Advanced proximity matching with Pattern Matcher

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ABSTRACT

In a semiconductor factory, each lithographic scanner is combined with a laser source and a track to form a lithocell. Quite frequently, lithographers have to deal with running the same lithographic process on multiple lithocells. Usually a new process is developed for one cell, and then transferred to other cells. However, small but non-negligible differences between lithocells, may result in yield losses. Nevertheless, several scanner's parameters (called proximity manipulators) can be used to compensate for these differences and match the secondary lithocells to the reference one.

Recently a new advanced process matching methodology called Pattern Matcher has been developed. Using this method, we performed successful proximity matching of several ArF scanners in the production environment. In this paper, we discuss the principles of Pattern Matcher approach as well as methodology for data acquisition and present results of our matching.

Keywords: lithography, proximity matching, Pattern Matcher

1. INTRODUCTION

When a new lithographic process is brought to mass production, it must be run on multiple litho tools that are available in the fab. However, use of multiple lithography systems can affect yield due to variations in the lithocluster if a process for matching is not deployed. Examples of these variations can be different scanner fingerprints (e.g. light source, optics) or uncorrectable differences in tracks. This can cause the same structures on a mask to be imaged with small variations. The magnitude of these variations depends on proximity of mask features (pitch and neighboring features) and optical proximity correction (OPC) rules such as applied biasing, assisting features etc. To quantify this effect i.e. collect a proximity fingerprint of the litho cell, lithographers use sets of different reference structures e.g. CD through pitch pattern (see Figure 1). Incorrect or insufficient proximity matching can result in significant yield loss.

The quantification of proximity differences caused by differences of lithocell performance becomes a challenging task when 2D structures such as end of line pullback have to be controlled. Normally lithographer has to determine a set of these representative structures for each layer during OPC process. In many cases a number of CD through pitch structures with addition of several critical 2D features (hotspots) is sufficient for adequate matching. The structures should reflect the process stability with respect to different sources of error (for quantification of laser bandwidth deviations, a combination of dense and isolated features has to be used). The right choice of representative features can be performed with the help of litho process simulation programs such as LithoCruiser by analyzing the impact of process parameters on features.

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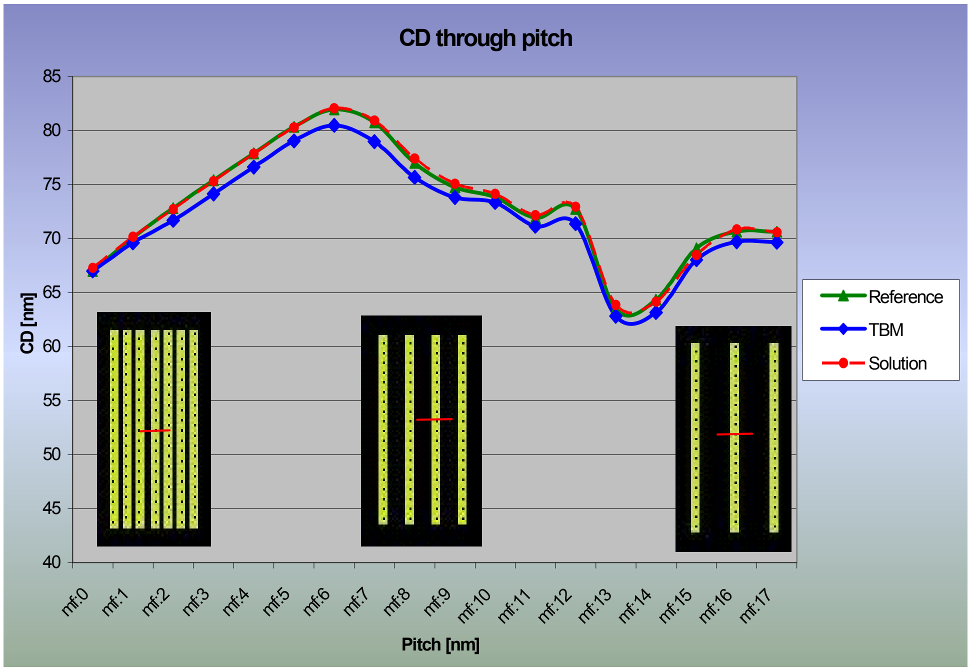

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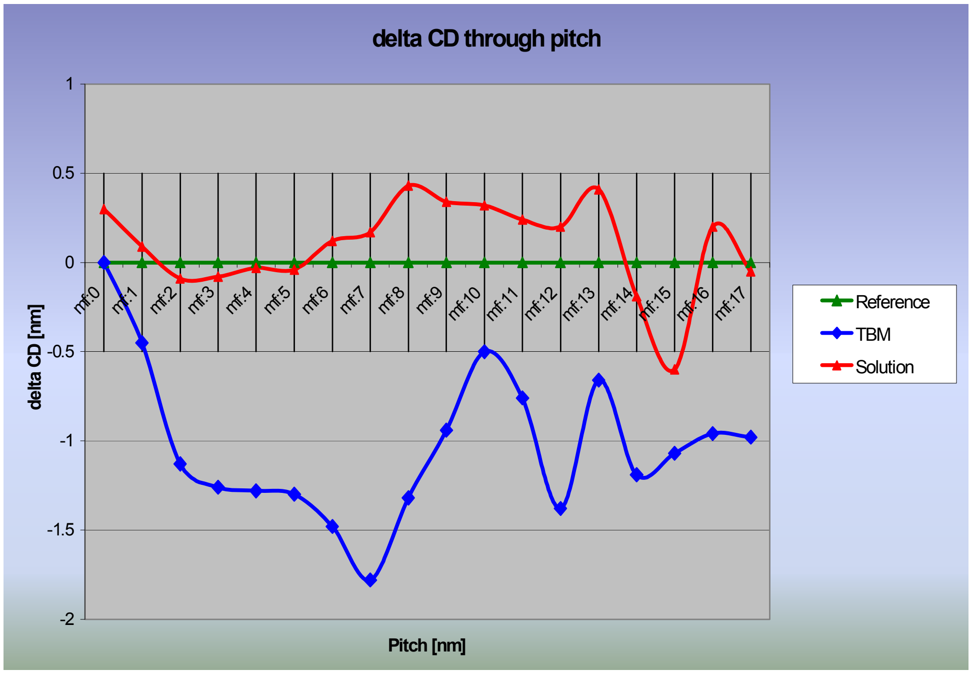

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Figure 1. Quantification of proximity fingerprints of two scanners. CD through pitch plot indicates different sensitivity of the structures with respect to the contrast differences depending on proximity (pitch): a) Example of CD through pitch plot for three situations: reference scanner (green curve), scanner to be matched (blue curve), scanner to be matched after tuning (red curve); b) the same numerical data shown in CD difference (delta CD) format with respect to the reference scanner. The matching process is successful when delta CD curve is within the tolerated region determined by lithographic process conditions.

2. METHODOLOGY

The main principle of Pattern Matcher is optimization of scanner exposure settings to match the lithocell proximity fingerprint to the target. For this purpose, we use the following proximity manipulators available on ASML scanners:

- exposure dose;
- numerical aperture (NA);
- sigma center (determined as sigma inner and sigma outer average);
- sigma width (determined as sigma inner and sigma outer difference);
- focus scan range;
- pupil ellipticity (used for independent adjustment of horizontal and vertical features).

We use the fact that various structures have different sensitivity with respect to these proximity manipulators (see Figure 2). Since we compensate for small CD offsets, the range for tuning manipulators is also small and process window size never deteriorates due to these adjustments.

Optimization process assumes that for small changes of all proximity manipulators except focus scan range, mask features have linear dependency. With regard to small focus scan range mask features have quadratic dependency.

The main steps of Pattern Matcher workflow are exposed bellow:

1. *Reference structures selection*

If the set of reference structures has already been determined, this step is relatively easy. We suggest to generate a CD-SEM recipe to measure automatically all reference structures to prevent any measurement errors caused by manual measurement.

If the set of reference structures has not been determined, it should be done by selection of representative features associated to the layer, based on simulation. If production mask does not contain sufficient amount or types of features, we recommend to use a test reticle that contains necessary reference structures.

2. *Get reference lithocell proximity fingerprint*

To perform data acquisition for the reference lithocell proximity fingerprint, a wafer is exposed at the nominal process settings. Reference structures are measured using the CD-SEM recipe.

3. *Get to be matched lithocell proximity fingerprints*

The same procedure as described at step 2 is applied on to be matched lithocell. It is strongly recommended to use the same CD-SEM for all measurement in order to avoid SEM to SEM offset.

4. *Identification of matching necessity*

At this stage, we compare two proximity fingerprints obtained from two cells. If CD differences between both fingerprints are within required tolerances, the matching is not needed. Further actions are not required.

5. *Acquiring sensitivity data*

When the matching is needed, to continue we must determine the impact of proximity manipulators such as NA, pupil filling parameters (sigmas), focus scan range, dose, pupil ellipticity etc on the set of reference structures. This can be done either experimentally or by computation with a litho simulator such as LithoCruiser. Experimental determination is preferable because of higher accuracy, but it requires additional test wafers and measurements (see Table 1). If simulation is chosen, process should be calibrated with respect to the dose level to improve accuracy.

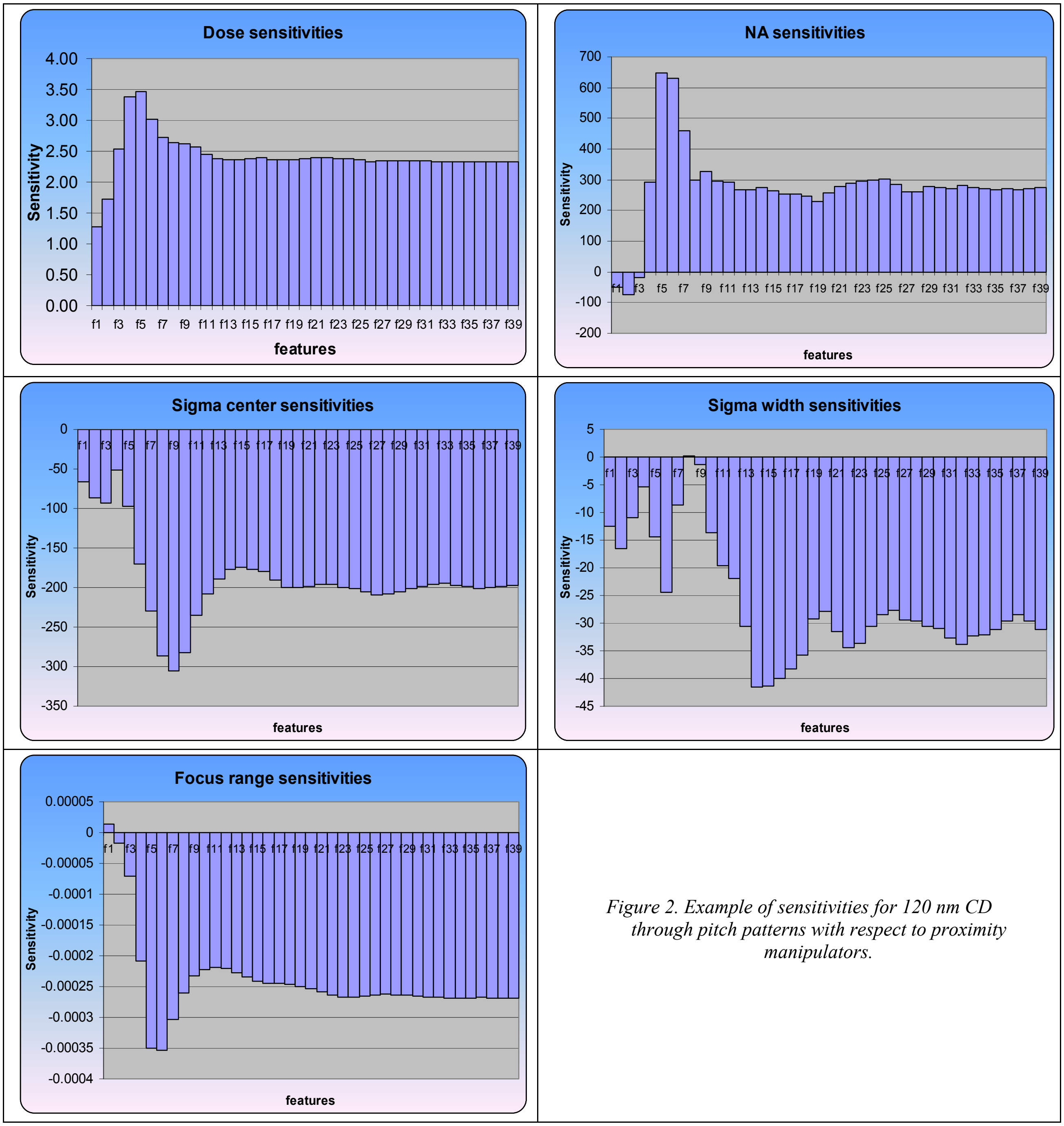


Figure 2. Example of sensitivities for 120 nm CD through pitch patterns with respect to proximity manipulators.

6. *Tuning*

Tuning proximity manipulators on the tools to be matched to reproduce proximity fingerprint of the reference scanner with the help of mathematical optimization. The merit function for optimization is determined by process requirements and can be chosen in different ways e.g. one of following

- root mean square (RMS) value of CD difference (delta CD) for representative features
- delta CD range – top to top difference for two features with smallest deltaCDmax-deltaCDmin

- maximal absolute delta CD value

It is often the case that several features in the set have tighter matching requirements. In this case the merit function can use different weights to improve matching of important features.

During optimization, we put constraints on manipulators range, in order to keep those within scanner capabilities, e.g. NA is limited by maximal tool NA, sigma range complies with illuminator limitations, focus scan range cannot be negative etc.

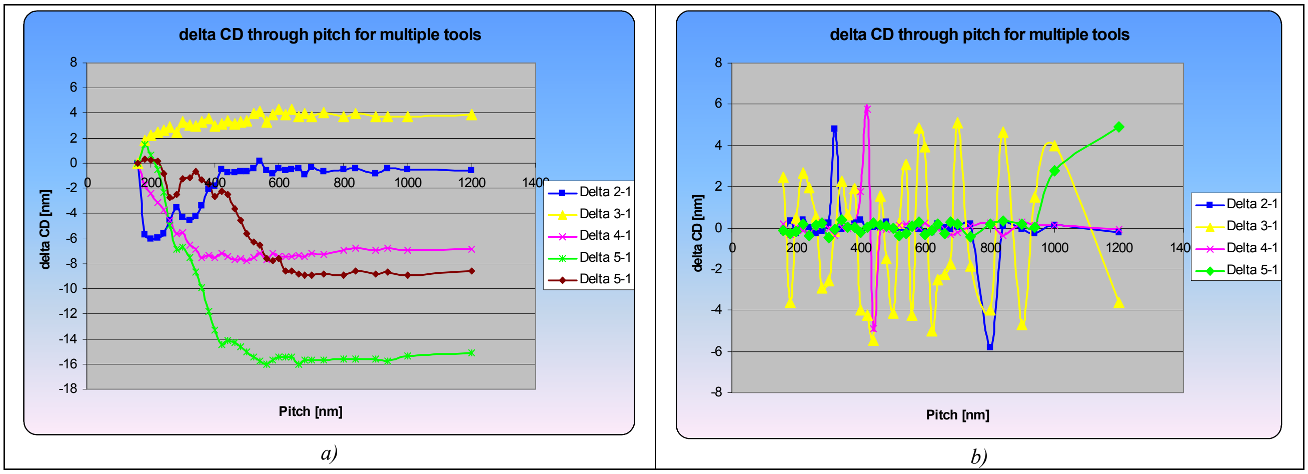
7. *Experimental verification.*

Finally, the new proximity fingerprint of the lithocell to be matched is collected. This is done by exposing wafers at the proposed settings calculated at step 6. If measured matching results does not fulfill required specifications at first attempt, a second iteration is suggested.

# wafer	Tool	Exposure settings							Explanation
		NA	Sigma Out	Sigma In	Sigma center	Sigma width	focus scan range, nm	Dose, mJ/cm2	
1	Reference	0.89	0.9	0.65	0.775	0.25	0	nominal 1	to collect reference fingerprint
2	TBM	0.89	0.9	0.65	0.775	0.25	0	nominal 2	to determine fingerprint on the tool to be matched
3	TBM	0.89	0.9	0.65	0.775	0.25	0	Dose meander	to collect energy sensitivity
4	TBM	0.93	0.9	0.65	0.775	0.25	0	nominal 2	to collect NA sensitivity
5	TBM	0.85	0.9	0.65	0.775	0.25	0	nominal 2	to collect NA sensitivity
6	TBM	0.89	0.95	0.7	0.825	0.25	0	nominal 2	to collect sigma center sensitivity
7	TBM	0.89	0.9	0.65	0.775	0.25	0	nominal 2	to collect sigma center sensitivity
8	TBM	0.89	0.92	0.63	0.775	0.29	0	nominal 2	to collect sigma width sensitivity
9	TBM	0.89	0.88	0.67	0.775	0.21	0	nominal 2	to collect sigma width sensitivity
10	TBM	0.89	0.9	0.65	0.775	0.25	100	nominal 2	to collect Rx sensitivity
11	TBM	0.89	0.9	0.65	0.775	0.25	200	nominal 2	to collect Rx sensitivity
12,13	TBM	to be determined							to be exposed for matching verification
14,15									Reserve

Table 1. Example of exposure/wafer planning for experimental determination of sensitivities

Pattern Matcher can be used to compensate tool-to-tool proximity mismatch for a wide range of pitches when mismatch is systematic and repeatable. However, it cannot be used when proximity mismatch is randomly drifting or when few pitches in regular CD through pitch distribution have significant offset with respect to neighboring pitches (see *Figure 3*).



a)

b)

Figure 3 Applicability of Pattern matcher for different delta CD through pitch fingerprints: a) Pattern Matcher can be used; b) Pattern Matcher cannot be used.

3. EXPERIMENT

This approach has been evaluated at ST Microelectronics 300 mm fab on a gate layer of 65 nm process. Three scanners have been matched: one TWINSCAN™ XT:1250 and one TWINSCAN AT:1250 scanners as ‘to-be-matched’ and one TWINSCAN AT:1200 as the reference. The matching task was quite challenging because maximal Optical Proximity Effect (OPE) offset before matching has been measured as small as 2.5 nm. After process stability analysis for the product layer, we had chosen 90 nm line through pitch structures as a representative set of features. In total 34 features with OPC have been selected.

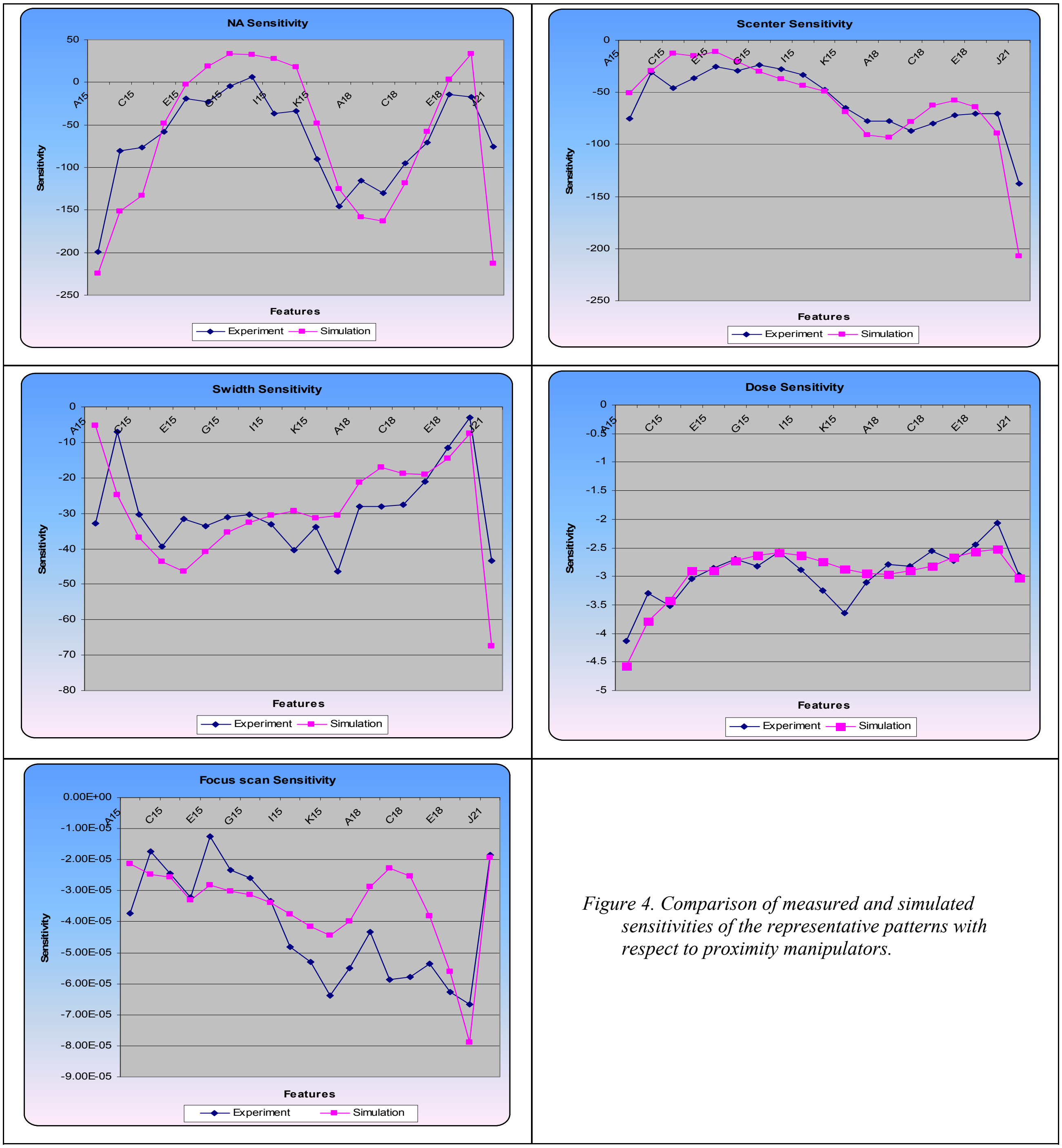


Figure 4. Comparison of measured and simulated sensitivities of the representative patterns with respect to proximity manipulators.

Because of small proximity differences between scanners, we had to use the most accurate tuning methodology. For that, we decided to determine proximity manipulators sensitivities experimentally. To complete the methodology evaluation, we verified sensitivities by simulation using LithoCruiser. However, minor differences have been observed (see *Figure 4*).

Obtained optimized illumination conditions are shown in *Table 2*.

Scanner	Corrections for parameters				
	NA	σ_out	σ_in	Focus scan range (nm)	Dose
XT:1250	0	+0.005	+0.005	+76	+2%
AT:1250	+0.01	+0.006	0.006	0	+1%

Table 2. Optimized illumination conditions for two scanners to be matched

4. RESULTS

Matching has been very successful. After matching, residual CD difference was below 1.5 nm in terms of ΔCD range. This is considered as a good matching for this layer/technology node (see *Figure 5* and *Figure 6*). The overall improvement for all measures was at least 20%, and for some measures up to 50%.

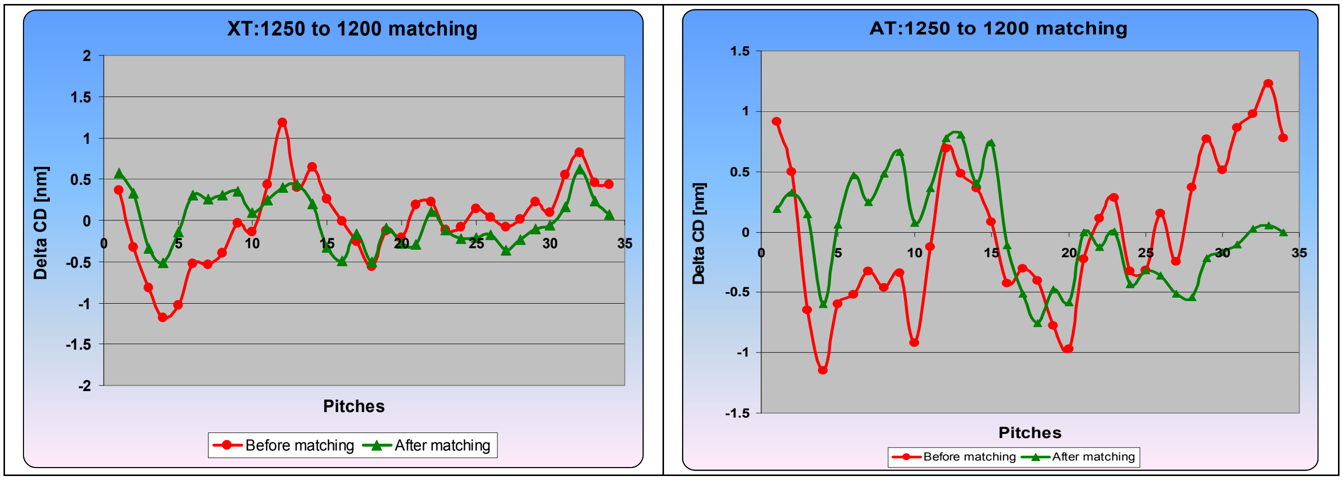


Figure 5. CD variation for 90 nm through pitch features before and after matching

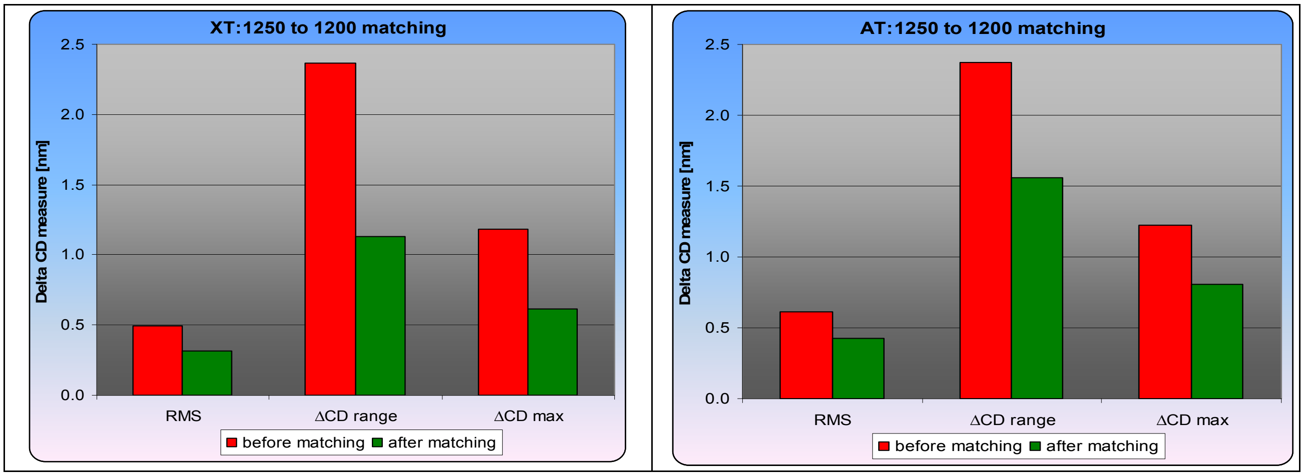


Figure 6. Improvement of scanner-to-scanner matching given for different measures

Another remarkable fact is that we have been able to predict resulting proximity fingerprint with very high accuracy (see *Figure 7*).

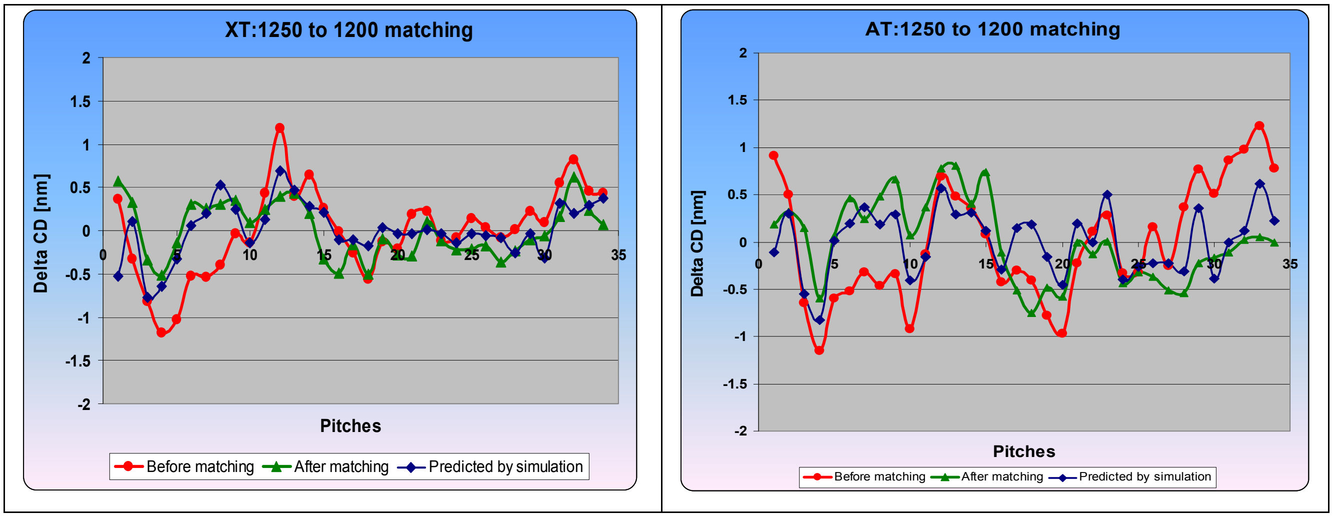


Figure 7. Comparison between predicted and achieved matching,

5. CONCLUSIONS

Evaluation of Pattern Matcher has been performed for matching of three ArF scanners in the semiconductor factory environment. Although Initial tool-to-tool proximity difference has not exceeded 2.5 nm in terms of maximal CD difference, we have been able to reach significant matching improvement. Two matching solutions for XT:1250 and AT:1250 scanners to match them with AT:1200 have been given. The experimental verification of solutions has been performed successfully.

We are looking forward to apply Pattern Matcher to improve scanner performance for other products.

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