CD inspection by Nuflare NPI 6000 tool

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Abstract

Critical Dimension uniformity (CDU) is one of the most critical parameters for the characterization of photomasks. Lately it has been shown that advanced CD (critical dimension) SEM tools and mask processes can distinguish the random short-range CD variation from the global CD signature, which is driven by process and design characteristics. Current electron beam writers can utilize this global CD signature information and correct the CDU of photomasks accordingly. Therefore a detailed knowledge of the signature will benefit strongly photomask CDU.
Electron beam writer based signature compensation relies primarily on CD signatures derived from CD SEMs. Here higher spatial resolutions of the signature are achieved only by high cycle times at metrology. The trade off between cycle time and resolution leads to a CD resolution somewhere around one cm. Even then the photomask will have to stay a substantially percentage of the total cycle time at a non-value added process step.
In this paper we argue that the solution for this dilemma can be found at a completely different process area – at inspection. We present data showing that the novel CD map feature of the NPI inspection tools enables CD maps in unparalleled resolution in the mm region. This far exceeds CD SEMs by a factor of 100. Also utilization of a tuneable spectrum of different features are not limited to selected CD measurement sites. The CD map is generated in parallel to the traditional defect inspection and works for pre- and post pellicle inspections equally well.
To evaluate the method we used a single die layout of a current logic design and referenced all data only to database. Nevertheless, the data presented will demonstrate the excellent repeatability of the CD map measurement and the good matching to CD SEM measurements.

Keywords: Critical Dimension Uniformity (CDU), cycle time, CD signature, CD inspection, CD SEM

Introduction

One of the most interesting recent advances in metrology was the development of a CD measurement (critical dimension) capability during photomask defect inspection.[1-3] This novel technique has various names by each tool vendor. For clarity the functionality will be called CD inspection in this paper similar to defect inspection. CD inspection combines two unique advantages. Firstly, it allows saving cycle time by enabling the combination of CD metrology and classical inspection in one production step. This exchanges classical CD SEM metrology in favour of CD inspection. The cycle time acceleration could be significant considering current CD measurement point counts around one thousand for high end reticles.[4] Secondly, the CD inspection capability has a superior spatial resolution to classical CD SEM metrology. The primary advantage of this is the independence of adequate CD measurement sites and CD measurement strategy. CD signature artefacts due to a low measurement density are overcome because almost all structures are analyzed. This allows multiple new applications to use the new data. The spatial high resolution data can be used to replace CD signature determination by CD SEM and support improvements for CD compensation methods[5] as well as hot spot analysis. In fact it is important to focus on the most promising use case and bring it into production. For production, additional challenges have to be overcome. In particular, the generation of quality data during CD metrology creates a high demand for accurate and traceable CD measurement data. At this point CD inspection has not yet reached the same level of traceability and further developments are necessary. In general it might be necessary to have both techniques (CD inspection and CD metrology) operate in parallel to understand their different behaviour as well as to assure CD data integrity of both approaches.

In this paper we concentrate on one usage for integrating CD inspection into production and report on a comparison between classical CD SEM signatures with the CD inspection signatures. In earlier work we have shown already that CD signatures are very robust against the actual hardware to evaluate them.[6] To assess CD inspection we used normal production photomasks with logic design and a single chip layout. Optical proximity correction (OPC) of the layout is normal for 32 nm node. The OPC reduces the number of possible CD measurement sites with classical CD SEM dramatically, because it significantly diminishes sites that are really identical post OPC. Nevertheless qualitative comparison for the investigated products is possible.

Experimental

In total we will present data from four reticles in this paper. One poly contact (PC) layer and three metal layers. The PC layer was chosen because it consists of areas with very different design solutions. The metal layers are from the same device and will be used to show the reproducibility of the results.
We measured the reticles by means of a CD SEM - LWM 9045(Advantest) and inspected by NPI 6000 (Nuflare). The measurement point distribution for CD SEM was identical to typical production. Only one dense feature (no OPC) was used for analysis. The amount of measurement points varied from 20 to 50.
All masks have been inspected with the P70 algorithm die-to-database that allows defect detection down to 50 nm. For the analysis of the CD inspection results we tested multiple averaging methods of the data. Finally, a grid size of around 1mm showed excellent CD details in the signature as well as enough smoothing of measurement noise. Furthermore, we restricted the analysis of CD features to a limited design CD range.
The software of the NPI 6000 supports this functionality by evaluating only those features within a predefined certain CD feature size. Nevertheless, it is not possible so far to analyse only for instance the 120 nm dark isolated lines that are longer than 1µm. Right now CD inspection on the NPI 6000 does average all

features with the correct design CD. To avoid too much averaging, four different result files are generated, one for dark lines in x, one for dark lines in y and the same for clear lines in both directions. We found that a CD window of 100 nm around the dominant CD size works very well for our photomasks. However, please note that this value strongly depends on the CD linearity of the mask features and also on the given design solution. For instance, pooling an isolated small line with a dense large line might give wrong signatures. In this case the derived signature might depend more on the ratio of these two features around a point of interest than on the actual CD signature within a uniform feature.

The recorded data has been analyzed using the software packaged available in R (version 2.9.2) in particular for signature plotting and smoothing algorithms (packages akima and fields). The measurement times for inspection with and without CD inspection have been recorded.

Results

The measured CD signatures of the four photomasks are shown in figures 1 through 4. A quantitative analysis of the differences was unfortunately not possible, because exactly where the biggest mismatch between CD inspection and CD SEM could be seen when the density of CD SEM measurement sites was extremely low. We attribute this to the fact that real production masks were used. It does indicate that the measurement strategy requires a thorough review once both CD techniques are in production.

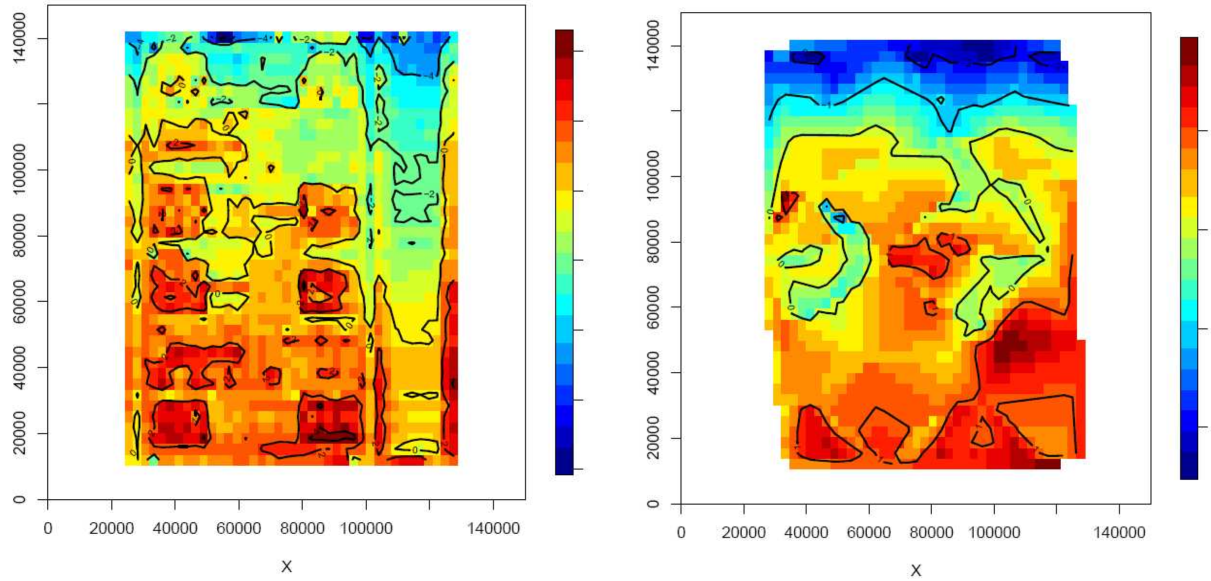

Figure 1: Left) CD inspection report for dark lines in y-direction of a poly contact layer with several characteristic design solutions. Right) The same reticle measured by CD SEM. Due to lack of CD SEM measurement sites almost none of the subareas are resolved. The pronounced CD change in the upper edge is well visible and also the characteristic stripe on the right edge.

In figure 1 the major advantage of CD inspection is instantaneously visible. The data density is on a length scale of 1 mm (and could be much smaller) in contrast to larger than 1 cm for CD SEM metrology. This reveals novel details of the CD signature, uncovering design dependencies and so far, unseen process behaviour.

The observed structures (die like hot spots) correlate exactly with the design density, opening the question whether real reticle properties (e.g. loading) have been measured. To answer this question is currently not possible. It proved impossible to find well suited CD SEM measurement sites to confirm or disconfirm this. Another possible explanation is that in the area with high design density other features were used than in the area with lower design density. In this case also proximity and linearity effects would result in signature differences. They could result for example if the dominant structure in the high density area is a dense feature and the dominant structure in the surrounding is an isolated feature or if one feature is on the upper end of the investigated CD band and the other one at the lower end. This could result in the 2-3 nm difference.

Please note that the CD difference found by NPI 6000 is much larger than the CD SEM differences by about 50%. We assume that this is a simple calibration offset which can be determined and corrected. The same kind of offset is visible in figures 2-4.

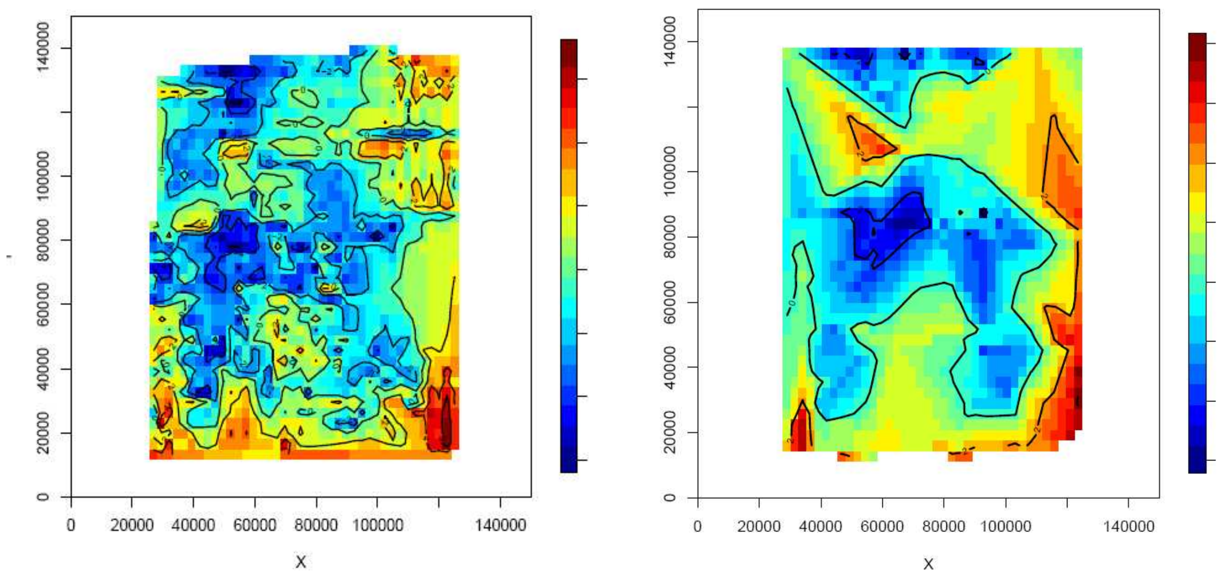

Figure 2: left) CD inspection report for dark lines in y-direction of a metal 2 layer with a characteristic lower right edge hotspot and middle left cold spot. Right) CD SEM report of the same mask.

In figure 2 the metal 2 layer of a different device is depicted. Here a characteristic cold spot in the middle left and a hotspot lower right have been resolved by both techniques. The elongated cold spot in the upper right seen by CD inspection has no counterpart at CD SEM. In this area no adequate measurement sites are available. Or in other words, the CD SEM measurement is blind for this cold spot.

In figure 3 the metal 3 layer of the same device as the metal 2 of figure 2 is depicted. It should be noted that the metal 3 is dominated by structures in x-direction. In contrast, the metal 2 predominately consists of y-structures. It is therefore very interesting that the same characteristic cold spot in the middle left and hotspot lower right have been resolved by both techniques.

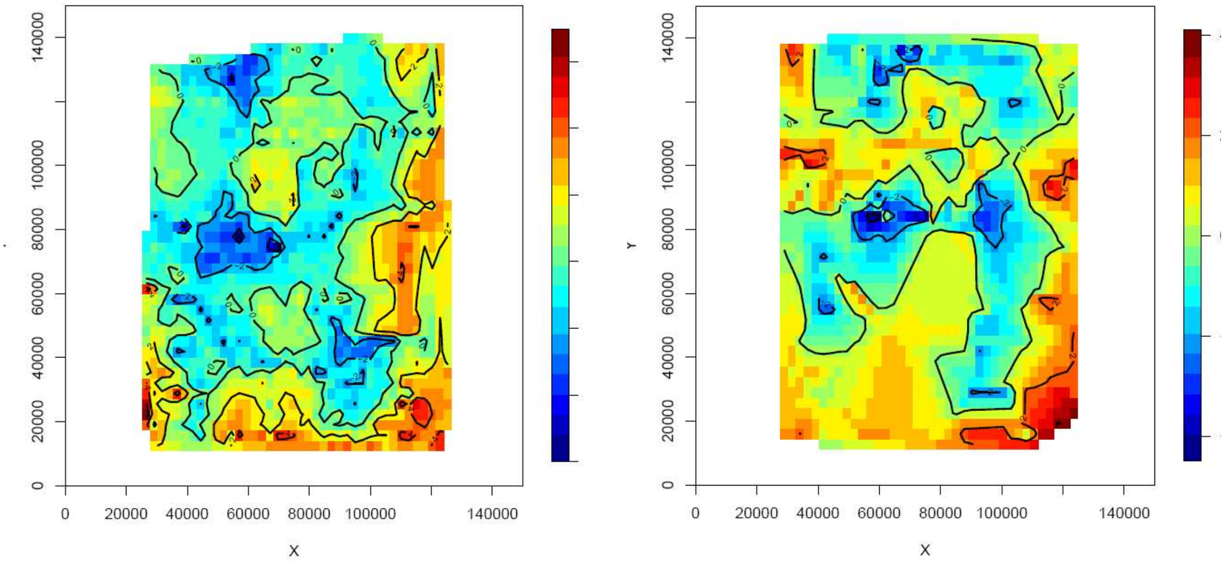

Figure 3: left) CD inspection report for dark lines in x-direction of a metal 3 layer of the same device as in figure 2. Right) CD SEM report of the same mask. The characteristic lower right edge hotspot and middle left cold spot are clearly visible, but not as pronounced as for the metal 2 layer. This can be seen in both reports.

The elongated cold spot in the upper right seen in the metal 2 is not present in the metal 3, because a completely different design solution is used here. We found it surprising that both techniques show a less pronounced but yet similar trend for hot and cold spot behaviour when comparing metal 3 with metal 2 layer.

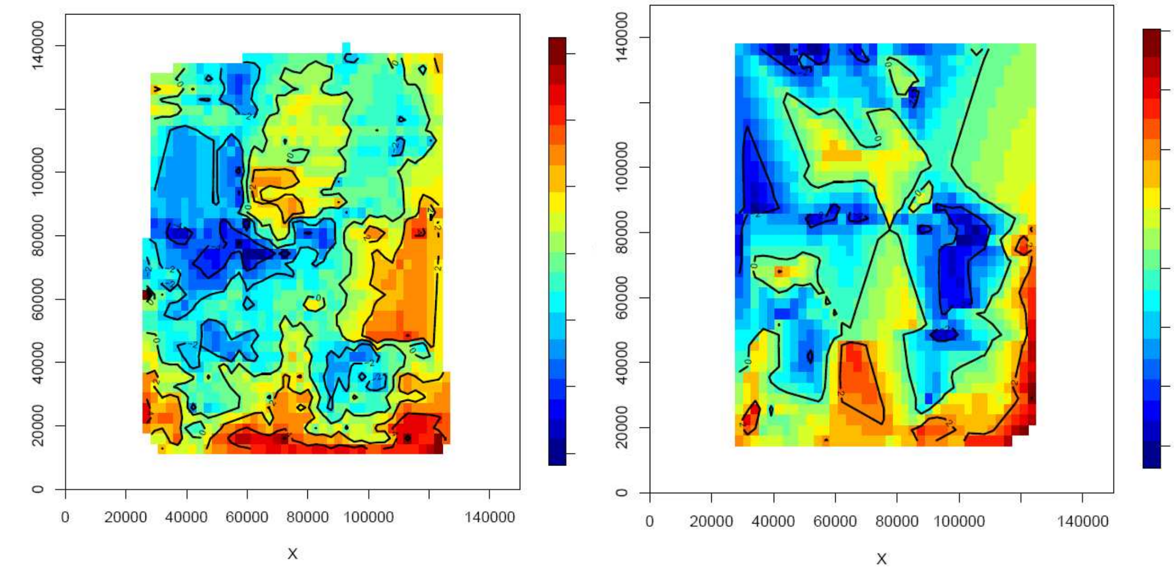

Figure 4: left) CD inspection report for dark lines in y-direction of a metal 4 layer of the same device as in figure 2 and 3. Right) CD SEM report of the same mask. These reports show the largest deviation, in particular in the upper edge and in the middle.

In figure 4, the metal 4 layer of the same device as layer 2 and 3 layer is shown. For these layers the largest deviation between the two techniques has been observed. In particular the cold spot in the upper middle and middle right seen on CD SEM does not match to the CD inspection signature. Here, the root cause cannot be the missing CD SEM measurement sites. However, even with these mismatches the signatures still show a large resemblance.

For all inspected masks no increase of the inspection time was recorded applying the CD inspection. Thus defect inspection and CD inspection work truly in parallel for the NPI 6000. This is a major prerequisite to really combine the functions.

Conclusion

In this paper it was successfully shown that CD inspection is capable to reproduce the CD signature of a photomask with superior resolution. It does allow investigation of design effects for loading in a completely new data density. Design and process effects could be investigated on a length scale of 1 cm with CD SEM. With CD inspection the length scale is 1 mm and below. Very subtle signature influences can be detected opening a wide field of possible new process understanding for all front end processes, like mask writing, develop, and etch.

CD inspection reproduced the correct CD signatures for real production plates with single die logic layout of the 32nm node. Differences of CD inspection signatures to classical CD SEM signatures are mainly driven by the huge resolution difference of the data. It will take much more effort to find out whether the found design dependence for CD is real or not. Our current CD SEM data is not sufficient to answer this question completely. The more general gap behind this problem is the traceability of CD inspection data or even more precise the unknown traceability of averaged huge amounts of data.

The same problem arises for very specific measurements of single targets. Therefore, CD inspection does not support investigation of linearity and OPC effects right now. It should be mentioned that this might not be a technical problem of the measurement, but a software challenge to analyze the data accordingly.

In summary, CD inspection might not be good enough to replace CD metrology completely right away. Nevertheless CD inspection already delivers excellent CD signature information. This makes this novel technique interesting as an additional CD method that could development into a front up CD solution very quickly depending on the demand for better CD resolution and shorter cycle time.

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