Matching of Different CD-Metrology Tools for Global CD Signature on Photomasks

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Abstract

Critical Dimension uniformity (CDU) is one of the most critical parameters for the characterization of photomasks. For years the understanding was that CDU describes a rather random fluctuation of the CD across the mask. With more advanced CD tools and mask processes the local short-range CD variation (on a length scale of micrometre) can be distinguished from the global CD signature (typically on a length scale of centimetre). Recent developments in the pattern generator sector allow correcting for such global CD signatures. This triggers the current challenge to find stable methods to characterize the global signature of photomasks.
In our work we present matching results of a technique that calculates the CD signature using exponentially weighted surrounding points. We investigated different CD SEM tools of different technology generations. We show that our method allows determination of the CD signature independently of the measurement tool with low uncertainty and moderate measurement effort. This holds even true when the CDU value is mainly dominated by the measurement error. Thus our method provides a tool to extend the utilization of older generation metrology tools as well as the possibility to improve the measurement capability for CD signature of current tools.

Keywords: Critical Dimension Uniformity (CDU), Toolmatching, Thin plate splines

1. Introduction

The precise targeting of critical dimension (CD) on photolithographic masks is an essential part of the mask production process, especially because CD measurement is an essential part for defining the usability of the mask in wafer production. By communicating CD values the following has to be kept in mind:
1. Problems to derive a single result for the distance between e. g. the left and the right edge of a given object can occur since it concerns a) a complex three-dimensional structure and b) the process itself has a systematic influence on the obtained results (since it defines how all the different parameters are represented in the CD measurement)[1].
2. CD is not homogeneous among the mask (see figure 1). Many steps in the mask production process can introduce spatial CD variation over the mask. Therefore CD variation is not only stochastically distributed over the mask but exhibits a pronounced signature in most cases. The main contributors to spatial CD correlations are local loading effects and global process parameters. Local loading effects are electron beam

parameters which reflect short range electron interactions. The distribution of molecules in the etch chamber is one example for a global process parameter contributing to the CD variation.
3. CD SEM tool performance varies between different tool generations as well as between different tools of the same generation. Due to the tightening of metrology requirements it might become necessary to exchange the used CD tools with each new technology node.

Up to now, efforts in matching CD-SEMs to each other concentrate on trying to minimize CD offsets between tools [2]. New efforts additionally use the CD-SEM image information for a direct physical matching of CD-SEMs [3].
However, matching the measured CD signature across a wafer or mask has not been included into these investigations so far. Especially if different tools from different suppliers are used, which is typical for mask makers, it is not necessarily evident that the measured CD signature is always the same.
In this paper we present a method to match CD signatures measured on different tools even of different technology generations allowing to extend CD tool utilization as well as to optimize performance of tools of the latest technology generation.

2. Experimental

Various special test masks have been produced showing different levels of CD signatures. Furthermore nearly 400 engineering masks with the same design have been analysed. The sampling plan included approximately 120 measurements of features with a nominal CD of 180nm as well as 240nm across each mask.
The masks have been measured on different tools and the CD results as well as the signatures have been compared to each other. To ensure that the signature is independent of the measurement direction and the measurement tool, one mask has been measured once with 0° and once with 90° rotation.
We used tools from two different suppliers of three technology generations:

Tool	Supplier	Generation
SEM1	1	3
SEM2	1	2
SEM3	2	2
SEM4	1	1

3. Results and Discussion

3. 1. Method to determine the CD signature

A Method suitable to characterise CD signatures on mask must achieve several requirements [4].

- The method should yield a smooth surface fitting the data in a way that the left residuals consist of noise only.
- The method should allow to characterize the correlated CD deviations from the mean in a spatially resolved way.
- The method should be flexible enough to account for variable signatures
- The method should use only minimal presumptions about the functional form of the signature

A promising approach uses thin plate splines (TPS). TPS smoothing [5] uses a roughness penalty approach to separate noise from the actual signature. The advantage of using splines is based on the flexible data description by interpolating between each data point and by going exactly through each data point simultaneously. In the roughness penalty approach splines are used to approximate the raw data Y_i but not at the cost of an arbitrary roughness of the spline surface g.

$$S(g) = \sum_{i=1..n} \{Y_i - g(t_i)\}^2 + \lambda \int g''(x)^2 dx \quad \textbf{(1).}$$

The first term in equation (1) is the sum over the squared differences between the raw data Y_i and the smooth surface g.The strength of surface smoothing is determined by the parameter λ in equation (1) which will be determined by cross calibration (to find the smoothing parameter with which the smoothed curve has a minimal mean square distance to a new measurement point). Since not all the measurement points have the same weight the practical approach is to leave out points. This means that on a data set of N points we compute N smooth curves for an explicitly chosen parameter λ with each point of the set being once removed from the data set.

3.2. Current tool matching method

Tool matching has been done so far in a way to define one tool as the “Golden Tool” or Master Tool”. This tool is calibrated using a certified standard. Using sub-standards, all other tools are matched to this Master Tool by adjusting the CD offset accordingly. The matching is tracked by a daily SPC control. For matching individual targets with different nominal CD values have been selected to match the absolute CD values as well as the CD linearity between all tools.

3.3. New tool matching method

A disadvantage of the previous method is the negligence of the CD signature.
To ensure that there is no tool induced CD signature, a special test was accomplished. One mask was measured twice: one normal measurement with 0° rotation and a measurement with 90° mask rotation. Let us suppose that the tools do not contain an own signature the two obtained signatures must be identical. Fig.1 clearly shows that the CD signature is not influenced by the measurement tool itself. Fig.1 (left) shows the signature measured in 0° orientation, fig.1 (right) in 90° orientation. This result was confirmed by doing the

same measurement also on a second tool. In case a tool induced CD signature is present, it has to be taken out of the data before continuing.

a)

SEM 1 SEM 2

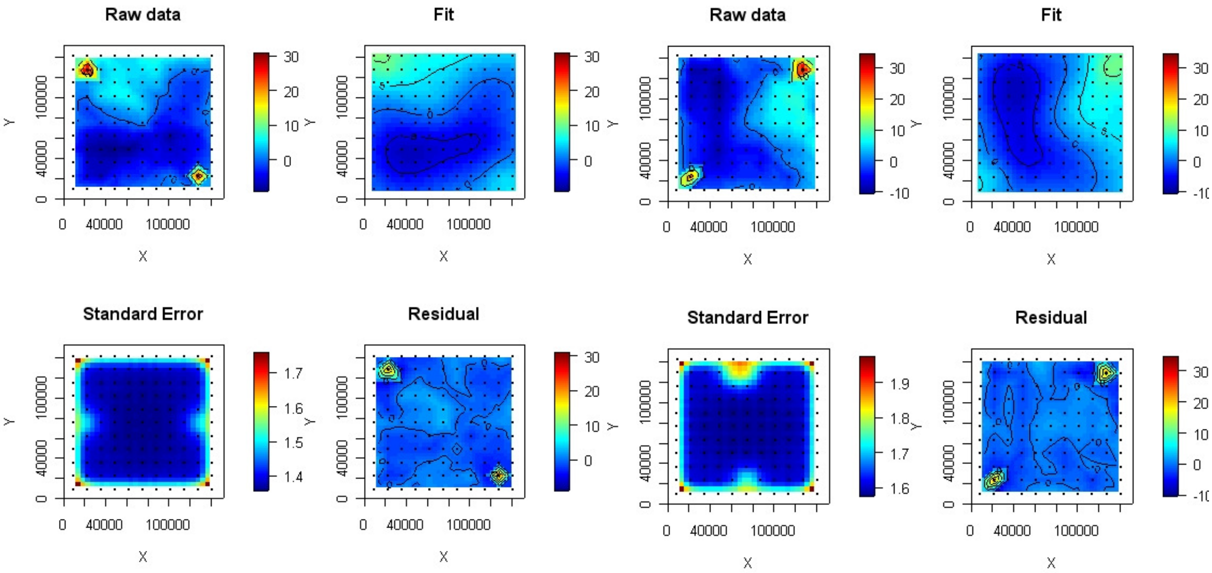


Figure 1: CD uniformity plot of a mask without intentional CD variations. The spatial CD variation over the mask is depicted as a temperature map. Negative CD deviations from the mean are depicted in blue and positive deviations in red. The measurement depicted on the left hand side has been measured at 0° mask orientation, the right hand measurement at 90° mask orientation

Our further investigations refer to the difference between the older tools from supplier 1 and one of the new tools from supplier 2. As the results in figure 2 does not bear a significant offset.

The behaviour of noise level 3sigma is very interesting; the deflection between the tools amount to 0.2 nm. An influence on noise level only is attributed to short range CD variations. These short range variations interfere with tool noise level [6].

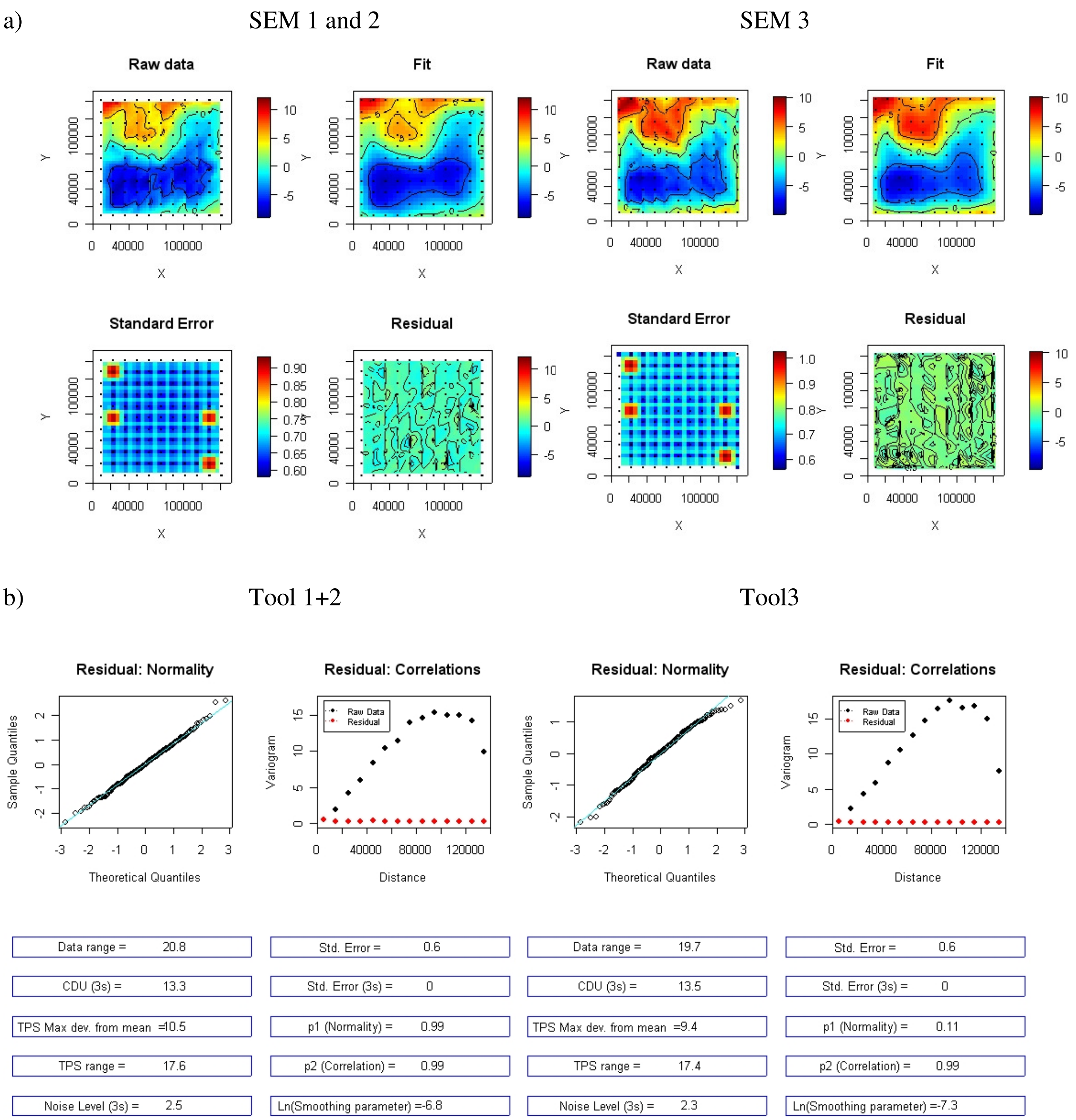
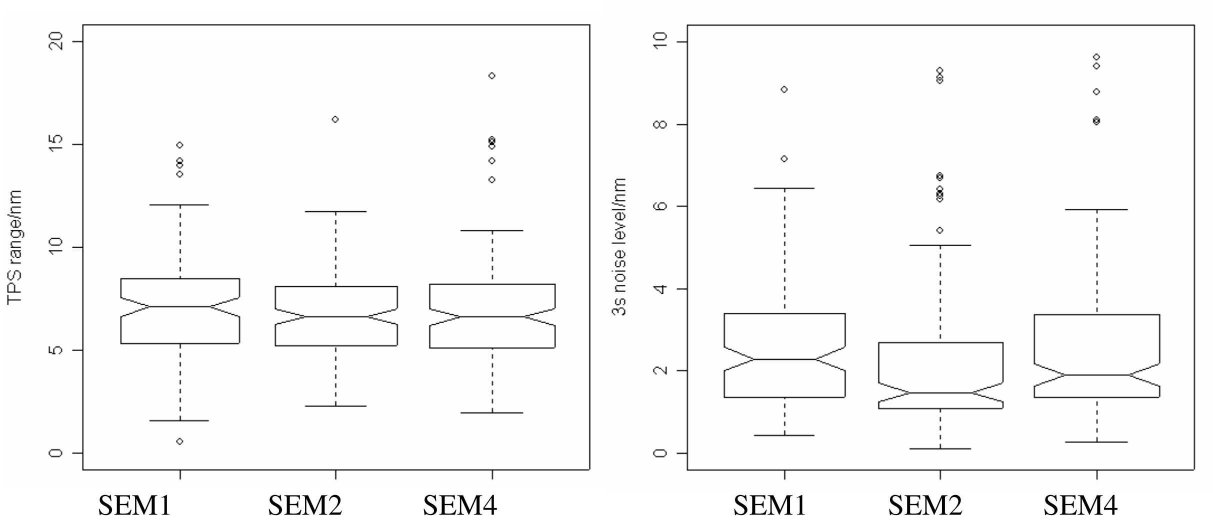


Figure 2: a) CD uniformity plot of a special test mask design with induced CD variations. The test mask was measured on tools from different suppliers and of different technology generations. Since raw data, fit and noise level are almost identical the tools match.
b) Data evaluation from mask shown in figure 2a)

Furthermore we investigated the fitted CD values and the noise level behaviour for nearly 400 engineering test masks to get additional results for CD signature matching. The expectation is that on masks with the

same design, noise level and signature should be almost identical. The box plot in fig.3 (left) shows that the 3 sigma range of all three tools is almost identical. However, the noise levels show small differences between the tools from different technology generations. This shows that the applied method to fit the CD signature can correct for the different CD noise due to different CD-SEM tool generations which is mainly due to differences in CD-SEM precision and resolution.
Expectedly the TPS range and noise level should decrease from node to node connecting to increasing requirements (see figure 3 a) and 3 b)).

a)



b)

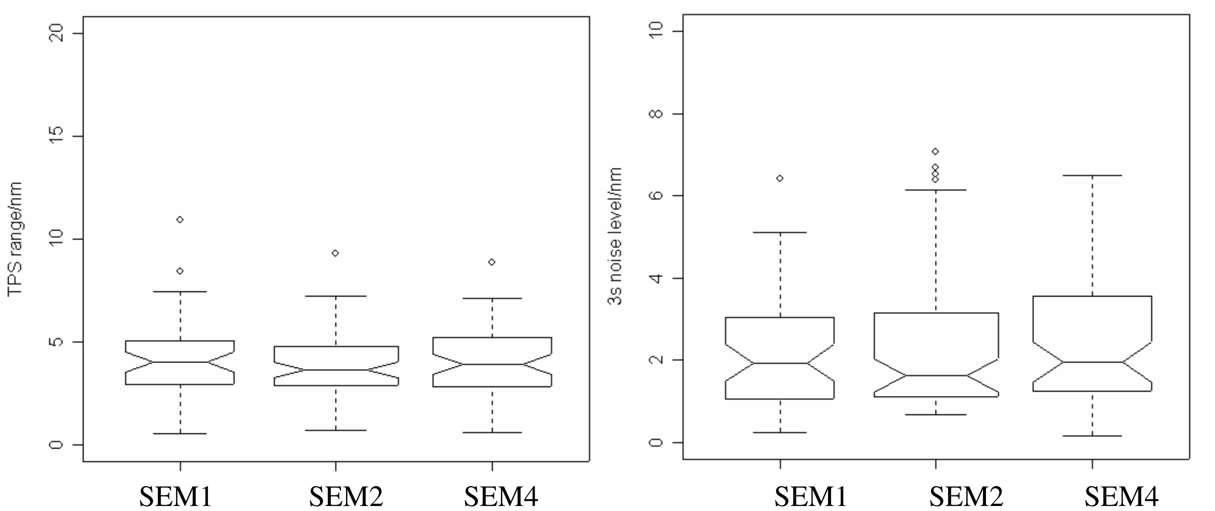


Figure 3: a) Data evaluation from ca. 400 engineering masks mask. An incoherent tool matching exists, since TPS range and 3 sigma noise level shows small deflection. Nevertheless TPS range and noise level are similar, so that the tool matches.
b) Same data evaluation as shown in 3 a) but next technology node

As you can see in figure 3 the 3 sigma noise level does not slash as much as the reduction of TPS range. This means that the noise level is influenced by the mask production process itself. We expect a minimum noise level by using scatterometry; at the moment investigations are ongoing.

Summary

In this paper we have proposed a stable method for tool matching beyond CD offset determination by using the signature of a photomask. We have also demonstrated that this approach has low uncertainty and moderate measurement effort. It gives the possibility for reliable tool matching, independently of the tool generation and tool supplier and allows to take out measurement errors from CDU values. This methodology allows to utilize metrology tools for CDU determination for more than one techno logy generation and allows additionally determination of CD signatures which are below the noise level of the metrology tool as well as below the contribution of local short-range CD variations.

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