

Intra Field CD Uniformity Correction by Scanner Dose MapperTM using Galileo[®] Mask Transmission Mapping as the CDU Data Source

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ABSTRACT

Intra-field CD variation can be corrected through wafer CD feedback to the scanner in what is called the Dose Mapper (DOMA) process. This will correct errors contributed from both reticle and scanner processes. Scanner process errors include uncorrected illumination non uniformities and projection lens aberration. However, this is a tedious process involving actual wafer printing and representative CD measurement from multiple sites. A novel method demonstrates that measuring the full-field reticle transmission with Galileo[®] can be utilized to generate an intensity correction file for the scanner DOMA feature. This correction file will include the reticle transmission map and the scanner CD signature that has been derived in a preliminary step and stored in a database. The scanner database is periodically updated after preventive maintenance with CD from a monitoring reticle for a specific process. This method is easy to implement as no extra monitoring feature is needed on the production reticle for data collection and the new reticle received can be immediately implemented to a production run without the need for wafer CD data collection. Correlation of the reticle transmission and wafer CD measurement can be up to 90% depending on the quality of CD data measurements and repeatability of the scanner signature. CD mapping on the Galileo[®] tool takes about 20 minutes for 1500 data points (there is no limit to the number of measurement point on the Galileo[®]), which is more than enough for the DOMA process. Turn Around Time (TAT) for the whole DOMA process can thus be shortened from 3 Days to about an hour with significant savings in time and resources for the fab.

Keywords: Intra-field, Reticle Transmission, Dose Mapper, DOMA, CD CDU, Galileo, Scanner signature, Mask Transmission Mapping

1. INTRODUCTION

In today's manufacturing processes, and especially for 45nm node and below, CDU becomes a major contributor to yield and consequently a big concern for the lithography engineers. Main contributors to the wafer CDU are:

1. The mask CDU, being affected by the mask manufacturing process (film, writing and etching signatures) and CDU degradation due to DUV exposure in the scanner and mask cleaning,
2. The scanner CDU signature and
3. The resist process magnifying the CDU of the aerial image in the wafer plan.

Contributors to the CDU, that show a distinct signature across the mask, even on the exposed resist, can be compensated using a localized dose adjustment in the scanner while exposing the wafer. This feature is incorporated in ASML scanners as the Dose Mapper.

In this paper, the results of a collaborative study between GLOBALFOUNDRIES in Singapore and Carl Zeiss SMS (Pixar Technology) in Israel are presented. Using the Galileo[®] to accurately scan a reticle's transmission, converting the transmission map into a Critical Dimension (CD) map and to use it to feed forward to the ASML Dose Mapper, 50% improvement in final CDU can be achieved.

Additionally, in order to take the scanner signature into account, the Carl Zeiss Galileo[®] tool can be used (with the help of a reference tool for reticle CD measurement or wafer CD measurement) to extract the scanner CDU signature for CDU prediction and improvement.

2. BACKGROUND

2.1 Process flow of Galileo® Transmission measurement tool feeding the ASML Scanner DoseMapper

As shown in other publications, reticle intensity measurements can be used as a source for reticle CDU feedback to the scanner^[3-7]. The method works only if reticle CDU is systematic and is a major source of the wafer CDU contributions. Current studies shows that with the advanced development in mask technology in CDU control, scanner contribution to the wafer CDU have also become one of the major sources.

In this paper we present a method of correcting wafer CDU using Reticle Transmission (RT) uniformity measurements and a scanner signature, derived from Reticle Transmission (RT) uniformity measurements. Reticle Transmission (RT) measurement is a macro view of the transmitted light intensity. By using this RT measurement, long range proximity effects can be corrected. In regions where small pitch line and space features are clustered, the variation will be more significant compared to isolated features. This observation is closely related to the MEEF. A correlation setup is done with a monitoring reticle to determine the constant (k) from the linear relation of RT with respect to CD.

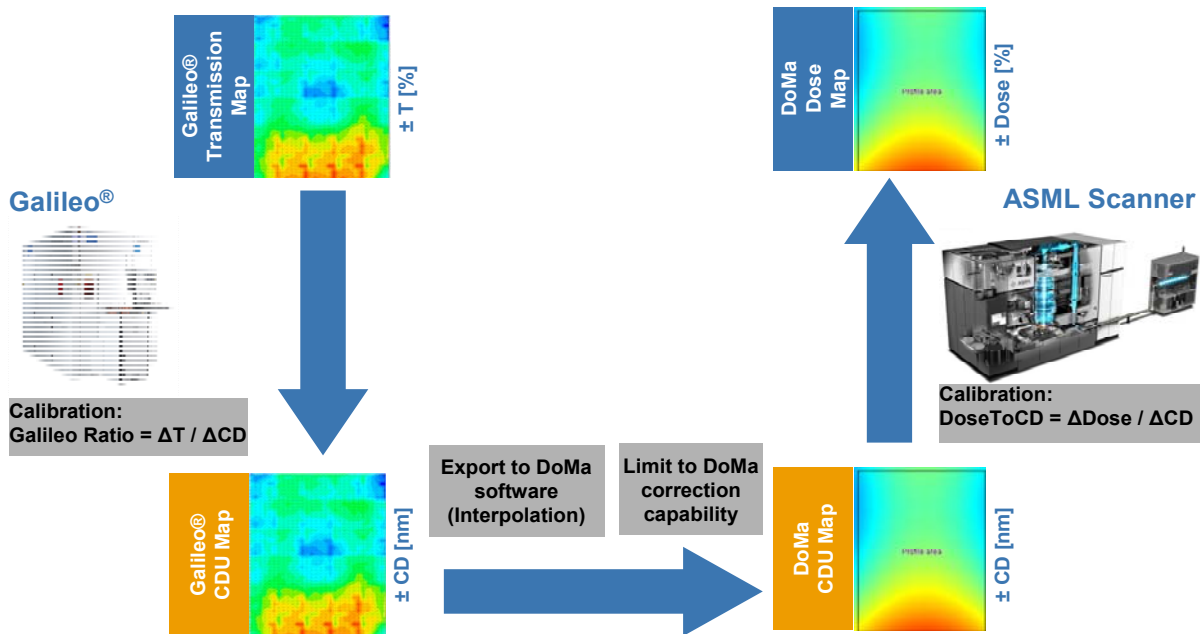


Figure 1 – Process flow of Carl Zeiss Galileo® Transmission measurement tool feeding the ASML Scanner DoseMapper

Figure 1 shows the work flow of compensating CDU for resist CD using Galileo® Transmission measurement tool to feed forward to the ASML scanner DoseMapper. This will save on wafer printing on scanner with high Work-In-Progress (WIP) and long hours of CD measurement (typically about 5-8 hrs) that are needed to setup the wafer CD recipe and CD data collection for DOME. Furthermore in the current practice, measurement features with suitable requirement design pitch and CD are needed to be identified on MEBES for each unique tapeout. There are occasions where only limited suitable features can be found on the devices which create situations of unrealistic representation of the mask systematic error. Henceforth, CD mapping on the Galileo® tool presents a faster Turn-Around-Time (TAT) for the whole DOME process with repeatable accuracy. It is easy to implement on the production reticle as no production wafer is needed for CD measurement. Correction can be applied on first production wafer whereby no unique/extra monitoring feature is needed on the production reticle for data collection. The new reticle received can be immediately implemented onto production run without the need for wafer CD data collection.

2.2 Work flow of Galileo® Transmission measurement tool to generate a correction file for the scanner

In this paper we report measuring a full-field reticle transmission map using Galileo® Transmission measurement tool and utilizing it to generate a correction file for the scanner. This correction file includes the reticle transmission information map obtained. The scanner process signature for a specific layer was derived after subtracting its reticle transmission map from its wafer CDU map. This scanner signature can further be stored in a database. The scanner database will be periodically updated after scanner Preventive Maintenance (PM) using the CD of a monitoring reticle for that specific process.

Figure 2 shows the novel flow for obtaining the scanner signature using a monitoring reticle. Before commencing production runs for a new device tapeout, various scanner signatures will be set up using a monitoring reticle. Full field wafer CD measurement data will be collected for various scanners. Correlation between reticle transmission map and wafer CD map will be performed and a specific scanner signature will be derived. Thereafter the specific scanner signature for a specific layer and wafer process will be stored into the database for production runs. Periodic update of the scanner signature will be conducted as and when necessary and after every PM. For new production runs, the new production reticle will undergo RT measurement on Galileo® during the in-coming check. Combining the RT map with its respective scanners signature, a specific correction file for that reticle will be derived and stored in the scanner database for wafer printing.

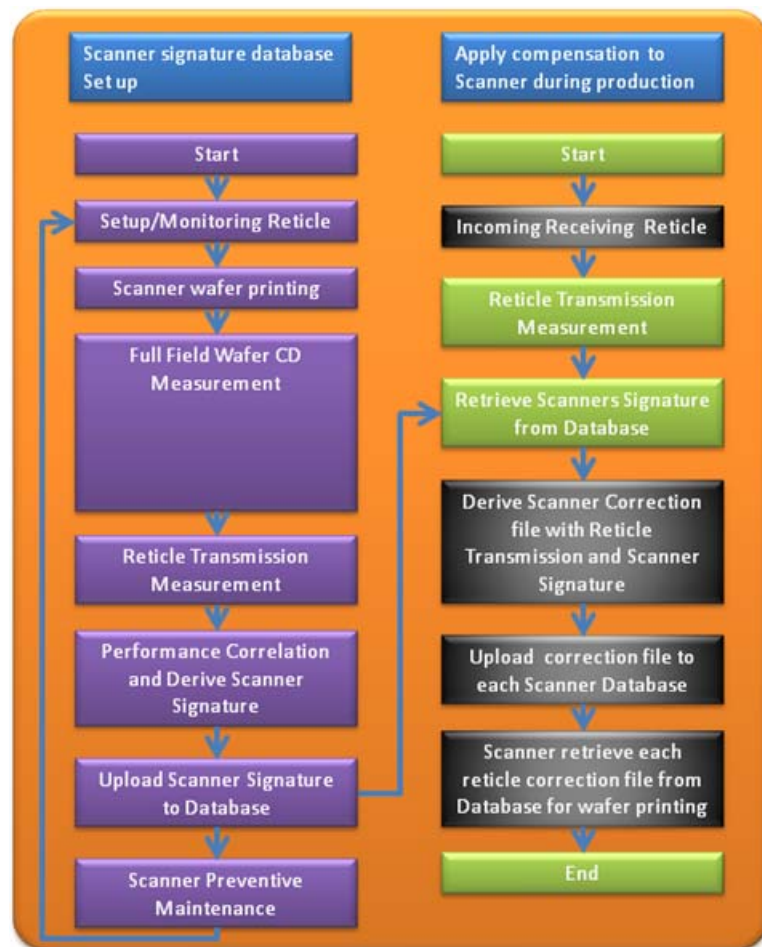


Figure 2 – Scanner signature setup and production reticle correction file generation flow for resist CDU improvement

2.3 Introducing the Galileo® Reticle Transmission measurement system

The Galileo® is a non-imaging transmission measurement system with high transmission repeatability and extremely high signal to noise (SNR) ratio. The Galileo® uses a deep UV lamp as the light source, which helps to get a more stable, low noise and “low cost performance” illumination as it is required for very high sensitivity transmission measurements. The Galileo® scans various measurement locations across the mask using a DUV spot of 180µm-600µm diameter (FWHM), resulting in a transmission value on each location which is averaged over the area of the spot. A reasonably resolved mask transmission map is generated within 30 minutes using the Galileo®. However, higher lateral resolution can be generated if needed.



Figure 3 – Galileo® Reticle Transmission Measurement

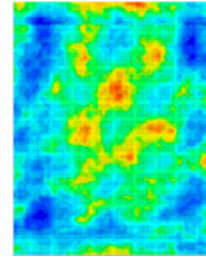


Figure 4 – Galileo® Transmission Map measured on reticle

2.4 CDU measurement using Galileo®

The transmission uniformity map (Figure 4) correlates to the wafer CDU with a calibration factor, which needs to be calibrated either using mask or wafer CD data generated by an alternative CD measurement system (e.g. CD SEM or optical CD). In order to generate a CDU map as seen in Figure 4, the critical features covering the averaging area of the spot needs to be spread over the mask on several locations.

2.5 Transmission maps and the correlation to wafer CD

The CDU distribution on the wafer can be described by equation (1):

$$\Delta CD_{Wafer} = \left(\left(\frac{\Delta CD_{Mask}}{4} \right) + \Delta CD_{Scanner} \right) \times MEEF$$

Equation (1)

To transfer the Galileo® transmissions maps to the CDU maps (where the units of each measurement point is in nm) a one-time calibration process (per design rule/layer) is needed correlating the Galileo® data to a reference tool measurement, usually wafer CD, OCD or Mask CD.

Under the assumption, that the CDU range is mainly contributed by the mask, the slope of the Galileo® Transmission vs. Wafer CD correlation graph is used to generate the calibration factor. This process already takes the resist MEEF (Mask Error Enhancement Factor) into the calibration.

Converting the Galileo® map into CD map

In this step, the wafer CD data is used to convert the Galileo® RT map into a CD map. Both sets of data are plotted and correlated to each other. The Galileo® data is of high resolution and consist of many measurement points. The wafer CD/OCD or Mask CD are usually limited by the number of measurements to around 150 points per field only. Due to that problem the Galileo® application is used to interpolate the original data to the same coordinates and number of points as of the reference tool’s wafer CDU data. This interpolation can be seen in Figure 4 vs. Figure 6. Both Figure 4 and Figure 6 show the same CDU measurement grid where Figure 6 is a Galileo® map plotted in low resolution for the correlation purpose.

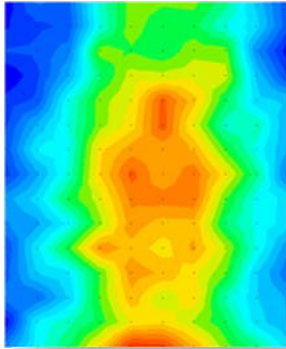


Figure 5 – Wafer Measurement

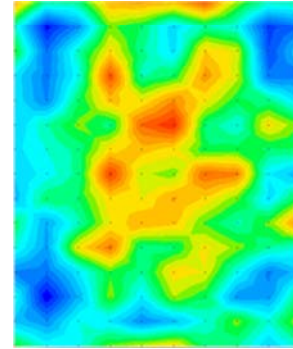


Figure 6 – Galileo® scan (interpolated)

2.6 Scanner signature extraction

To account for the additional influence of the scanner signature on the wafer CDU, the scanner signature can be derived in first approximation using a mask with a small CDU signature and wafer prints. The scanner signature can then be used to predict the wafer CDU more accurately. Figure 7 shows the process of extracting the scanner signature and then using it to create a DoseMapper correction map.

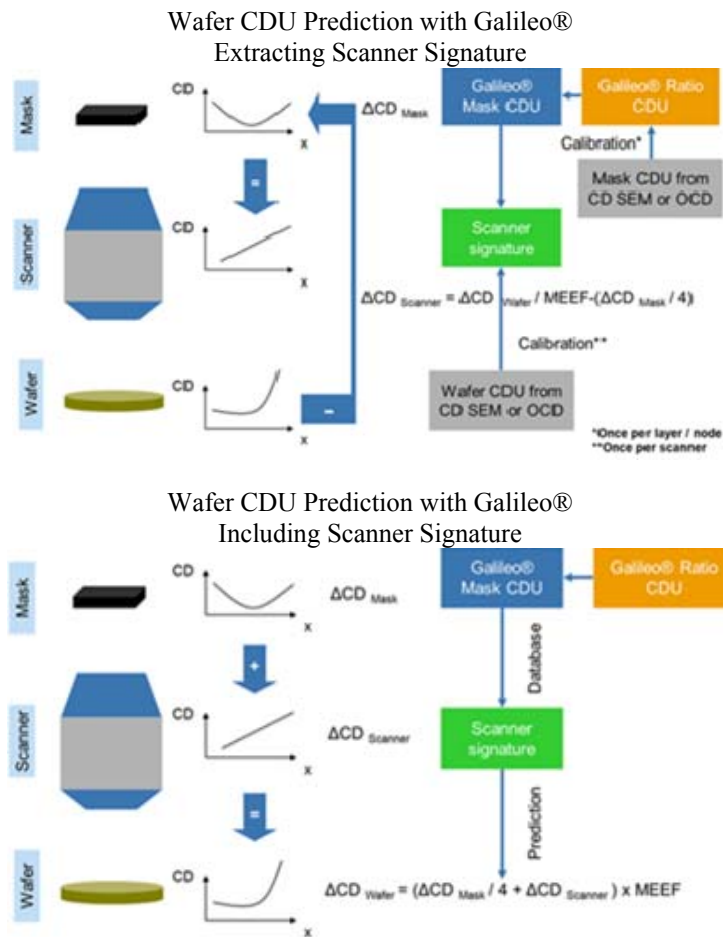


Figure 7 - Wafer CDU prediction with Galileo®. Extracting and using the scanner signature

3. RESULTS

3.1 Wafer CDU map correlation to Galileo® TRU (Transmission Uniformity) map

The Galileo® Transmission map measurements show the mask signature whilst wafer CD results show the mask signature + Residual (mainly scanner non uniformity). Henceforth, in order to have the most significant wafer CDU correction by DOMA the scanner signature should be added to the mask signature as measured by the Galileo®.

The mask non-uniformity correlation to the scanner signature is presented in the following formula in equation 2:

$$\text{Mask Signature} \times \left(\frac{CD}{Dose}\right) = (\text{Wafer CD}) - (\text{Scanner non uniformity})$$

Equation (2)

The $\frac{CD}{Dose}$ is estimated in the Correlation graph in Figure 8 and is reported in nm/%dose. All CD data for mask and scanner in this paper is provided in nm at wafer level.

Figure 8 shows the slope of the formula in Eq (2) that represents the factor for conversion of the Galileo® map. In this case, the correlation between the CD data and the Galileo® data is 71% ($R = \sqrt{0.505} = 0.71$) and the derived factor is 1.434nm/%.

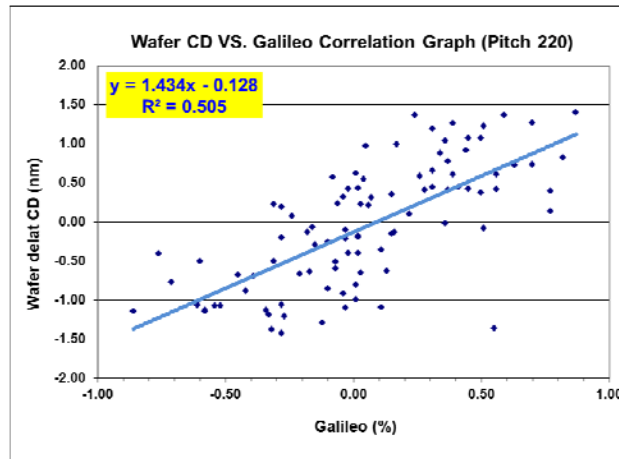


Figure 8 - Correlation graph of wafer CD vs. Galileo measurement

The Galileo® transmission map is basically a dose map. With this factor, it is now possible to convert the Galileo® transmission map from Figure 9 to a CDU map. By applying the CD/dose factor of ~1.45 (1.434 from Figure 7), the mask CD contribution was calculated to be approximately 2.5nm.

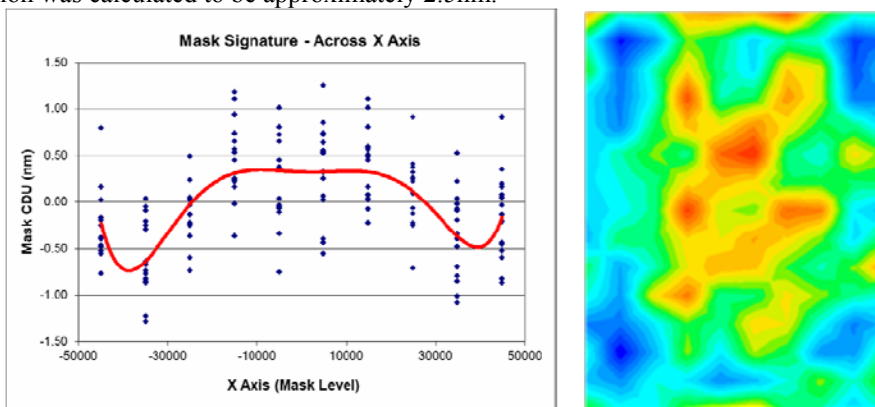


Figure 9 – Galileo® mask signature and its CDU map

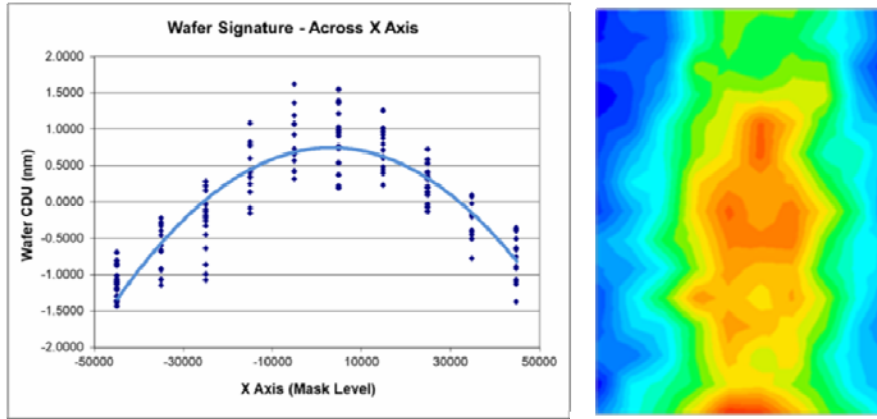


Figure 10 – Wafer CD signature and its CDU map

Figure 10 shows the wafer intra-field CDU as measured by CD-SEM system.

3.2 Correlation with & without scanner signature

From Eq. (1) that represents the wafer CDU, the scanner signature can be calculated. Since the Galileo® was calibrated against wafer data where the MEEF is already included and accounted for; Eq (3) signifies the extraction for scanner signature:

$$\Delta CD_{Scanner} = \Delta CD_{Wafer} - \Delta CD_{Mask}$$

Equation (3)

Figure 11 shows the graphical representation of the scanner signature. With the Galileo® application it is also possible to interpolate the scanner signature into a high resolution map that can be used with any new reticle.

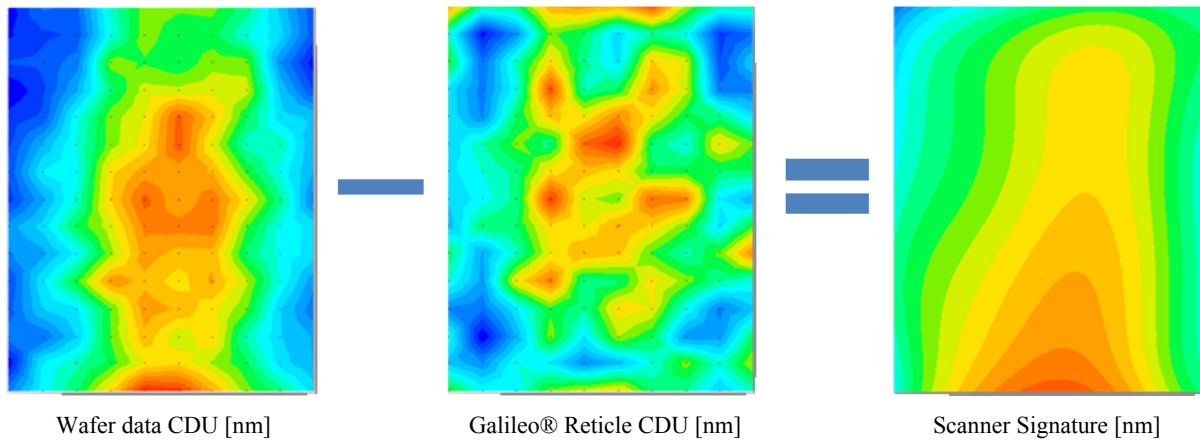


Figure 11 – Graphical representation of scanner signature extraction

Figure 12 shows a good correlation between the scanner signature derived based on the method shown in Figure 11 and the actual scanner signature obtained from standard across-slit uniformity measurement at wafer level. In this case, the correlation is close to 80%.

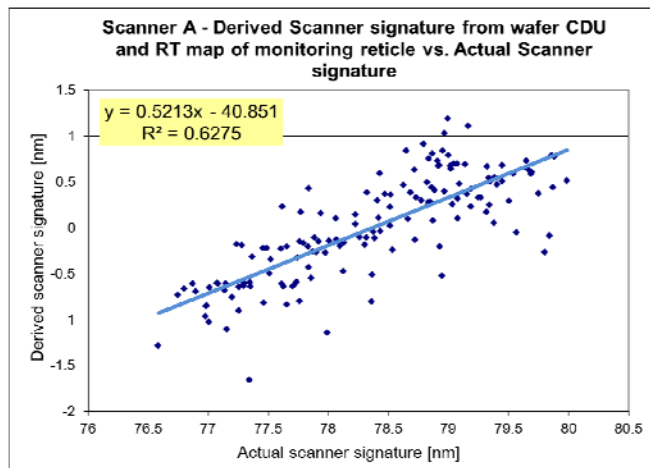


Figure 12 - Derived scanner signature from wafer CDU and RT map of monitoring reticle in correlation to actual scanner signature

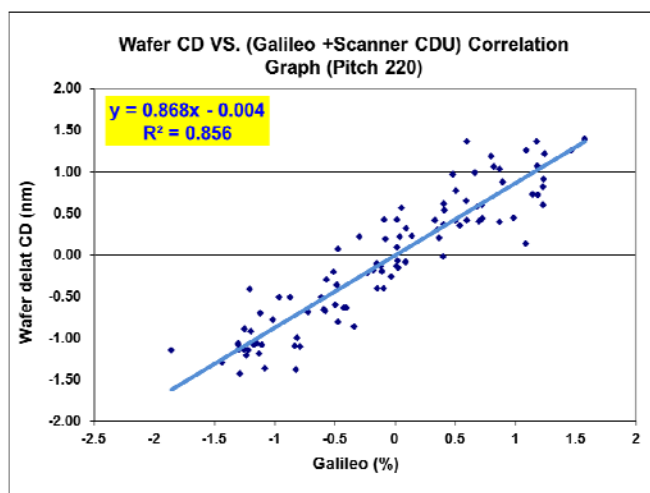


Figure 13 – Correlation graph of wafer CD vs. Galileo® measurement with scanner signature (220nm pitch)

Figure 13 shows an improved correlation between wafer CD data and Galileo® data, which includes the scanner signature for the same mask as in Figure 8. After including the scanner signature the correlation factor is improved to 92.5% ($R = \sqrt{0.856} = 0.925$) as compared to 71% in Figure 8.

Having derived the scanner signature, it can be easily used to estimate the final wafer CD uniformity by interpolating and overlaying it on any reticle scanned on the Galileo® for the same scanner signature on similar layer and wafer process. Combining the Galileo® RT map with its respective scanners signature, a specific DOMA correction file for that reticle can be derived and used for the DOMA CDU application (instead of using wafer CD).

Cases where mask CDU signature is insignificant compared to the scanner signature

A different case where mask CDU contribution to wafer CD is minimal and scanner signature is very significant is shown in Figures 14 and 15. Figure 14 shows the wafer correlation to Galileo® CDU for this mask without scanner signature whilst Figure 15 exhibits the wafer correlation to Galileo® CDU with scanner signature. There is almost no correlation to wafer data without the scanner signature in Figure 14 which would render only noise for DOMA application. However, a useful 60% correlation is observed with scanner signature applied on the Galileo® scan as shown in Figure 15.

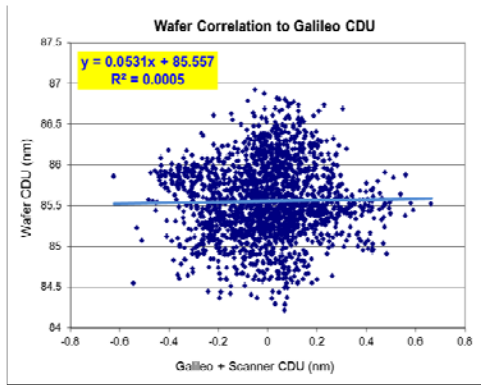


Figure 14 – Wafer correlation to Galileo® CDU without scanner signature

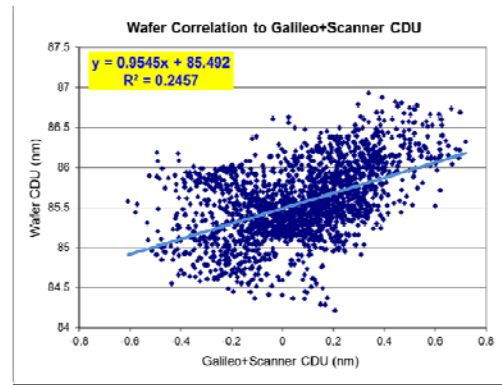


Figure 15 – Wafer correlation to Galileo® CDU with scanner signature

It is clear from the above example that applying our technique will provide valuable DOMA correction files in both cases, either if the mask contribution to the wafer CDU is large relative to the scanner signature as well as in cases where the mask CDU is very good and the main contributor to wafer CDU is the scanner signature

3.3 CDU improvement with Galileo® & scanner signature

As the scanner signature was extracted based on one feature type (i.e Line feature of a specific design pitch, multiple array dies) of a monitoring reticle, there is a need to convert its “range” when using it on other type of reticles (e.g. for relaxed design rule or single-die reticle). Hence, the averaged transmission of the calibration and the new reticle will be used in order to calculate the factor to compensate the scanner CDU.

The dose ratio between the two masks (dose ratio = transmission ratio) is to be taken into account in order to use it to convert the scanner signature to the new mask. In the progress of this test, the scanner signature was derived from a test reticle with the average transmission of about 20%. The average transmission of the reticle to be corrected was 45% and in order to derive the correct range the map was multiplied by the ratio of the transmission ranges of $\frac{20\%}{45\%} = 0.44$

DOMA Simulation and production results

With the scanner signature adapted to the new scanned reticle, the scanner map can now be interpolated/ extrapolated to fit the new reticle. From Eq. (1) that represents the wafer CDU, the combined map will describe the final wafer CDU ($Wafer_{CDU} = Mask_{CDU} + Scanner_{CDU}$). Using the scanner signature generated from a specific design pitch, CDU improvement for that pitch will be improved while other pitches will have “lower” improvement only, but will still be improved all together. Henceforth, we can generate a signature based on more features, giving a different weight for each critical pitch as needed. Furthermore, scanners can be easily tracked for changes in signature (due to PM, usage etc) and DOMA application will be updated with a new signature promptly with new file generated per reticle for specific scanner as needed. Table 1 provides simulated results of running the Galileo DOMA process on several production masks in the fab.

Device description	Die size	3sigma from wafer before correction [nm]	Corrected 3sigma with Galileo® & scanner signature [nm]	CDU Improvement (DOMA simulation)
2x3 layout (6 dies)	X Large	1.134	0.585	48.4%
3x4 layout (12dies)	Large	1.886	0.853	54.7%
3x5 layout (15 dies)	Large	0.827	0.653	21.0% (*)
4x5 layout (20 dies)	Medium	0.662	0.469	29.1%
4x6 layout (24 dies)	Medium	1.385	0.995	28.1%
6x7 layout (42 dies)	Small	1.371	0.951	30.6%

(*) This reticle correction map was tested on a production wafer and yielded 17% real CDU improvement

Table 1: CDU improvement (simulation and production) summary table in terms of layout and die size

3. DISCUSSION

Galileo® metrology data is streamed in a feed-forward approach through DoseMapper into the scanner, to create a dose compensation recipe which improves the overall CDU performance. From Table 1 it can be seen, that by applying the described process of using the Galileo® transmission measurement for reticle CDU prediction and scanner signature extraction to feed the ASML Dose Mapper, significant CDU improvements have been achieved on several masks

Other than reticle transmission of new reticles and design pitches anchored, die sizes and layout will also contribute to the amount of CDU improvement. Table 1 shows the CDU improvement summary in terms of layout and die sizes. The results show that larger die sizes are more sensitive to MaskCDU and ScannerCDU. Hence CDU improvement is greater for larger die size array. The results discuss that intra-field wafer CDU gains for single-die reticle by using conventional method of correcting through wafer CD feedback to the scanner using DoseMapper is negligible. This is because there are larger non-uniformities in reticle manufacturing process than in a multiple-die reticle. The resist coating processes and etching processes non-uniformities are more dominant for single-die reticle as compared to multiple-die reticle. Henceforth, a single-die reticle will normally show a prevailing radial effect with tilt than multiple-die reticle. As a result, Galileo® metrology data will be able to correct for these sources of CDU errors and improve the wafer CDU for larger die size devices tremendously.

4. CONCLUSIONS

In this paper, it has been demonstrated that a full-field reticle transmission map measured using Galileo® can be utilized to generate a correction file for the scanner and efficiently reduce intra-field CDU on printed wafers. The scanner process signature for a specific layer can be derived by subtracting its reticle transmission map from its wafer CDU map. After extracting the scanner signature, it can be easily used to estimate the final wafer CD uniformity by interpolating and overlaying it on any reticle scanned on the Galileo® for the same scanner signature on similar layer and wafer processes. Our conclusions from this study are:

1. This feed-forward method can effectively replace the feedback concept using send-ahead wafers and extensive CDSEM measurements.
2. It is easy to implement in production as no production wafer is needed for CD measurement.
3. Correction can be applied already on the first production wafer.
4. No unique monitoring feature is needed on the production reticle and no wafer CD or after-etch CD measurement is needed on the production reticle.
5. The result is a significant cost and resource saving and will improve fab productivity.

5. ACKNOWLEDGEMENTS

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