Measurement, Separation, and Amelioration of Transverse Scanning Synchronization Error

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ABSTRACT

The need for lithographic tool advances for reducing feature size, pitch (low k1 processing), and improving overlay stems directly from next generation circuit layout and performance roadmaps1. Overlay error or layer-to-layer misalignment tolerances have continued to decrease to the point where a few nanometers of misalignment can seriously impact process and device yields. In this work, we expand our previous work2 and introduce a new scanner aberration monitoring methodology that can both measure and deconvolve lens distortion from scanning synchronization error while simultaneously providing machine corrections for accurate tool matching. Experimental data taken from several machines suggests it is possible to ameliorate scanning synchronization error for each machine and improve tool-to-tool matching at the level required for next generation processing. Finally, we discuss applications of this new technology including practical fab implementation and discovering problematic scanning tool signatures.

Keywords: aberration, accuracy, distortion, in-situ, lithography, metrology, overlay, reticle stage, scan, scanner, synchronization, wafer stage

1. INTRODUCTION

As chip dimensions decrease the tolerances for layer-to-layer overlay are also reduced. Since overlay registration error on critical layers can impact performance and yield of chips, understanding the sources of overlay error in a lithographic exposure tool becomes crucial. There are two types of overlay errors, inter-field and intra-field. The inter-field errors are the actual positions of fields printed on the wafer relative to other fields (grid and yaw). These errors are usually due to the accuracy of wafer stage of the exposure tool. The intra-field errors are the overlay errors that each field on the wafer has relative to the center of the field. The errors include translations in X and Y, rotation, magnifications (or scale) in X and Y, and orthogonality in addition to higher order terms. The root cause of these overlay errors can be found in lens aberrations, lens distortions, scan irregularities, scan synchronization error between reticle and wafer stages, and reticle alignment. The machine error discussed in this paper is intra-field error.

There are two categories of dynamic distortion: lens distortion, which relates to a2 and a3 in Zernike coefficients and is repeatable, and scan synchronization error between reticle and wafer stages, which includes both systematic and random or non-repeatable errors. There are known techniques to measure distortion in the industry, most of which make the assumption that the stage motion is perfect and/or the center of the lens is distortion free3, which in general is not true.

For this work, we reintroduce Distortion Mapper (DMAP)TM from Litel Instruments4, 5, 6, which is used to measure and separate out distortions due to the lens and scanning synchronization error. First, we measured dynamic lens distortion and scan synchronization error for two scanners. Next, we compared the total distortion measured by DMAP (lens distortion and average scan synchronization errors were added) to a direct total distortion measurement technique7. The scanning synchronization error for each tool was used to make adjustments to ameliorate the error between scanner A and scanner B by at least 70%. Finally, we discuss applications of the DMAP technique, such as understanding and adjusting the scanning direction dependent distortion.

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2. METHODOLOGY

DMAP is a resist-based technique used to measure machine distortions. It can separate scan synchronization error from lens distortion by a self-referencing technique, which provides absolute, not relative measurements. The technique uses standard frame-in-frame (or box-in-box) overlay structures and a conventional overlay metrology tool. See Figure 1 for a flowchart of the DMAP process. Unlike standard stage metered measurement technique widely used in the industry, errors in DMAP are completely independent of scanner stage accuracy and repeatability. Since DMAP uses an overlay reticle, it can also be shared between multiple lithography exposure tools of different models and wavelengths.

In the DMAP method, we use alignment wafers with horizontal and vertical scribe lines that define fields of 36mm by 36mm on the wafer. The scribe lines on the wafers are exposed so that the patterns are symmetric from any of four notch orientations (down, up, right and left). This is necessary because the DMAP technique requires exposures at different notch orientations. For this reason, there are wafer alignment marks (WAMs) along the scribe lines to achieve precise wafer alignment at all notch orientations. Like the scribe lines that define the fields, WAMs along scribe lines are designed so that the location of each WAM is the same at all notch orientations. Once all patterns for the alignment wafer are exposed onto a resist-coated wafer, the wafers are etched and resist is removed. This leaves the wafers with etched alignment wafer patterns on a substrate. This allows the user to use the same wafer multiple times.

The DMAP technique uses an overlay reticle, which contains an 11x13 matrix of DMAP structures. Each DMAP structure has a big frame (outer frame in frame-in-frame structure) with two smaller frames (inner frame in frame-in-frame structure) to the top and the right of the big frame with a constant distance, dp, from the big frame (see Figure 2). The pitch between the DMAP structures is p in both X and Y directions. DMAP has a ‘Dynamic Intra-field Measurement, Lens (DIML)’ technique to measure dynamic lens distortion and a ‘Dynamic Intra-field Measurement, Scan (DIMS)’ technique to measure scan synchronization error.

![Flowchart for DMAP technique.](image)

**Figure 1:** Flowchart for DMAP technique.

**Figure 2:** DMAP structure consists of a big box (outer frame for frame-in-frame structure) and two smaller boxes (inner frame). DMAP structures are separated by distance ‘p’ in both X and Y directions. The distance between a big box and small boxes is ‘dp’ in both directions.
2.1 DMAP (Dynamic Lens Distortion)

The DIML technique measures the scan averaged lens distortion divorced from wafer stage and scan synchronization errors. In Zernike terms, lens distortions relate to $a_2$ and $a_3$, respectively, and represent X and Y tilt in the exit pupil phase shift. While Zernike terms $a_2$ and $a_3$ create feature independent shifts, the process-induced shifts come mostly from 3rd order coma terms, $a_7$ and $a_8$. Higher order coma terms ($a_{16}$, $a_{17}$, $a_{29}$, $a_{30}$, $a_{46}$ and $a_{47}$) also contribute to the shift, but are generally of lower order magnitude than the fundamental modes described above. The following equations show how dynamic lens distortion in X (DXL) and Y (DYL) are calculated:

\[
DXL = a_2\cdot[-\frac{\lambda}{(\pi*NA)}] + a_8*f(\sigma, NA, \text{feature}) + \ldots\text{higher order terms}\quad(\text{Equation 1})
\]

\[
DYL = a_3\cdot[-\frac{\lambda}{(\pi*NA)}] + a_7*g(\sigma, NA, \text{feature}) + \ldots\text{higher order terms}\quad(\text{Equation 2})
\]

where $\lambda$ is scanner wavelength, NA is the numerical aperture of the scanner used and $f, g$ ($\sigma$, NA, feature) are factors that are dependent of $\sigma$, NA and feature. Zernikes can be determined by using a Litel In-Situ Interferometer (ISI)\textsuperscript{TM} 8, 9, 10. The lens portion of intra-field distortion depends on the cross scan coordinate (in X) and is independent of scanning direction (in Y). Because lens distortion is independent of the scanning mechanism, it is repeatable and can be described as vector plots across the scanner slit.

The DIML technique requires three exposures. The first exposure is called ‘0-shear’ exposure in which the overlay reticle is exposed without any shift in dynamic mode at two fields defined by the alignment wafer. This will expose 11x13 DMAP structures in two fields after global wafer alignment using WAMs.

The second exposure is exposed on one of two fields that were exposed with the ‘0-shear’ exposure at the same notch orientation. In the field, the overlay reticle is exposed again dynamically, but with an X wafer shift of ‘p-dp’. This is called an ‘X-shear’ exposure. The shift is set so that the small frames on the right of the big frame on column 1 from this exposure overlaps with the big frame from a column to the right of it (column 2) from 0-shear exposure. Since a whole column is shifted in X, only 10x13 matrix of structures would have frame-in-frame structures that can be measured for the overlay error using a conventional overlay metrology tool.

The third exposure is exposed on the field that was not used in the ‘X-shear’ exposure. For this exposure, R180-shear, the wafer is rotated 180 degrees (for example, if the 0-shear and X-shear were exposed at notch down orientation, R-180-shear is exposed with notch up). Again, after wafer alignment using WAMs, the overlay reticle is exposed dynamically with a shift of -dp in the X direction so that a big frame from 0-shear exposure overlaps with a small frame from R180-shear, and vice versa. This exposure results in two frame-in-frame structures at each of 11x13 sites. Only one frame-in-frame structure from each pair is measured on an overlay metrology tool, and from these results the DMAP software reconstructs the lens distortion. The figure below (Figure 3) shows what X- and R180 shears look like after exposure.

![Figure 3: This illustration shows what X-shear and R180-shear look like after the DIML exposures.](image)

2.2 DMAP (Dynamic Scanning Synchronization Error)

Unlike dynamic lens distortion, distortion due to scanning synchronization error between reticle and wafer stages consists of both systematic and random contributions. Figure 4 defines our conventions for scan synchronization. X and Y are defined as instantaneous slit center position on wafer. The effect of wafer to reticle stage synchronization error on printed feature position is described by the moving average over the illumination slit of the instantaneous translation and yaw synchronization error. We denote $(DXS,DYS)(Y)$ as the moving average of the translation error and $DQS(Y)$ as the
moving average of the yaw. The intra-field error due to scanning synchronization errors in X and Y (DXS_total and DYS_total, respectively) for each location (X,Y) can be easily calculated by the following equation (Equation 3):

\[(DXS_{total}, DYS_{total})(X,Y) = \text{Intra-field error due to scanning synchronization error} = (DXS(Y), DYS(Y) + X*DQS(Y)) \]  

(Equation 3)

where DXS(Y) and DYS(Y) are in units of nm, X in mm and DQS(Y) in µrad. The scan synchronization errors, DXS(Y), DYS(Y) and DQS(Y), are functions of the scan direction (Y). Because of the fact that the error has a non-repeatable component, we cannot measure the repeatability of the DIMS technique.

There are three exposures for a DIMS wafer. The first one is the same as the DIML exposure described above (0-shear) but all fields are exposed, instead of the two fields exposed in DIML exposure. DIMS wafer has one type of exposure pattern in all fields (in DIML, there were X-shear and R180-shear patterns). After 0-shear is exposed on all fields, the wafer is rotated 90 degrees (wafer can be rotated to either notch right or left). In this work, the wafer was rotated to notch right. There are two exposures with wafer notch at right: ‘R1-90’ and ‘R2-90’ shears. Both shears are exposed with smaller blade setting, which only expose 11x11 of DMAP structures, instead of 11x13. This is done so the 0-shear looks as if it is 13x11 when the wafer is rotated 90 degrees. So even with reticle masking blades set to expose 11x13 for R1-90 and R2-90 shears, one row on top and bottom does not overlap with the 0-shear exposure. The difference between these two shears is the shifts that are put on each one. One of them is shifted one column to right and the other one to left. A small shift in Y direction may be added so that DMAP structures are interlocked from 0-shear and R1-90 and R2-90 shears. Different wafer shifts are required when the wafer is rotated to notch left. DIMS measurements consist of 2 sets (one from overlapping between 0-shear and R1-90 shear and another one from overlapping between 0-shear and R2-90 shear) of the 11x11 matrix of frame-in-frame structures in each field.

2.3 Total Distortion

The most common and well-known method to measure the total intra-field distortion uses an overlay reticle with an array of big boxes (or outer boxes) evenly spaced across the reticle and with a small box (or inner box) at the center of reticle. First, the full field is exposed onto a resist-coated wafer. This prints an array of outer boxes in a field. Then reticle blades are set so that only a single inner box is exposed. The inner box is selected at center of slit. Then the wafer is repeatedly shifted and exposed so that the inner box overlaps with all outer boxes on overlay reticle layout. Using the overlay data measured from the box-in-box structures resulting from the exposure, the lens distortion can be easily calculated.

There are three issues with this technique. The first is the assumption that the center of lens contains zero distortion. The distortion seen at the center of the lens would manifest itself as translations in X and Y on all box-in-box structures at the wafer, which can be calculated and removed. The second issue is the assumption that the stage motion error can be neglected. There are random and systematic errors in stage motion; the random errors show up as inaccurate distortion. This issue becomes a bigger problem when distortion from one tool is compared to another as there are differences in stage motion errors between the two tools. Lastly, this method is not generally capable of separating scan synchronization errors from lens distortion.
Total intra-field distortion as measured by DMAP is the sum of dynamic lens distortion (DIML) and average dynamic scan synchronization results (DIMS). The total intra-field distortion can be calculated using the following equation:

\[
(D_{XT}, D_{YT})(X,Y) = (D_{XL}(X) + D_{XS}(Y), D_{YL}(X) + D_{YS}(Y) + X*D_{QS}(Y))
\]

where \(D_{XT}\) and \(D_{YT}\) are the total intra-field distortion in the X and Y directions, respectively. DMAP determines \(D_{XT}\) and \(D_{YT}\) to within translation (\(T_x, T_y\)), rotation (\(\theta\)), orthogonality (\(\phi\)), scale X (\(S_x\)) and scale Y (\(S_y\)). In other words, DMAP determines all modes higher than 1st order in X and Y.

Another well-known way to measure total intra-field distortion difference between two tools is direct AB measurement from here on, we call it AB test. In the AB test, a resist-coated wafer is exposed with only inner frames across field on tool A. The wafer is removed from tool A without the developing process, is sent to tool B without any coating process and is exposed with outer frames (see Figure 6). After the wafer is developed, the overlay data off the frame-in-frame structures are measured on a conventional overlay metrology tool. Note that the AB test data also contains modes that DMAP (DIML and DIMS) does not measure (\(T_x, T_y, \theta, \phi, S_x\) and \(S_y\), as explained above). Also, the data still contains components that are not of the form of scan synchronization error or dynamic lens distortion, such as trapezoid terms (\(D_{XT}=X*Y\)).

3. EXPERIMENTAL RESULTS

In this work, we tested two scanners (tool A and tool B) that are from the same manufacturer, but are from different generations. Tool A is an older generation scanner. On both scanners, we exposed two wafers, one to check lens distortion (DIML) and another to test distortion due to scan synchronization error (DIMS) using the techniques described in the previous sections. All wafers were measured on a conventional overlay metrology tool. For this experiment, we exposed all wafers using conventional illumination settings with the maximum numerical aperture (NA) of each tool (NA=0.80 for tool A and NA=0.86 for tool B) and \(\sigma\) of 0.80 for both tools. These illumination settings were chosen to reduce 3rd order coma contributions (see Equations 1 and 2), which are \(\sigma\), NA and feature dependent, to about zero. Note that no aberration data was used for either scanner. If aberration data were measured using the ISI, and included in the test, there is no need to use specific exposure conditions to expose wafers; the coma and other aberration induced shifts are automatically calculated and accounted for by the DMAP software.

3.1 Dynamic Lens Distortion (DIML Results)

In this section, we discuss the repeatability check of the DIML technique used. Since dynamic lens distortion (scan averaged lens distortion) is repeatable, we measured four sets of data from three different model scanners. On each scanner, we exposed four sets of X-shear and R-180 shear on a wafer. All four sets were measured on an overlay metrology tool and reconstructed separately. For each scanner, RMS was calculated for both DXL and DYL. The average of RMS values for DXL and DYL is the repeatability of the DIML technique for each scanner. The averaged RMS values for three scanners were 0.46nm, 0.69nm and 0.46nm. As shown in the data, the repeatability of the technique is far less than 1nm. Again, this check was done separately from our main work of this paper to show how repeatable and reliable the lens distortion measurement metrology was. In the foregoing the magnitude of the data has been scaled.
To measure the dynamic lens distortion on tools A and B, we only exposed one set of X-shear and R180-shear since we have already shown the DIML technique is repeatable. Figures 7 a) and b) show the dynamic lens distortion vector plots for both tools across slit. DXL and DYL for two tools are plotted separately in Figures 7 c) and d). The lens distortion data for two tools was compared. An analysis of the DIML technique is listed in Table 1. Figure 8 shows the DXL and DYL difference between two tools. DYL is well matched between the tools (peak of less than 0.1), but DXL shows a difference greater than 0.4 peak (vide infra).

Table 1: Maximum values for DX, DY and vector of lens distortion data for tools A and B.

<table>
<thead>
<tr>
<th></th>
<th>Tool A</th>
<th>Tool B</th>
</tr>
</thead>
<tbody>
<tr>
<td>DX max</td>
<td>0.39</td>
<td>-0.56</td>
</tr>
<tr>
<td>DY max</td>
<td>-0.38</td>
<td>-0.46</td>
</tr>
<tr>
<td>Vector max</td>
<td>0.49</td>
<td>0.72</td>
</tr>
</tbody>
</table>

3.2 Scan Synchronization Error (DIMS Results)

For both tools, we exposed patterns necessary to measure scan synchronization error (DIMS) on separate wafers. A total of 13 fields were exposed on each wafer (7 fields exposed with up scan and 6 with down scan). Using the DMAP software, and the measured data from an overlay metrology tool, and the dynamic lens distortion (measured by DIML technique), we were able to calculate the scan synchronization errors in all 13 fields separately for both tools. Figures 9 and b below show vector plots of average field scan synchronization for both tools. The data for all 13 fields was simply averaged. Tables just below vector plots list minimum, maximum and range for DXS_total, DYS_total and DVS_vector (DVS_vector was simply calculated by taking square root of sum of squares of DXS_total and DYS_total). The DXS_total range for tool B is less than half of that for tool A. Although the differences are not significant (DYS_TOOL A~DYS_TOOL B), tool B had smaller DYS_total and DVS_vector than tool A. The figures (Figures 10 a, b and c) below show the average DXS, DYS and DQS with 1-sigma excursion bars for each location plotted for both tools. Excursion bars indicate the scan-to-scan variability present in the machine as a function of Y-field position. Note that DYS and DQS charts for tool A have big differences.

Figures 7 a), b), c) and d): Figures 7 a) and b) show the vector plots of lens distortion for tools A and B, respectively. Figures 7 c) and d) show DX and DY, respectively, data across slit for both tools.

Figure 8: This chart shows the difference between tool A and tool B for DXL and DYL. The bigger the number, the poorer the matching. DYL is well matched, as seen in the chart. DXL has much bigger differences.

Figure 10 a, b and c): Figures 10 a, b and c) below show the average DXS, DYS and DQS with 1-sigma excursion bars for each location plotted for both tools.
excursion bars at Y=2.45mm and Y=4.90mm, respectively. These are due to an effect that will be described in section 4.2. As shown in the charts, tool B shows smaller synchronization error than tool A for all three components.

Figures 9 a) and b): Figure 9 a) is a vector plot of scan synchronization error for tool A, and Figure 9 b) is the same vector plot for tool B. For each tool, there is a table with statistics for DXT, DYT and DVS vector.

Figures 10 a), b) and c): These charts a), b) and c) are average DXS, DYS and DQS with 1-sigma excursion bars (calculated from data from 13 fields) plotted for tool A and tool B on the same charts.

3.3 Total Distortion (DIML + DIMS)

Two of the three methods to measure total intra-field distortion discussed in section 2.3 are compared in this section: a) DMAP by adding dynamic lens distortion (DIML data) and average scanning synchronization error (DIMS data), and b) the AB test. We compared two results to see how they are correlated to each other. The AB test results between tools A and B are the direct distortion difference measurement between the tools with 6 modes that DMAP does not measure (Tx, Ty, θ, φ, Sx and Sy) and trapezoid terms discussed above. Total distortion measured by DMAP is absolute distortion for each tool.

In order to correlate the two methods we removed the six 1st order terms and trapezoid terms. The charts below (Figures 11 a and b) show the correlation between the two methods in X and Y. DX_D and DY_D are the total distortion differences between two tools measured by DMAP, which was obtained by simply subtracting DXT and DYT for tool A from those of tool B. DX(B-A) and DY(B-A) are the AB test results for X and Y, respectively, after removing terms that are not measured by DMAP. Note this data was obtained before we made any adjustment to scan synchronization error on tool A. As shown below, both charts have a slope of about 1 with excellent correlations of R²~0.9. RMS difference between DMAP and the AB test was 1.1nm for DXS and 0.8nm for DYS. This RMS difference is consistent with the repeatability of the AB measurement technique.
Figures 11 a) and b): Correlation plots for DXS (a) and DYS (b) between DMAP technique and direct AB comparison (AB test) after removing 1st order terms and trapezoid terms from AB test results. As shown in these charts, there was an excellent correlation between two techniques ($R^2 \approx 0.90$) with a slope of ~1.

From the AB test results, we extracted the scan synchronization components from the data, $(DX_{EX}, DY_{EX})(Y)$. The extracted data were compared to the DMAP scan synchronization error (DIMS) results obtained by combining the separate machine characterizations. As shown in Figure 12, the charts show a slope of about 1, and excellent correlation ($R^2 > 0.90$). RMS difference between DMAP scan synchronization components and the AB test extracted results is 1.0nm for DX and 0.8nm for DY.

Figures 12 a) and b): Correlation plots for DXS and DYS between DIMS results and the scan synchronization errors extracted from AB test. Excellent correlation is shown.

3.4 Scan Synchronization Error Amelioration

The main purpose of this experiment was to measure, separate and match (reduce) the transverse scanning synchronization errors between two tools. Based on high correlations between DMAP and the AB test results, we believed that corrections to the inferior tool would result in noticeable improvement on tool-to-tool matching in scan synchronization errors. The DXS, DYS and DQS components for both tools, before making corrections, are shown in Figures 10 a, b and c in section 3.2.

In this work, we added corrections to tool A because it suffered larger scan synchronization error than tool B in all three components. To get the corrections for three components (we call them $<DXS>$, $<DYS>$ and $<DQS>$), we simply subtracted DXS, DYS and DQS of tool A from those of tool B (we subtracted A from B, not the other way around, since we exposed inner frames on tool A and outer frames on tool B). When tool A was corrected using the scan profile (machine correctables $<DXS>$, $<DYS>$ and $<DQS>$), we minimized the scanning distortion difference between the two tools.

After adding the corrections on tool A, we exposed the DIMS wafer on tool A again to measure the scan synchronization error after the corrections. In Figures 13 a, b and c, we plotted three cases for all three terms (DXS, DYS and DQS); ‘BEFORE’, ‘CALCULATED’ and ‘MEASURED’. The ‘BEFORE’ lines are the scan synchronization error data of tool A before corrections were added to it. The ‘CALCULATED’ lines are predicted data. We added ‘BEFORE’ data and corrections to get the ‘CALCULATED’ data. Lastly, the ‘MEASURED’ lines are scanning synchronization error data measured with DIMS after corrections were added to tool A. As can be seen, ‘CALCULATED’ and ‘MEASURED’ data overlap very well. RMS difference between ‘CALCULATED’ and
‘MEASURED’ data for DXS, DYS and DQS were 0.40nm, 0.51nm and 0.02µrad, respectively. Note that these corrections were made to tool A to match the scan synchronization error of tool B.

The figures (Figures 14 a, b and c) below show DXS, DYS and DQS for tool A after corrections plotted with those of tool B (tool B was not adjusted). Scan synchronization error data after corrections on tool A are well matched with tool B. The RMS difference values between tool B and tool A after the correction were improved from 1.78nm to 0.40nm in DXS, from 1.48nm to 0.51nm in DYS and from 0.06µrad to 0.02µrad in DQS. Figures 15 a and b show the improvement in DXS, DYS and DQS differences between the data taken before and after corrections. DXS and DYS were ranging between around +/-0.4 before the corrections. After the corrections, the range was reduced to about +/-0.1. Similarly, DQS range was reduced to ~+/−0.05 from ~+/−0.2. Figures 16 a and b are the vector plots of scan synchronization error difference before and after corrections. An average RMS difference between the before and after the corrections was improved from 3.11nm to 1.81nm (making a significant improvement in the overlay budget). Below each plot, a table lists minimum, maximum, range and standard deviation values for DXS_{total}, DYS_{total} and DVS_{vector}. The ranges for all three were improved by an average of 70%.

Figures 13 a), b) and c): DXS, DYS and DQS charts, respectively, with ‘BEFORE’, ‘CALCULATED’ and ‘MEASURED’ values.

Figures 14 a), b) and c): DXS, DYS and DQS charts, respectively, for tool A (after adjustment) and tool B

Figures 15 a) and b): Figure 15 a) charts DXS and DYS of tool A, before (dotted lines) and after (solid lines) the corrections. Similarly, Figure 15 b) shows DQS data before and after the adjustment.

Figures 16 a) and b): Figure 16 a) charts DXS and DYS of tool A, before (dotted lines) and after (solid lines) the corrections. Similarly, Figure 16 b) shows DQS data before and after the adjustment.
Figures 16 a) and b): Scan synchronization error vector plots for tool A before (a) and after (b) the corrections. Each plot has a table with statistics just below the plot.

To see the changes in the total intra-field distortion before and after corrections, we exposed an AB test wafer after making corrections. Again, the data was exposed on 13 fields, averaged, and 6 modes (Tx, Ty, θ, φ, Sx and Sy) were removed. The trapezoid term is included in the results. The figures below (Figures 17 a and b) show the DX and DY data before (‘PRE’) and after (‘POST’) corrections, separately. For each block of data, the minimum, maximum and +/-1 standard deviation range values are plotted. The standard deviation was reduced by 30 to 50%, while a 20-40% reduction was seen in extreme (minimum and maximum values). At the worst points, 4.9nm reduction was shown.

Figures 17 a) and b): DX (a) and DY (b) data for AB test after removing 6 modes. For both plots, ‘PRE’ is before the corrections, and ‘POST’ is after. The numbers listed just next to each plot are maximum, +1 standard deviation, -1 standard deviation and minimum, from top to bottom.

4. APPLICATIONS

4.1 Scan Synchronization Matching Utility

We were able to control the scan synchronization errors on one tool to match another tool. This increases the utility of the DIMS data. The first use is what we determined in this work, matching scan synchronization errors among two or more tools. The second use is to minimize the scan synchronization errors to zero on all tools. The third use is to control the errors on all tools to some arbitrary values.

4.2 Scan Direction Dependent Scan Synchronization Errors

Because scan synchronization error varies from scan to scan, we focused our study on the comparison between up (+) and down (-) scans. When the DIMS wafer was exposed, 7 fields out of 13 were exposed with up scan, and 6 fields were exposed with down scan. Using the scan synchronization error data from tool A, we plotted ‘ALL (average of all 13 fields)’, ‘UP (average of all 7 up scan fields)’ and ‘DOWN (average of all 6 down scan fields)’ for DXS, DYS and DQS.
(see Figures 18 a, b and c). As seen in the plots, there are some differences in up and down scans, especially in DYS. More than 0.4 difference was seen in DYS between up and down scans at Y=0.

For comparison, we generated the same plots for tool B, which is a newer generation scanner (see Figures 19 a, b and c). Up and down scans are matched better on tool B than tool A. Maximum difference in scans in DXS and DYS is less than 0.2, and ~0.15 for DQS, where it was more than 0.4 for DXS and DYS and ~0.19 for DQS on tool A.

The ability to adjust the scanner to correct for the difference in distortion between up and down scans would significantly enhance tool performance.

4.3 ‘Bump’ Issue (Scan Distortion Anomaly)

While we were analyzing the scan synchronization error data for two tools, we noticed that there was a ‘bump’ in the scan synchronization error data for tool A (rotational or DQS component). This bump is, in particular, recognized in DQS data at Y=4.90mm location. We also see the bump effects in DXS and DYS data but they are located at Y=2.45mm location. All of the bump effects in tool A were seen in a field index of (0,2), which was the first field exposed on the wafer; the effect was not seen on any other fields on the same tool. We also checked the data for tool B but did not see this effect. Since we used the same reticle, technique and software to calculate the scan synchronization errors for both tools, we can prove that the bump effect is not due to the technique we used.

We had previously measured tool A about 4 months prior to correcting it. The figures below (Figures 20 a, b and c) show the DQS data for the data taken on tool A in: a) time T-4 months (T is the date we made corrections), b) T, before corrections and c) T, after corrections.
The scanning anomaly could be due to many possible causes. The first possibility may be that the wafer stage is dragging/hitting something (akin to wires or cables) at the same location on the wafer. Another possibility could be a defect exists on the interferometer mirror used to determine the wafer stage location at the location (X=0.0mm and Y=2.45mm: 4.90mm). Whatever the cause, a further investigation is needed to resolve the abnormality. It would be interesting to determine if the same effect in the same field was visible if the field was exposed with down scan, instead of the up scan used previously. Another test that would be interesting to run is to expose more fields in the same Y location, but different X locations (fields (1,2) and/or (-1,2)). This would show us that if the effect is in only Y location dependent or both X and Y dependent.

5. CONCLUSIONS

In this work, we showed DMAP results correlate very well (R²~0.90) with AB-test results after 6 terms and trapezoid terms, which DMAP does not measure, were removed. Based on this, we are confident that we would be able to ameliorate the scan synchronization error difference between two tools. We were able to reduce the difference in DXS and DYS from +/-4nm peak to +/-1nm and in DQS from +/-0.2µrad to +/-0.05µrad by adding corrections, which we calculated based on DIMS data from both tools, to tool A to match tool B. Similar reduction was seen in the total distortion data measured in the AB test. 30-50% reduction was seen in the standard deviation, and extreme was reduced by 20-40%. We were able to reduce 4.9nm at the worst points. We were also able to show that scan synchronization error is scan dependent (up and down scans). We determined that entering separate correction values for each scan can minimize the error difference between the scans. Finally, DMAP is also a great metrology tool to find irregularities in a scanner similar to the bump anomaly issue we found in tool A.

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REFERENCES