Lot Correction Optimizer and Simulation

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Concept

The results from a calculation of the systematic variations in overlay modeled data can be used as a feedback mechanism to scanner positioning or as a highly accurate method of estimation of positioning errors in locations on the field, wafer or lot not actually measured. Two tabs appear after a modeled data analysis as shown in figure Sim1. These tabs provide utilities to assist in the evaluation of lot-correction techniques and in the visualization of performance through simulation.

Full-wafer overlay **Simulation** employs the systematic errors of the process to estimate distributions and is significantly more accurate than a corresponding statistical calculation that assumes a random distribution of the process errors. As a result this is the preferential method of advanced users for pass/fail or lot-gating metrics in the lithography sequence. The method however is rarely used for IntraField analyses and the full potential of the technique has therefore not be realized by the industry.

Lot Correction Optimization tools within Vector Raptor provide a method of examining the effects of various methods of correction averaging. Obviously the engineer cannot calculate lot pre-exposure corrections for every single field or wafer-quadrant on the lot. Corrections therefore need to be averaged and then inserted into the pre-lot recipe for exposure. The problem then arises on what level of averaging should be used?

Should corrections use the average of all wafers and fields measured in a calibration sequence or should more sophisticated

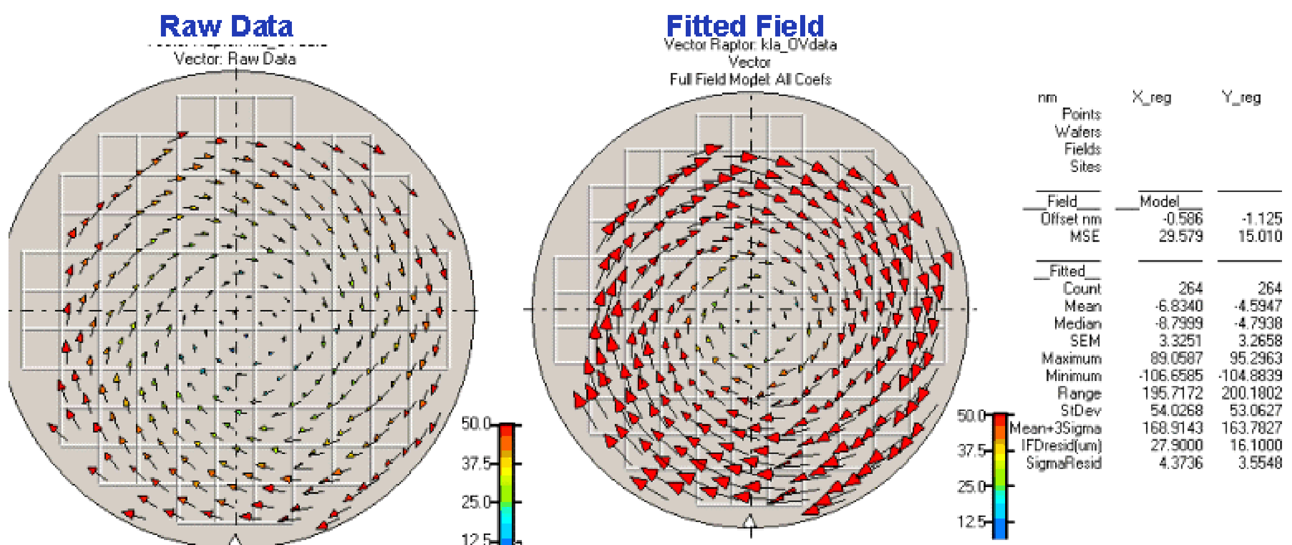

Figure Sim-1: (Left) Raw data with overlay rotation

(Right) Field-model fitted overlay meeting distortion by using only the Offset coefficient.

alignment schemes employ finer levels of averaging?

The following dataset illustrates the need for a Lot Correction Optimizer. The plot on the left side of Figure Sim-1 replicates a set of data on a wafer that contains only a wafer-rotation error.

If a simple field model of the form dx = A +BX –CY is applied to each field on the wafer, then the overlay distortion can be accurately calculated as shown in the figure on the right side of Sim-1. Notice that the model only needed to fit each individual field's offset in order to successfully match the errors found on the wafer. The average field offset for the wafer is (X,Y) =(-0.586, -1.125) nm

If, as is common in production, the average field offset value were then used to correct for overlay error in the lot, the correction would be applied as shown in the left side of figure Sim-2. Unfortunately for this type of error, the wafer-rotation is not corrected and will show up in the residuals to the average field as is shown in the right side of figure Sim-2. This implies that any product lots exposed using the field-average correction on this tool/reticle combination will also result in an overlay distribution as shown in these residuals.

Vector Raptor's Lot Overlay Correction Optimizer provides the tools needed to discover the results that can be obtained through the use of lot-coefficient-averaging of corrections. Averaging schemes for lot, wafer and field based correction averaging can be combined with selective inclusion of individual coefficients to exposure the optimum strategy for minimization of errors due to processing, bake, lens/reticle heating, film stress and other highly systematic errors.

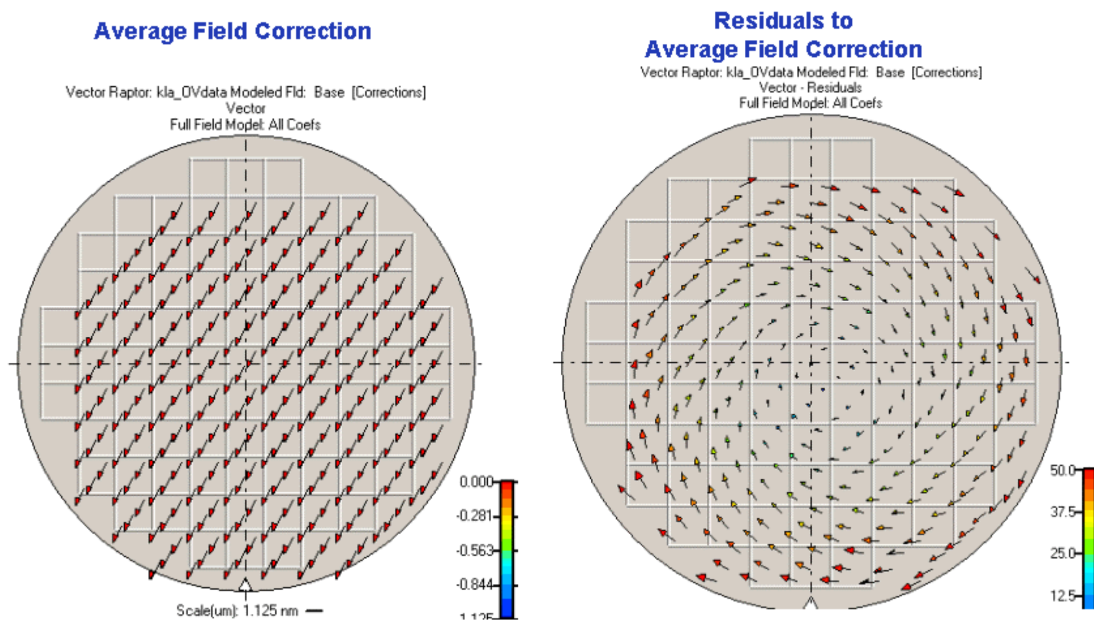

Figure Sim-2: (Left) Average field offset correction applied to lot exposure

(Right) Resulting residuals to average field-model correction.

Lot Correction Optimizer

When a dataset is modeled, each wafer, field and sometimes each subfield row or column is separately fitted to discover the presence of systematic variations in performance. As these systematic variations are found to replicate across broader areas of the dataset, their stability as a process or tool characteristic phenomenon increases. The most simple stable variations, such as offsets, magnification errors and rotations, can be easily corrected and since they tend to change as the exposure tool is used, should be monitored on a regular basis.

Feedback mechanisms rely on the averaging of systematic values while assuming stability at some level of the lot-processing sequence. For example, a lens aberration can be expected to be stable for an extended period if exposure adjustments are not changed. In contrast to the stability of the lens signature, reticle-scan oriented distortions are highly dynamic since they are intimately tied to the rapid mechanical movements of the reticle-plate loading and scanning mechanisms.

Signature extraction for overlay corrections is highly dependent upon the process, toolset generation and the design rule level of the products in production. Wafer and stage-grid corrections may require a periodic evaluation of multiple wafers in a lot

for selected levels to discover the onset of lens and reticle heating or even variations in process film reflectance. Should fields located in the wafer center be exposed under the same alignment parameters as those near the edge-bead? What level of correction should be attempted?

Vector Raptor's Lot Correction utility provides the tools needed to determine the proper level of signature averaging needed for alignment corrections for each tuning control of the alignment system.

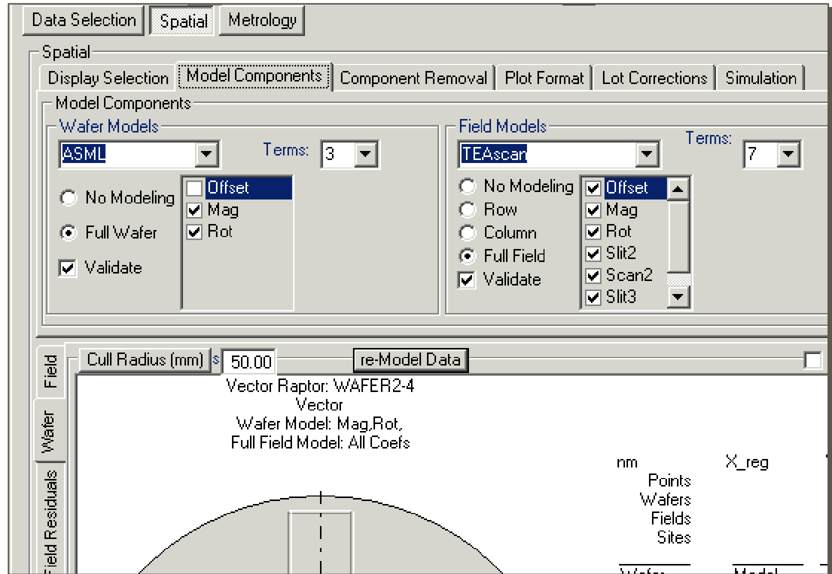

Figure Sim-3: Tabs for Lot Corrections and Simulation Visualization

Simulation

Statistical sampling involves the metrology of a few selected data points on a wafer that are assumed to be part of a random population. An evaluation is then made to continue fabrication of the lot based upon a statistical calculation of the distribution of this small sample.

Overlay errors in semiconductor manufacturing are highly systematic. The assumption, tacitly made by a statistical analysis, that the errors are random can lead to disastrous results for the process. Results from this methodology often result in process instability as poor alignments are allowed to continue processing or poor metrology results in the rework of a properly exposed set of wafers.

Vector Raptor's Simulation utilities provide the tools to evaluate systematic error behavior overly greater areas of the lot. Now a metrology set containing a few points per field can be extrapolated to obtain an true estimation of the systematic variations of data across the exposure, wafer and lot. The systematic estimation of data used in pass/fail lot gating will result in more reliable production decisions and in the visualization of the true systematic performance of the exposure toolset.

Lot Corrections Interface

The Lot Corrections tab presents a series of simple tools that work in conjunction with the check-box selections of the Model Components interface shown in figure Sim-3. The coefficients of a wafer and/or field model must first be calculated using the Model Components selection. The Lot Corrections tab of figure Sim-4 then provides the controls for evaluating the results that will be obtained by the different levels of coefficients averaging for overlay correction. Averaging optimization will differ for each process and design rule used in the fabrication process.

The coefficients selected by check-mark in figure Sim-3 will be those averaged for the correction. Unchecked coefficients will be ignored and their contribution will not be removed from the data. The example shown in Sim-3 has selected all of the modeled coefficients for the field and wafer with the exception of the wafer-offset. Removing all of the check marks so that only Offset is selected will result in a simulation that only experiences the removal of the offset term.

The radio-button Setup control of figure Sim-4 is then used to determine the basis for correction averaging. Wafer and field models are available depending upon the type of modeling just performed on the data. The Wafer-model column of figure Sim-4 provides options for averaging the wafer-grid correction based upon the average Lot values as shown or each wafer.

Similar to wafer modeling, the Field-model column provides Lot and Wafer averaging

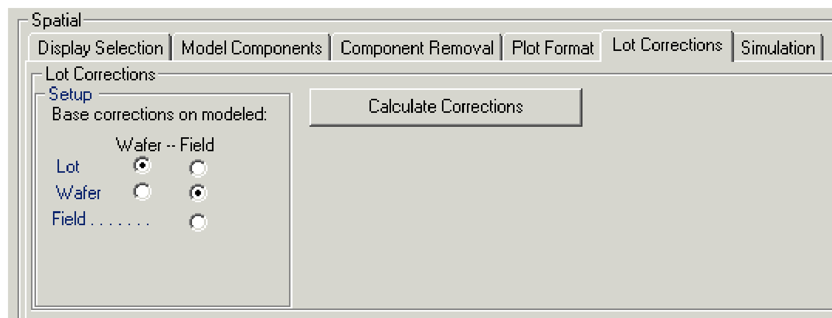

Figure Sim-4: Lot Correction Controls

but with an added option of including the fitted values of each individual field.

The overlay data for the lot shown in the example shown in figure Sim-3 has modeled both wafer and field systematic errors. The user in this example then went to the Lot Corrections interface of figure Sim-4. All of the wafer-modeled coefficients, with the exception of the un-checked wafer-offset, will be averaged for all wafers in the lot and their systematic overlay values will then be included in the simulation.

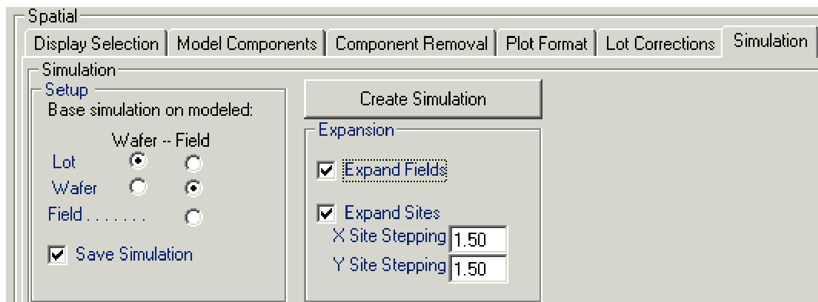

Figure Sim-5: Lot Correction Controls

After pressing the "Calculate Corrections" button the analysis of Sim-4 will average the field coefficients for each wafer and calculate the resulting average field systematic overlay. Field-average values are then added to the wafer-simulated values previous corrected and the residuals calculated. The analysis next moves to the next #2 of the lot and repeats the calculation of fitted and residual values for this wafer. The process is repeated for all wafers of the dataset.

The standard data visualization tools of figure Sim-3 are next used to evaluate the results of the simulation. This figure details the corrections that would be applied to the lot based upon the averaging of level detailed in the setup. The influence that this correction method will have on the level of overlay errors in the dataset can be seen by pressing the Wafer Residuals or Field Residuals tabs.

Figure Sim-6 illustrates the level of overlay errors that can be expected on a lot if the Wafer Magnification and Rotation average for the lot are corrected along with the Offset, Magnification and Rotation values of the average field for each wafer. Field corrections were restricted to these values based upon a re-selection of the field-model coefficient check-boxes, figure Siim-3, and subsequent re-calculation of the corrections.

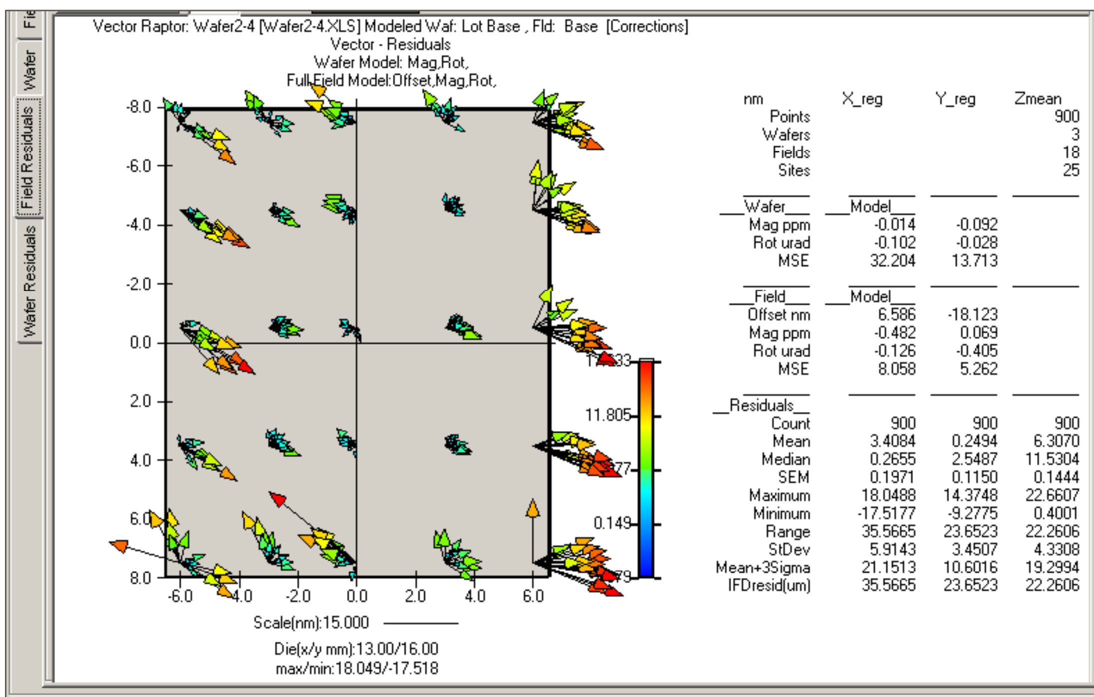

Figure Sim-6: Field based visualization of residuals after correction of Offset, Magnification and Rotation

Simulation Interface

Lot Corrections work with the modeled dataset to see the influence of various correction coefficient strategies upon the data. Simulations take this concept a step further and allow visualization of systematic errors that extend to points and fields beyond the current level of metrology-measured sites.

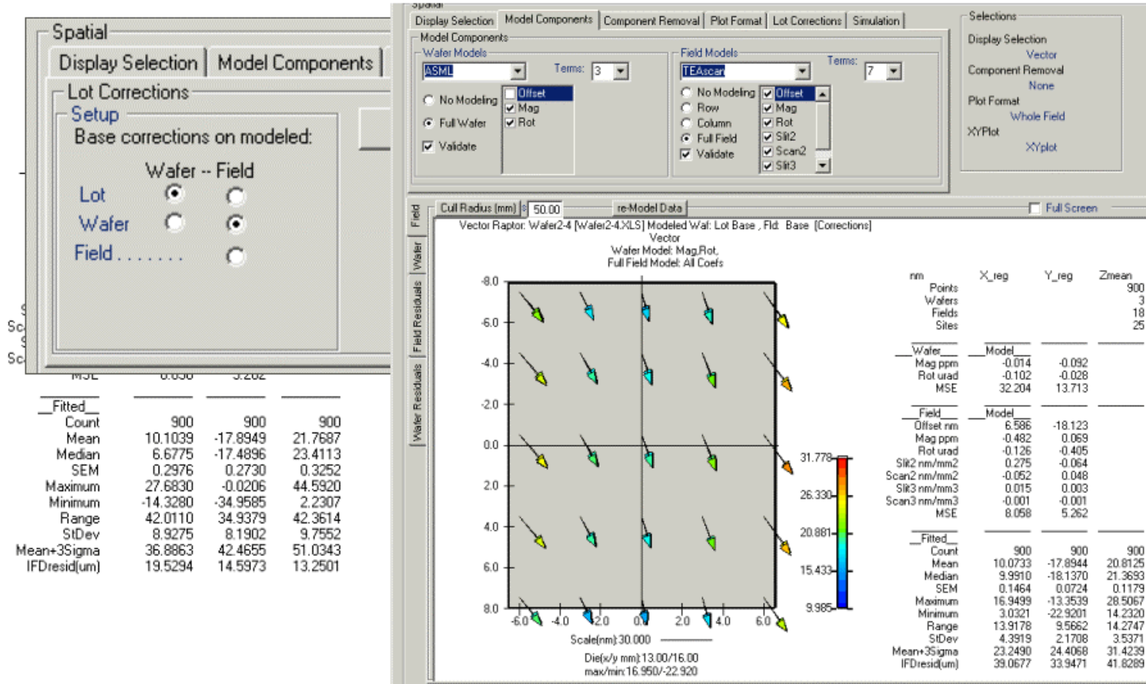

Figure Sim-7: Lot-correction simulation and visualization

For example, a modeled dataset containing five points per field and six fields on a wafer can be expanded to simulate the errors that would be measured if the metrology. This capability can be used in aberration visualization studies or as a method of determining the maximum systematic errors of a data lot when making pass/fail decisions during production lot gating.

The data Simulation data tab shown in figure Sim-7 is similar to the Lot Corrections interface. The simulation however has two check-box controls that control the simulation-expansion of data points to include every potential field on the wafer and/or change the X andY site step spacing of data points on the field.

Figure Sim-8 sillustrates the results of an expansion of data from a lot of 3 wafers with six-fields each to full-wafer coverage. The number of sites per field was also increased by selecting a smaller site-stepping value of 1.5 mm in x & y as shown in figure Sim-7. The data in Sim-8 included both wafer and field simulated values but used the lot-average value for the wafer coefficients and the wafer-average value for field values.

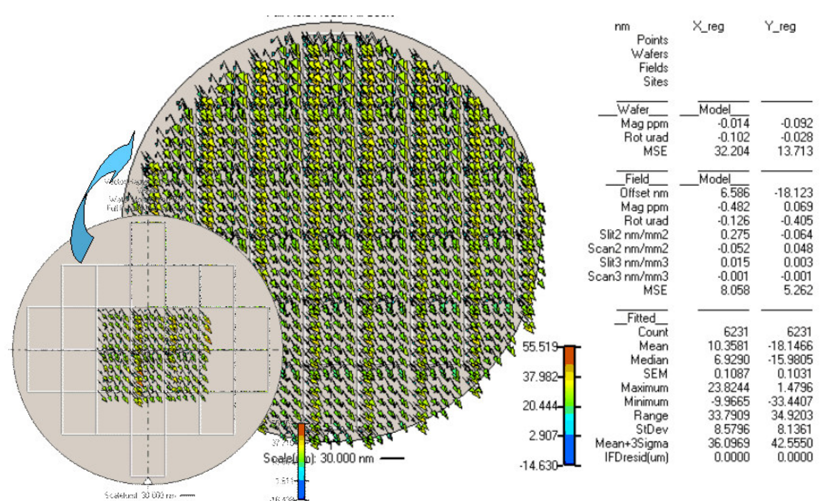

Figure Sim-8: Simulation expansion from six fields to whole-wafer

Note that if the Wafer-Average wafer model selection is chosen along with the Field-Average field-model values, then the exact simulations for the data lot will be expanded in the simulation. Field models calculated using the Row or Column model option cannot be exactly simulated.

Residual values are not calculated in this dataset and the dataset is an entirely new dataset. Site locations will be added to the data workbook's "Sites" datasheet and the data will be saved in the workbook as a datasheet.

The user can display and examine the statistics of this dataset. The dataset can also be modeled using any of the models stored in the wafer and field libraries.

The simulation dataset is now a part of the data workbook and can later be separately loaded and modeled the next time the original dataset is loaded by selecting it from the drop-down control as shown in figure Sim-9.

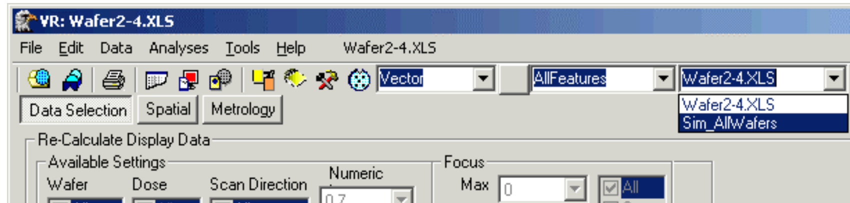

Figure Sim-9: Loading the simulated dataset for analysis.