the approach we show experimental data as well as results of imaging simulations. The set demonstrate successful matching of critical structures for ArF scanners of different tool generations.

Metrology, Inspection, and Process Control for Microlithography XXIII, edited by John A. Allgair, Christopher J. Raymond
Proc. of SPIE Vol. 7272, 72723A · © 2009 SPIE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.813609

1. INTRODUCTION

1. Typical source of errors that cause optical proximity mismatch and evaluate several approaches for proximity matching of different types of 193 nm and 248 nm scanner systems such as set-get sigma calibration, contrast adjustment, and, finally, tuning imaging parameters by optimization with Manual Scanner Matcher

Sigma set get calibration can be optimized on ArF immersion tool with a specific measurement and software that will minimize the Sigma Set and get Error.
On Dry ArF and Krf the commonly used approached is to make sure that the measured pupil is stable over time, with no paring effect or abnormality , best calibration of the pupil is obtain with the usage of Pupil Illumination optimization test so called LUPI.

The contrast adjustment method was used in the passed in order to compensate the difference in lasers wrt. OPE effects; It uses the means of tilt in wafer stage (EFESE techniques) to decrease the contrast quality in order to match a new laser generation to an older one. This method was then use in combination with other knobs to fine tune the proximity matching behaviors. This matching approach is explain in more systematic way to bring the match solution.

II Main contributions of OPE effects

Main contributors of proximity matching will be discussed in the following part with a budget breakdown analysis on what are the key contributors of the 1900 to 1700 proximity mismatch error as example.
In this chapter, the impact of variations of several machine parameters on the resulting CD as a function of pitch will be discussed. These parameters include NA, dose, focus, E95, Jones pupil... Furthermore, the dose, Na, Rx tilt Sigma width sensitivity is determined per pitch. In principle, all simulations are done by varying the parameter under investigation, fixing the target pitch at 170 nm by changing dose, and calculating the influence on the CD of the other 59 pitches at the same dose. This way of working corresponds to experimental execution of a tool-to-tool proximity test. As a result, the sensitivity of the target pitch to most parameters (except dose) is equal to zero.
This sensitivity expresses the CD variation per unit variation of the respective (machine) parameter. This sensitivity then corresponds to the PBA-variation per unit variation of the respective parameter (ΔPBA is defined as $\Delta(CD_{pitch} - CD_{reference})$ and $\Delta CD_{reference}=0$ as this is the target pitch). By multiplying the sensitivity with the possible variations from tool-to-tool the 'variation in proximity bias average' (ΔPBA) can be calculated for all pitches.

The total PBA-budget then equals the root-sum-square of all individual PBA-contributions. All sensitivities have been simulated using Lithocruiser (version 3.01).

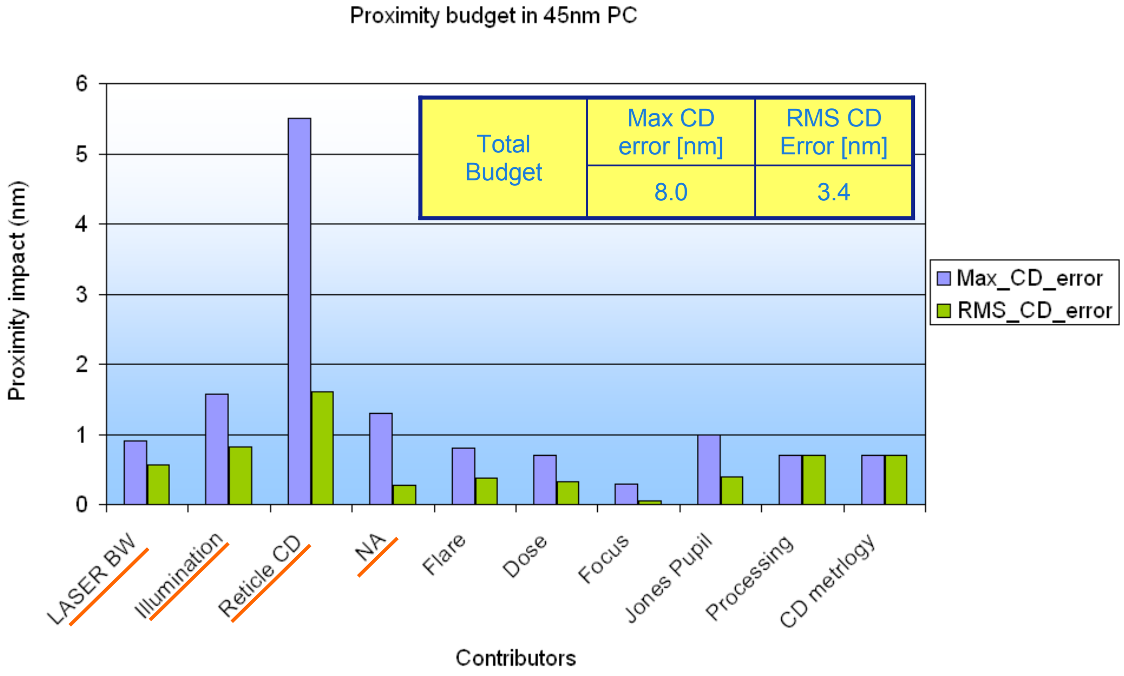


Fig1 . Proximity budget for 45 nm PC Layer when matching 1900 to 1700

In this case, the major contributors identified as reticule CD, illumination, LASER bandwidth and NA variation.

The reticle CD contribution especially at dense pitch is followed by illumination due to high reticle CD error enhancement factor. Tight reticle CD control between the matching machines , minimal pitch relaxation through design layout modification and tuning by different energy sensitivity will be one of the solution. The illumination will be optimized by tuning sigma and the NA contribution will be tuned by NA. The LASER BW contribution will be tuned by scan tilt range.

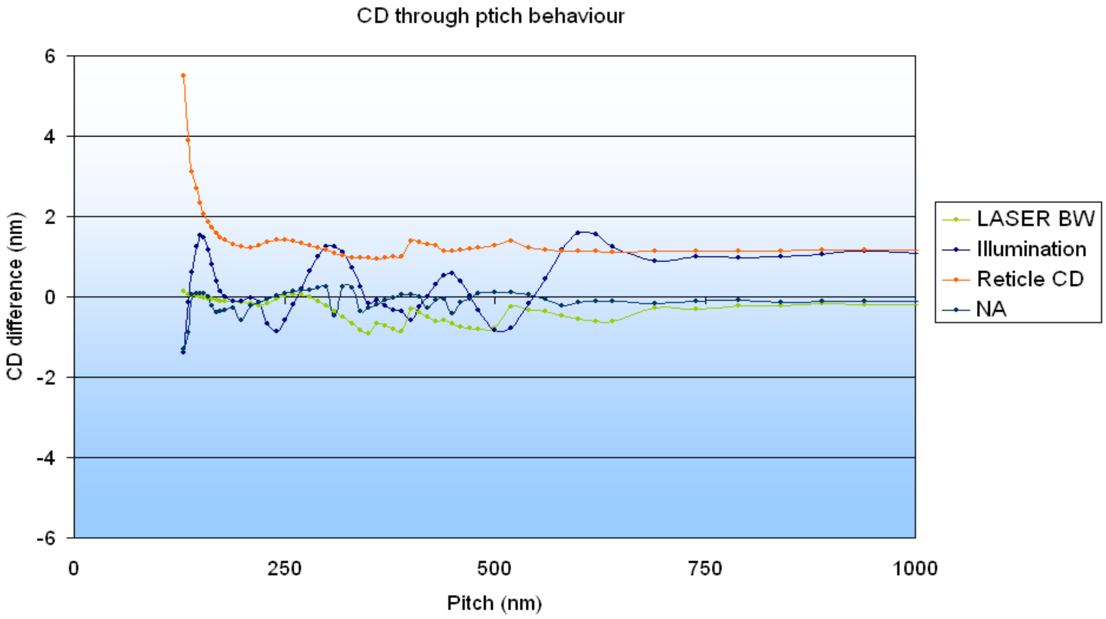


Fig 2. Simulated CD delta between 1900 and 1700 across the pitch-contributor's breakdown

III **CD BASED PROXIMITY MATCHING: WAY OF WORKING**

Two approaches are commonly used in order to minimize the OPE effects between tools; below is the generic approach that we used:

- Acquisition of reference data
- Determination of starting point
- Imaging simulations – optional
- Computation of sensitivities
- Tuning
- Experimental verification
- 2nd iteration (if needed)

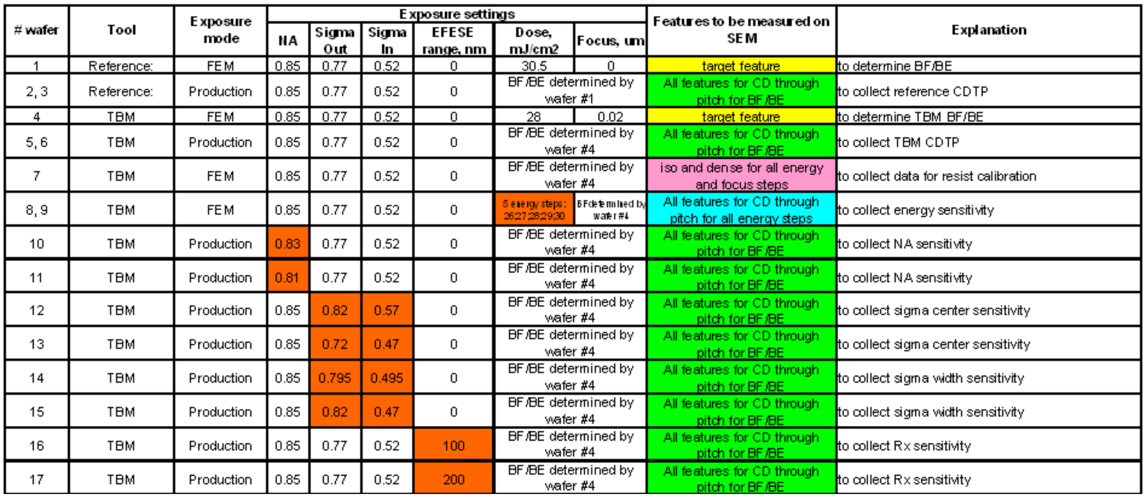
- Preparation and acquisition of reference data
  - Exposure Tools : In our case the reference machine was AT:1250 ArF702 and ArF703 to be matched XT:1450 B tool & C tool; The choice

for ArF702 as reference was made because OPE behavior is more closed to golden tool that OPC model was generated and the pupil of ArF702 is stable, illuminator in good conditions, whenever the tool itself is not in optimum state from illuminator point of view, it is very important to adjust it prior to Proximity matcher usage;

- Reticle; CD through pitch with 60 pitches from fully dense to Isolated Lines by AttPSM 6%; as a guideline here utilize the following rules of thumb:
  Sensitivities changes in low contrast areas (dense pitches)
  Sensitivity changes (particularly to sigma & NA) at pitches where a diffracted order enters the NA (near nλ/NA(1+sigma)).
  Select pitches most densely populated in the areas highlighted above.
  Most interesting pitches are near 1:1 pitch and equal to or greater than the pitch where the second order enter the NA which is a forbidden area.
  Pitches between the two highlighted areas above and less dense pitches can be more sparsely populated (no significant changes in sensitivities in these areas).
  Reference pitch for targeting was at 190 nm, for CD target at 85 nm
- Simulation; LithoCruiser TM 2.4.1
- 65 nm PC layer investigated
- NANO SEM used

- Exposure list used

We chose the experimental method to determine the sensitivity; means we have to expose a set of wafers described below to accurately per pitch determine the dose sensitivity, NA sensitivity, Sigma center sensitivity, Sigma width sensitivity and Rx tilt sensitivity



# wafer	Tool	Exposure mode	Exposure settings						Features to be measured on SEM	Explanation
			NA	Sigma Out	Sigma In	EFESE range, nm	Dose, mJ/cm2	Focus, um		
1	Reference:	FEM	0.85	0.77	0.52	0	30.5	0	target feature	to determine BF/BE
2, 3	Reference:	Production	0.85	0.77	0.52	0	BF/BE determined by wafer #1		All features for CD through pitch for BF/BE	to collect reference CDTP
4	TBM	FEM	0.85	0.77	0.52	0	28	0.02	target feature	to determine TBM BF/BE
5, 6	TBM	Production	0.85	0.77	0.52	0	BF/BE determined by wafer #4		All features for CD through pitch for BF/BE	to collect TBM CDTP
7	TBM	FEM	0.85	0.77	0.52	0	BF/BE determined by wafer #4		iso and dense for all energy and focus steps	to collect data for resist calibration
8, 9	TBM	FEM	0.85	0.77	0.52	0	5 energy steps: 26;27;28;29;30	BF determined by wafer #4	All features for CD through pitch for all energy steps	to collect energy sensitivity
10	TBM	Production	0.83	0.77	0.52	0	BF/BE determined by wafer #4		All features for CD through pitch for BF/BE	to collect NA sensitivity
11	TBM	Production	0.81	0.77	0.52	0	BF/BE determined by wafer #4		All features for CD through pitch for BF/BE	to collect NA sensitivity
12	TBM	Production	0.85	0.82	0.57	0	BF/BE determined by wafer #4		All features for CD through pitch for BF/BE	to collect sigma center sensitivity
13	TBM	Production	0.85	0.72	0.47	0	BF/BE determined by wafer #4		All features for CD through pitch for BF/BE	to collect sigma center sensitivity
14	TBM	Production	0.85	0.795	0.495	0	BF/BE determined by wafer #4		All features for CD through pitch for BF/BE	to collect sigma width sensitivity
15	TBM	Production	0.85	0.82	0.47	0	BF/BE determined by wafer #4		All features for CD through pitch for BF/BE	to collect sigma width sensitivity
16	TBM	Production	0.85	0.77	0.52	100	BF/BE determined by wafer #4		All features for CD through pitch for BF/BE	to collect Rx sensitivity
17	TBM	Production	0.85	0.77	0.52	200	BF/BE determined by wafer #4		All features for CD through pitch for BF/BE	to collect Rx sensitivity

Fig3. Measurement scheme

- Sensitivities determined experimentally is the chosen and preferred way in this paper; eventually simulated one can be used but in this case good simulation resist calibration is required

Features	180P	185P	190P	195P	200P	250P	300P	350P	500P	590P	990P	1190P
Reference CDs	86.6	83.6	84.7	86.4	83.9	83.8	83.6	85.7	85.5	87.2	84.3	83.6
Work Point CDs	87.7	85.4	85.1	87.5	84.9	85.1	85.3	89.0	87.4	89.2	87.2	88.5
ΔCD tolerances	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
E sensitivity	-2.13	-2.98	-4.45	-3.62	-3.59	-3.13	-1.84	-2.28	-1.95	-1.74	-1.11	-3.02
NA sensitivity	-78.73	-63.27	-3.52	2.39	-1.57	-52.26	-13.90	20.90	-72.84	-36.69	-143.40	-147.96
Sc sensitivity	-19.10	7.00	8.10	0.30	7.50	4.20	-68.10	-59.10	-107.90	-173.10	-102.70	-103.70
Sw sensitivity	15.10	8.30	5.60	-0.95	12.65	-13.50	7.95	-3.80	18.80	-14.80	-19.80	-28.80
FR sensitivity	2.74E-05	2.03E-05	-2.56E-05	-1.67E-05	3.98E-05	7.40E-05	-2.54E-04	-5.90E-05	4.24E-05	-3.41E-05	-2.13E-04	-1.37E-04

Recommended offsets for sensitivity determination
NA: ±0.02…±0.03
Sigma's: ±0.025…±0.05
Dose: ±5… ±10%
Scan tilt range: ±200 nm

- General rule of thumb: CD difference at maximal parameter offset should be about 10% of nominal CD

Goal is to actively match proximity between scanners
Using a reference situation, and a to-be-matched situation (pitch curves).
CD tolerance per feature is supplied to indicate critical structures.
Illumination settings (*E*, *NA*, *s*, …) are used as 'tuning knobs'.
Applicable for inter-scanner matching, but possibly also for process or reticle matching.

Main inputs are the measured through pitch curves for reference and to-be-matched work point.

Basic operation

Sensitivities per parameter ('knob') and feature are supplied.

The deviation between reference and tuned situation is quantified by the RMS (root mean square) merit function, a measure for the overall deviation between two through-pitch curves.

Per parameter the nominal setting and tuning range is given.

The optimal tuning setting resulting in the smallest reference deviation are computed using a least squares fit model.

In principle, all knobs are used, unless they do not rise beyond their specified thresholds.

Below is the results of predicted improvement after Pattern matcher is applied using the software

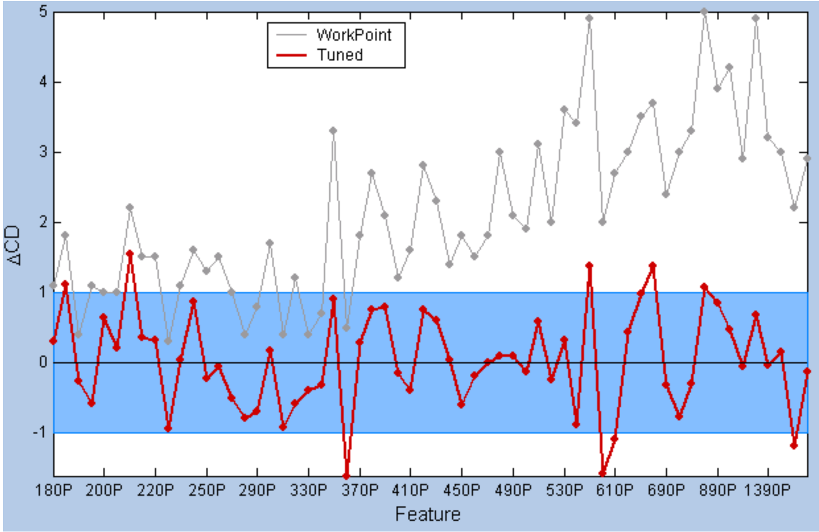


Fig4. Outcome of Pattern matcher simulated improvement

In Red these are the predicated improvement of the 1450 to 1250 mismatch, in grey these are the original default mismatch between 1450 to 1250

Experimental verification

These simulations are experimentally verified on ArF 703 & ArF704.

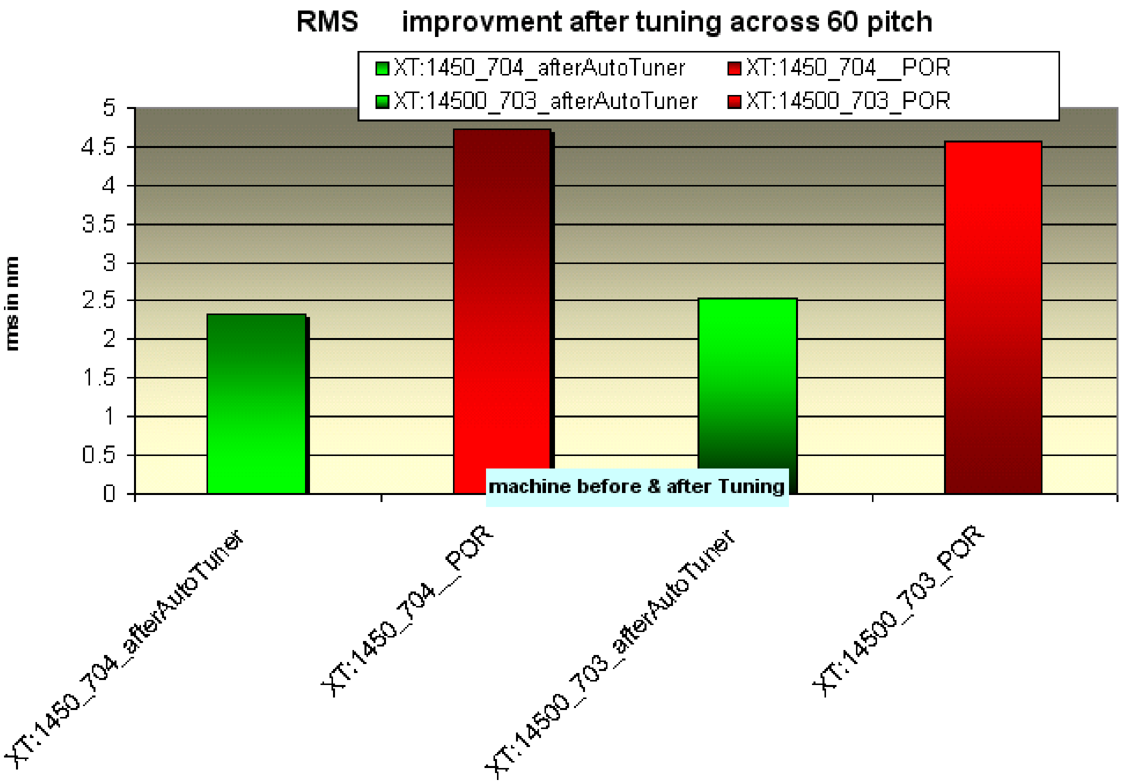


Fig5. On resist improvement verification

As depicted in figure 5, the improved mismatch between XT:1450 and XT:1250 is about 2nm RMS on the A703 and A704.

The next picture depicts the measured improvement per pitch across 60 pitch for A703

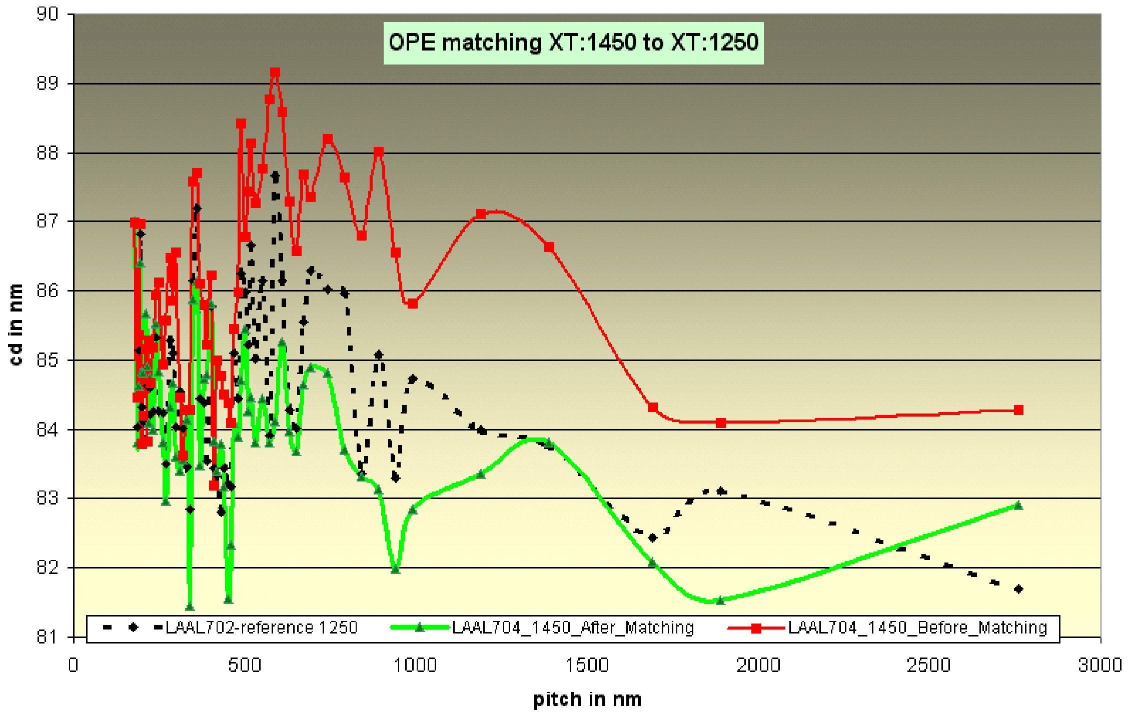


Fig6. Across pitches improvement verification on LAAL704

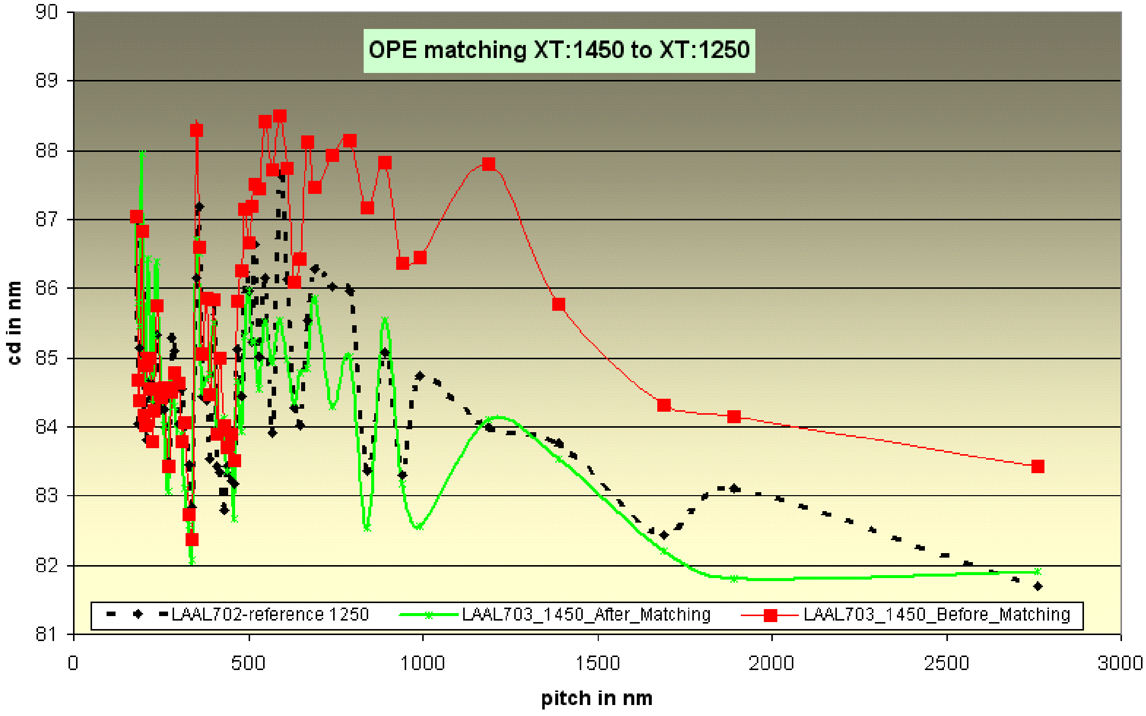


Fig7. Across pitches improvement verification on LAAL703

Process Window experimental verification

The main question now is to assert if the usage of new Illumination setting for improvement of the CD through pitch did not worsen the overall process window. The following slide depicts the process window with the new optimize setting that has been verified

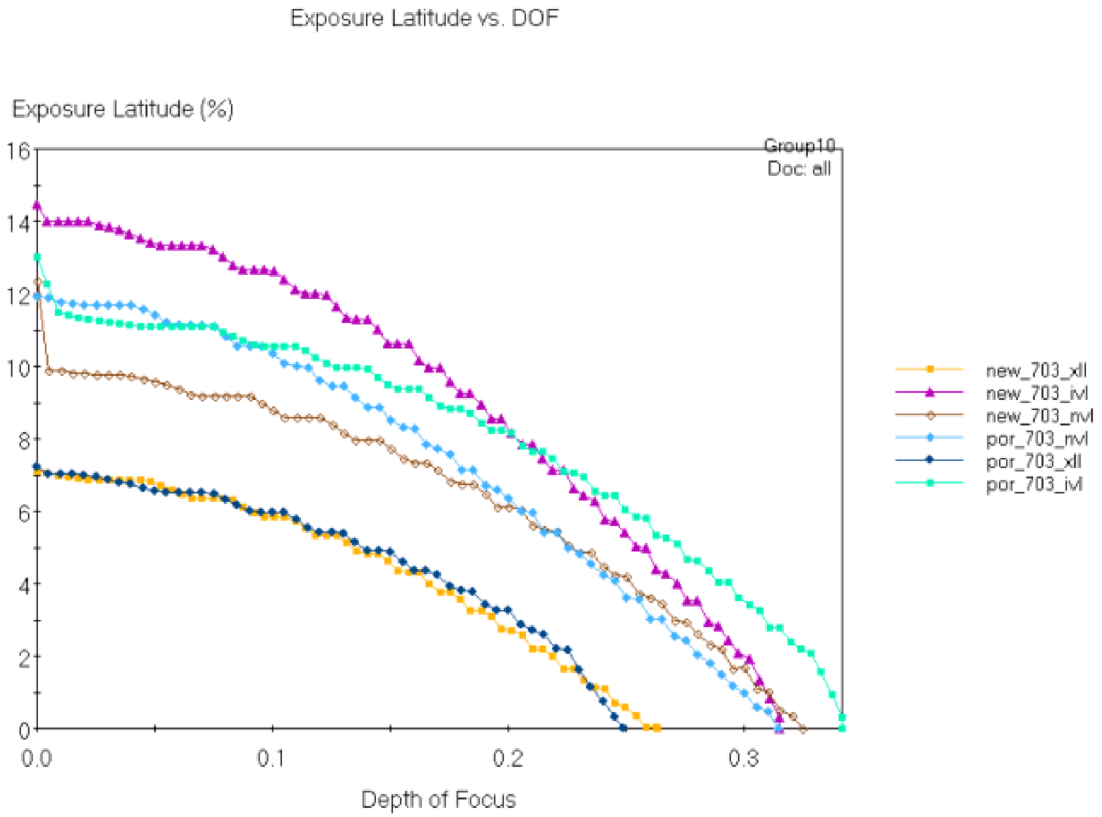


Fig8. Process windows verifications with new matched Illumination setting

Small Degradation of EL for NVL structure with new setting; No change for XLL Structure and Improvement for IL structure

IV. Conclusion

As mentioned above the present version of Pattern Matcher optimizes matching over a set of pitches that user selected, using adjustments such as numerical aperture (NA), dose and illumination. Pattern Matcher is available for TWINSCAN™ immersion, ArF dry and KrF systems. In this user's case no degradation on process window due to usage of new setting has been verified.

We can increase the tool utilization without restriction induced by tool due to non OPE matching.

REFERENCES

[0]L. Van Look, PROC. SPIE (2008) Tool-to-tool optical proximity effect matching
1] Armellin, L.-P., Torsy, A., Hernan, K., et al., "Illumination conditions matching for critical layers manufacturing in
a production context," Proc. SPIE 6154, 61543V (2006).
[2] Dunstan, W.J., Jacques, R., Rafac, R. J., et al., "Active spectral control of DUV light sources for OPE
minimization," Proc. SPIE 6154, 51542J (2006).
[3] Zhou, W., Yu, J., Lo, J., et al., "Proximity Matching for 193 nm scanner using scatterometry," Proc. SPIE 5754,
1249-1259 (2005).
[4] Palitzsch, K., Kubis, M., Schroeder, U. P., et al., "Matching OPC and masks on 300-mm lithography tools utilizing
variable illumination settings," Proc. SPIE 5377, 872-880 (2004).
[5] Finders, J., Dusa, M., "Matching multiple-feature CD response from exposure tools: analysis of error sources with
their impact in low-k1 regime," Proc. SPIE 5754, 164-176 (2004).
[6] Lee, E.-M., Lee, S.-W., Lee, D.-Y., et al., "Assessments on process parameters' influences to the proximity
correction," Proc. SPIE 5375, 287-295 (2004).
[7] Brunner, T., Corliss, D., Butt, S., et al., "Laser Bandwidth and Other Sources of Focus Blur in Lithography," Proc.
SPIE 6154, 61540V (2006).
[8] Lai, K., Lalovic, I., Fair, R., et al., "Understanding Chromatic Aberration Impacts on Lithographic Imaging," J.
Microlithography, Microfabrication and Microsystems 2 (2), 105-111 (2003).