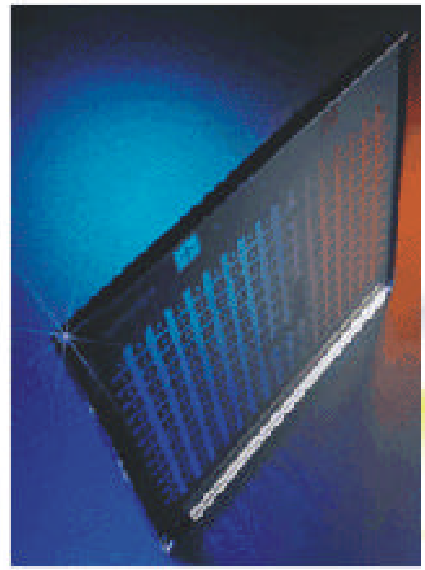
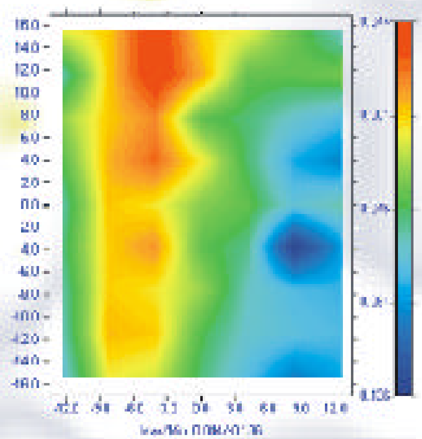
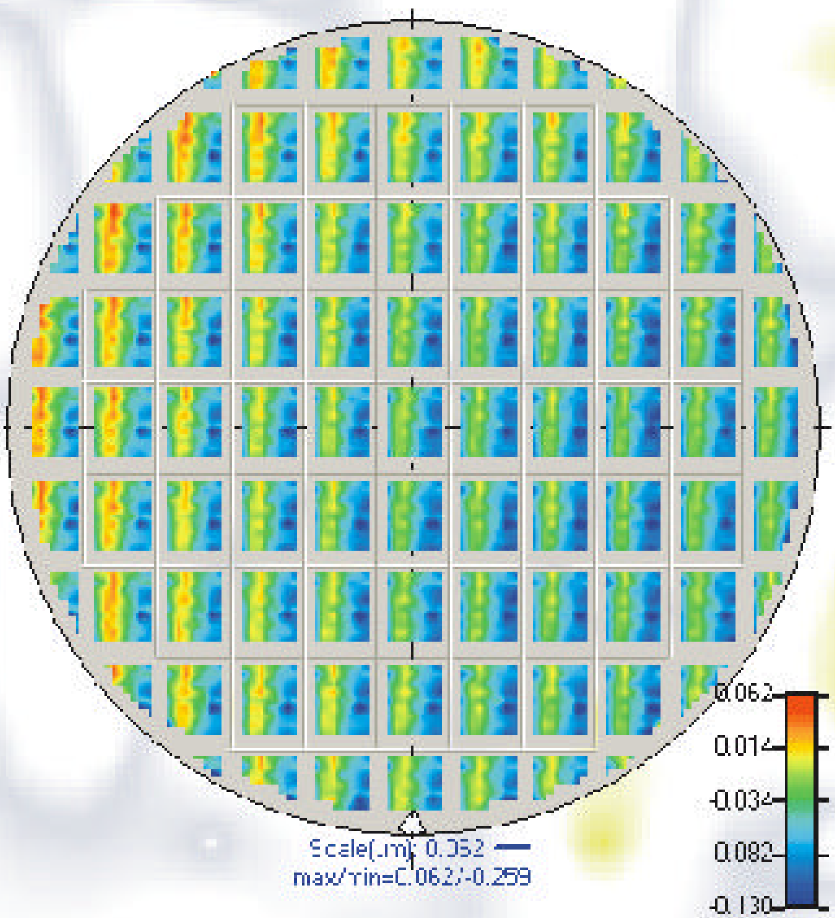
Main Menu

The Focus Monitor Reticle And Weir PSFM



Getting Started





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Overview

Objective

This brief manual is intended to answer initial questions and provide basic instructions for first use of the Benchmark Focus Monitor Reticle and Weir PSFM wavefront aberration analysis tools.

PSFM Reticle and Weir PSFM software

Benchmark Technologies and TEA systems have joined together to present the industry's most comprehensive toolset for the measurement and control of focal plane aberrations. The Phase Shift Focus Monitor (PSFM) reticle and it's associated calibration and analysis software package, Weir PSFM. This toolset provides an understanding of the true focus budget, its stability and potential performance level for every exposure tool in the facility. Focus signatures for each lens and exposure tool in the facility can be directly measured with a simple experiment and custom analysis. Whether you are conducting an exposure-tool acceptance, characterization, setup, maintenance or daily performance check the PSFM provides security in the knowledge that the task will be accomplished quickly and thoroughly.

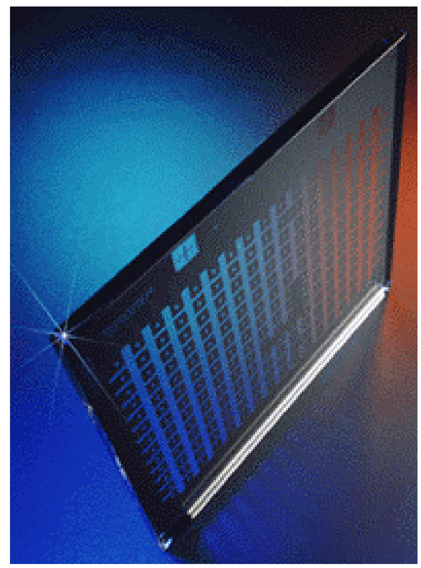


Figure 1: The Benchmark Phase Shift Focus Monitor Reticle

Focus is measured by exposure of a patterned or unpatterned wafer with the Benchmark Phase Shift Focus Monitor (PSFM) reticle. This reticle uses wavelength phase-shifting physics to force an out-of-focus pattern to physically shift the location of it's image placement by an amount and direction linearly related to the amount of defocus. The linearity of the focus-shift combined with the ability of the reticle to measure focus and dose matrices as well as fixed-focus arrays makes the PSFM Reticle the most accurate and robust method in the industry for controlling focus and wafer flatness.

PSFM reticle features can be measured on any metrology tool. The metrology is calibrated and converted to focus values using the Weir PSFM software. Weir PSFM also allows these calibrations to be applied to fixed-focus experiments to accurately model lens, scanner, wafer and film aberrations.

The Phase Shift Focus Monitor Reticle

The Phase Shift Focus Monitor (PSFM) reticle's functional concept is based on IBM and AMD[1] patents. The IBM patent consists of an isolated chrome line. The glass is etched on one side of the chrome line to a depth of one-quarter wavelength to give wavelets passing through it a ninety (90) degree shift in phase.

[1] AMD Patent currently applied for or pending.

The resulting image plane is at an angle to the wafer plane. Hence any vertical position adjustment of the wafer -- in other words defocus – results in a lateral shift of the image along the wafer plane. Only at zero defocus is the image fully centered with respect to the reticle. At all other values of defocus the image shifts linearly from this central position. The relationship is therefore linear and fixed for a given wavelength , numeric aperture and partial coherence.

The AMD patent employs a grating of lines with one side etched to a depth that also results in a 90 shift in phase for incident radiation. The net effect of the grating is to make the image wavefront' s slope with respect to the wafer plane steeper than the single line shifter. A steeper slope results in increased accuracy for the measurement of defocus.

There are distinct advantages to having two methods of defocus measurement on the reticle. The single-shifter of the IBM patent responds to changes in focus in the same manner as an isolated feature in the lens. Phase gratings, on the other hand, track the behavior of dense-packed lines, the optimum focus sometimes differing by as much as 0.1 micron. Similar to device feature behavior, phase-shift gratings of differing duty cycle and packing density will track the behavior of similarly nested features on devices. This behavior provides the opportunity for quick and accurate characterization of depth of focus and image response that reflects the true characteristics of the production device.

Each Benchmark Technologies reticle incorporates both IBM and AMD designs. Reticles are available for the 193, 248, 3xx nanometer technology nodes. Since phase depth depends on wavelength of light, the reticles cannot be interchanged for different wavelengths.

Weir Analysis Modules

The Weir Analysis combines three modules to provide an easy to use graphic analysis and data model for raw data, stage, lens and scan-slit "Focal" -type Aberrations and stage, lens and scan-slit process window characterization and matching. These modules, shown in Figure 2, are provided in two software products, Weir PSFM and Weir PW.

Weir PSFM functions with the Benchmark Technologies Phase Shift Focus Monitor (PSFM) as a calibration and analysis engine for exposure-tool focal plane aberrations. Weir PSFM provides calibration, analysis of the lens aerial image ("Best Focus") and utilities for model building and analysis of focus variations across the lens, scan, field, wafer and lot.

Weir PW is a semiconductor process analysis tool and is a separate product from Weir PSFM. Weir PW can import any format of metrology data. It provides tools for modeling, simulation, setup and characterization of the process, exposure and metrology tools.

Overview

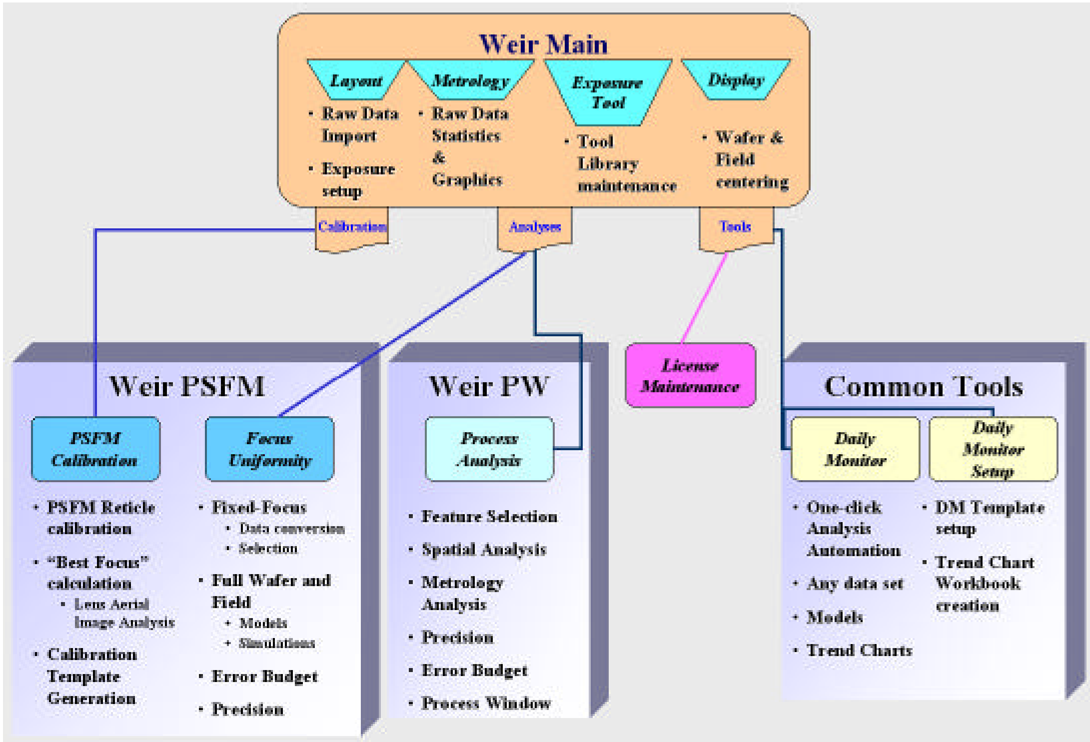


Figure 2:Weir Wavefront Analysis Software Suite

Weir Daily Monitor (DM) provides an easy to use interface for periodic process analysis sequences. Weir PSFM calibrations and the calculation of the lens aerial image "Best Focus" aberrations, PSFM fixed-focus studies and all metrology data sequences found useful by the engineer are coded into Weir DM templates. Templates provide simple, two-click analyses of complex, custom engineering procedures. The analyses can include automated data culling, reticle data removal, average and modeled field removal, focus-conversion, modeling and the storage of results into trend charts.

Installing the Weir PSFM Software

NOTE: Full Manuals are located on the CD-rom

Installation

You can access the manuals using the interface controls that appear on the main screen when first the Weir PSFM CD-rom is loaded. The CD-rom also contains presentations and tutorials for the use of the focus monitor.

The manuals are located in "/Documentation" sub-directory under the file-names:

WeirPSFMmanual.pdf	Weir PSFM manual
WeirManualDM.pdf	Weir Daily Monitor manual.

Place the CD-rom into your computer. It should startup automatically. If it does not, then click on the "Setup.pdf" file.

When the screen appears, click on "Install Weir Software".

Be sure to look at the CD-rom sub-menues. There are training video's, tutorials, background information and manuals for both Weir PW and Weir PSFM on disk.

You will need to obtain a demo license to use the software regularly. Without the license you can start the software up to 10 times before it will lock up. The license is keyed to the installation date and your computer. See the attached memo for license management and installation.

Obtaining a license is easy. When the software is first started Weir will display a License Maintenance screen. Record and email to Benchmark or TEA Systems the key shown as Installation "ID: A:". I'll return two Confirmation ID's that you can then type into the fields at the bottom of the screen.

Email Addresses:

Info@BenchmarkTech.com

WeirEngr@EnterMail.net

Removal

To remove the Weir Wavefront software:

?? Select the menu Start/Settings/Control Panel

?? Select the icon "Add/Remove Programs"

?? Select the Install/Uninstall tab.

?? Scroll down to "Weir Wavefront Engineering Suite"

?? Follow the on-screen instructions. All portions of the software will be removed.

Focus Monitor Exposures

Overview

Benchmark offers reticle designs for every wavelength used in photolithography today.

An initial calibration of the reticle must be performed because of this sensitivity of the reticle to both NA and PC. The exposure-dose should be approximately that used for test wafers however we will also describe a method for measuring the optimum value.

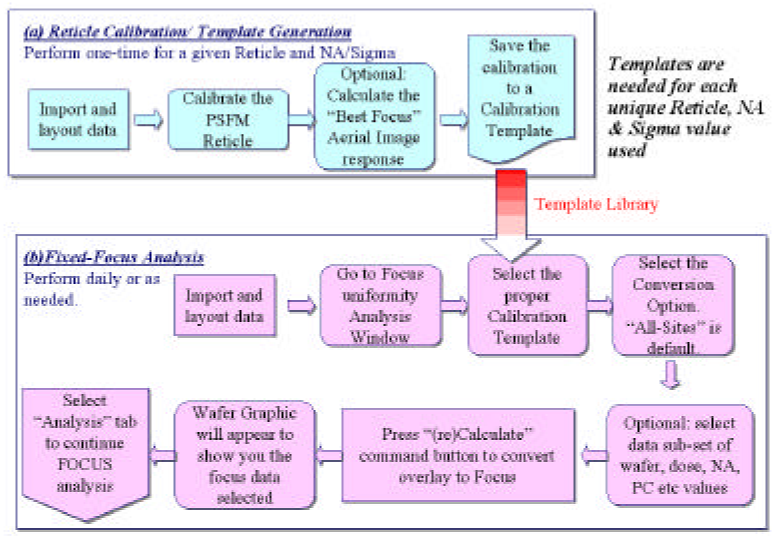


Figure 3: PSFM Calibration (top) and PSFM Template conversion of overlay to fixed-focus data.

Initial set of exposures

A thorough setup will require three (3) wafers:

Dose Matrix	Used to setup and calculate the optimum exposure for use of the PSFM Reticle.
Focus Matrix	Calibrates the PSFM reticle for the unique Numeric Aperture (NA) and Partial Coherence (PC) of the exposure tool. This matrix results in the best determination of the performance of the Aerial Image of the lens and it' s aberrations.
Fixed Focus	Used to analyze environmental focus problems such as tilt, bow, wafer –distortions, wafer-edge effects and other factors.

Ultra-Flat wafers are recommended but not critical for these analyses.

Reticle Feature Selection

The PSFM reticle contains both PSFM and PGM targets. The targets are arrayed in groupings; each group containing varying feature widths. The groups are set up for both 5x and 4x reduction tools using 2mm row and column spacing.

The reticle contains many box-in-box patterns with different chrome linewidths a portion of which is shown in Figure 4. For best process control choose a linewidth near to the resolution specification limit of the exposure tool or one nearest a device critical feature. Based on experience, feature F180 or F220 is a good place to start.

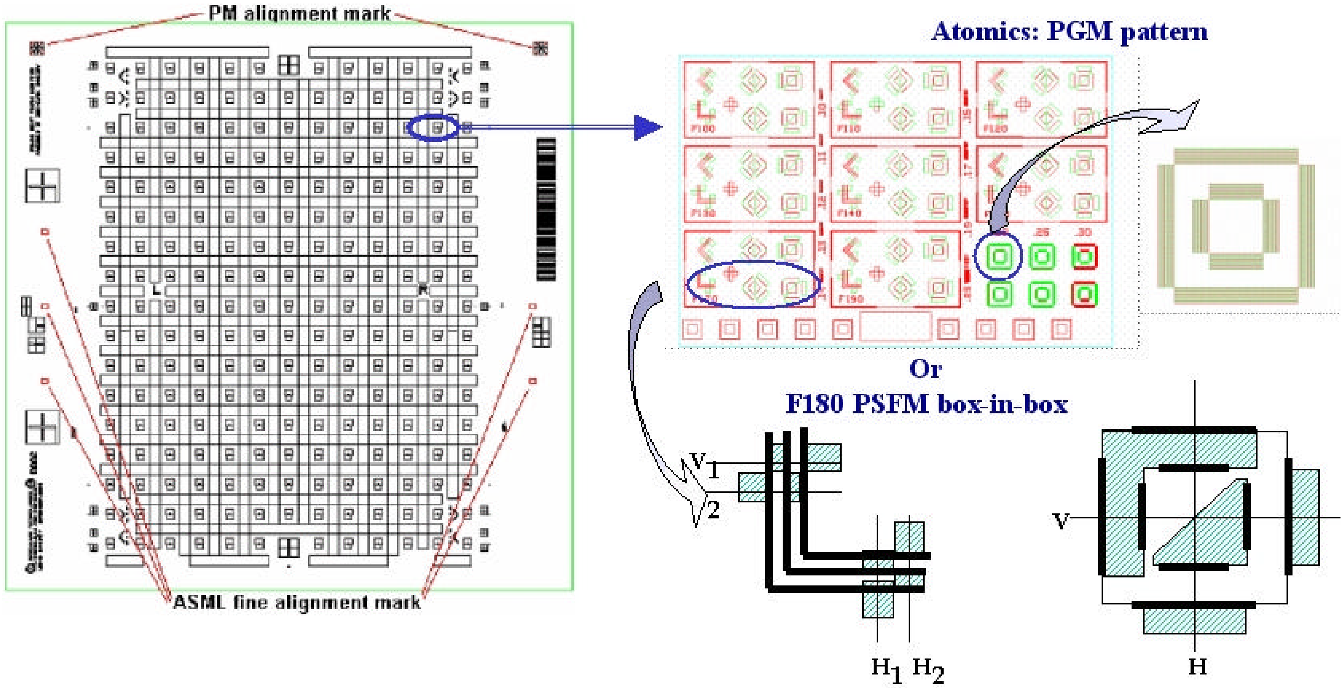


Figure 4: PSFM Reticle (left). Each target group(center top) is placed on 2 mm centers across the reticle. Select either a PGM target (top right) or a PSFM Box-in-Box or L-bar overlay.

Isolated features are the best evaluation tool for the measurement of aerial image aberrations. The fundamental design of the PSFM pattern implies that it replicates focus behavior for isolated features. PSFM patterns are therefore the best pattern to employ when performing a lens characterization.

PGM features emulate dense-paced line behavior. Use PGM patterns when evaluating process capability. A high-quality overlay tool is recommended for data gathering.

Exposure Recipes for the Test Wafers

We will need to expose three wafers initially; A dose-matrix, a focus matrix and a full-field, fixed focus wafer with exposures covering the entire surface. Expose the three wafers using the following settings.

Exposure Tool Properties

Illumination	Conventional
NA	Choose a production setting, probably around 0.6 or 0.7

Sigma (PC)	Select fairly coherent illumination. Around 0.3 or 0.4
StepSize	Select a field size that exposes the entire exposure area of the lens. This will be about 26x32 mm for a scanner or 27x27 for a stepper. Close the blades to allow a 1 mm border around the PSFM structures. This will be about 25x31 mm for a scanner.

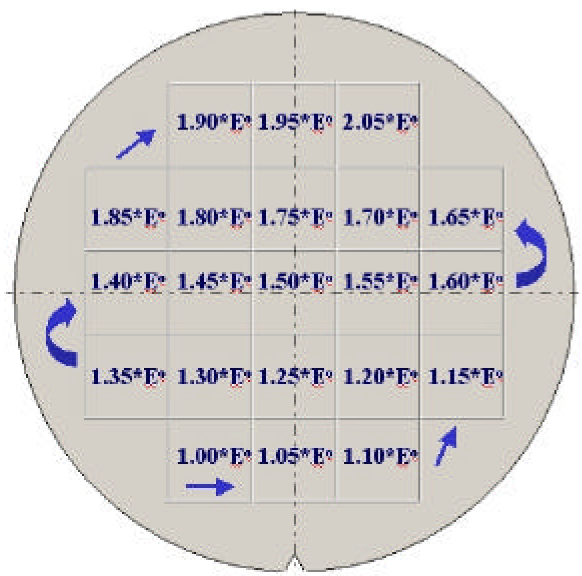
BARC and PhotoResist

Again, use the same BARC and resist process for all PSFM wafers. The resist should be thin, high contrast and positive. We recommend that you use a "normal" production recipe. Select a gate-level recipe as a starting point.

Edge bead removal is important, particularly for the fixed-focus wafer. A 3 mm edge bead is recommended.

Dose-Matrix Exposure

Dose Matrix



Purpose

To determine the optimum exposure dose for focus monitor sensitivity.

Frequency

At least one time, at first setup of the focus monitor.

When a new photoresist or change in process occurs. May not be necessary if the reticle tracks the process closely.

Methodology

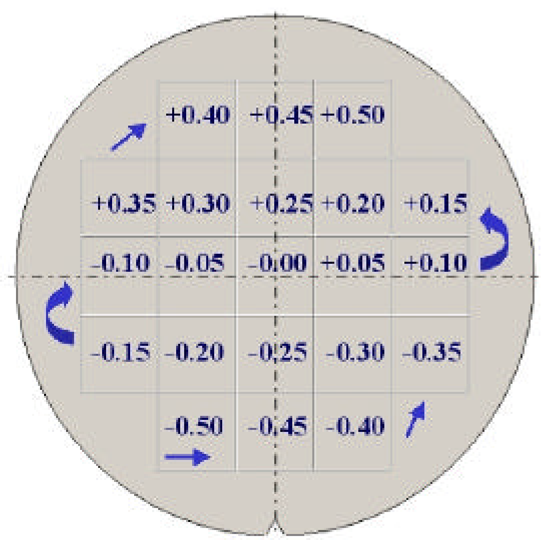
Two methods are available:

1. Determine the exposure where overlay measurements are independent of small variations in exposure dose.
2. Using multiple sites on a field, calibrate each site and examine the spread of focus calibration values for focus and offset as a function of dose. The center of the region

Dose Matrix
where the spread is minimized is optimum. Both methods are valid but #2 is more exacting.
Layout As shown above for a serpentine exposure. Use a step size that allows full-field exposures. This will typically be about 26x32 mm for scanners. **EBR** 3 mm or process standard program. **Energy** Start at E^o (dose-to-clear) and step-increase each exposure by ($0.5*E^o$) as sown in then wafer map above.

Focus Calibration Exposure

Focus Calibration Matrix



Purpose

?? Calibration of the Focus Monitor reticle.

?? Conversion of measured "overlay" shifts into focus data

?? Calculate the "Best Focus" aberration estimate of the aerial lens image.

Frequency

At least one time when exposure NA and PC conditions change.

Whenever a new Focus Monitor reticle is introduced.

When lens aberrations or scan/slit errors are to be characterized. This method can be used to determine focus Piston, Tilt and Bow as well as the total Intra-Field Deviation.

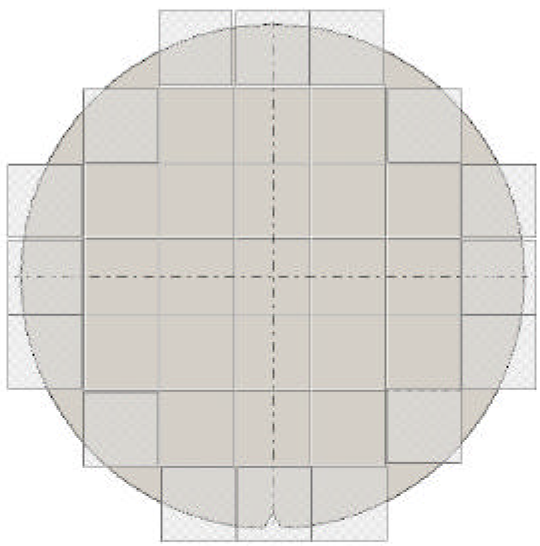
Methodology

Calibration of the Focus Monitor reticle requires a minimum of one point in the field to be fitted for a linear response of exposure-tool focus verses measured overlay. The slope and offset of this

Focus Calibration Matrix
calibration is then stored in a Weir Calibration Template. The template is then used to convert fixed-focus exposures of the focus monitor from overlay into focus data. Performing a separate linear calibration for every site on the reticle provides increased accuracy in the Weir Calibration Template. This multi-site calibration can also be used to model lens-aerial image aberrations that are insensitive to wafer and process variations.
Layout As shown above for a serpentine exposure. As in the dose exposure matrix, use a step size that allows full-field exposures. This will typically be about 26x32 mm for scanners. **EBR** 3 mm or process standard program. **Energy** Start at a focus of –0.50 microns and increase each exposure by 0.05 microns. Use the exposure-dose of the process or that determined from the Dose Matrix Wafer.

Fixed-Focus Exposure

Full-Field, Fixed Focus Wafer



Purpose

?? Wafer, process and exposure-tool characterization.

?? Edge-focus effect studies

?? Characterization of scan, slit, pitch, yaw, roll and tilt of the reticle stage.

?? Separate measurement of wafer-tilt and reticle tilt

?? Measurement of wafer and reticle bowing /

Frequency

As needed for process and tool characterization.

Full-Field, Fixed Focus Wafer
Methodology Exposre the entire area of the wafer. Measure, and use the Weir PSFM Focus Calibration Template to convert "overlay" into focus data. Use Weir PSFM to model wafer tilt, bow and bending-moments as well as individual field aberrations that result from wafer-edge effects, stage direction, scan direction and film non-uniformities. Use Weir PSFM to model changes in slit uniformity and scanning. Model focus response for isolated and dense features using the PSFM and PGM patterns of the Focus Monitor reticle.
Layout As shown. As in the previous matrices, use a step size that allows full-field exposures. This will typically be about 26x32 mm for scanners. **EBR** 3 mm or process standard program. **Energy** Expose at the optimum focus for the exposure tool and at optimum dose.

Metrology Setup and Options

In the previous section, we described the methods for exposing three types of focus monitor wafers. Those wafers were:

?? The Dose Matrix wafer

?? The Focus Calibration matrix and

?? The Fixed-focus wafer.

In this section we' ll review the options for selecting a measurement site and how many sites to measure.

The Focus Monitor reticle design may change over time. However, it is typically composed of a group of test patterns located on 2 mm spacings across the reticle. This implies that a scanner field can support 17 rows (Y) and 13 columns (X) of test-groups.

Dose Matrix Wafer metrology

This metrology function is very straight forward. Simply select a site in the middle of the exposure field using the feature size closest to your product design rules.

One-point per field for each field shown in the dose-matrix serpentine.

Focus Calibration Metrology

Single-Point Calibration Templates

If the focus matrix is to be used only for a quick calibration of the reticle, then only one point in the center of each field must be measured. This single calibration can then be used to convert fixed-focus exposures of the Focus Monitor into focus data with Wier PSFM.

Calibrating only one point of the focus monitor is not as accurate as measuring multiple sites across the field. The greater the number of sites, the more exacting will be the overlay-to-focus conversion of fixed focus experiments.

Stepper Lens Characterizations

Aberrations generated by the full-lens exposure of a "Stepper" or step-and-repeat camera are symmetric and radial in nature. Metrology time can be conserved by measuring patterns located on irregular arrays as shown in Figure 5.

This layout measured 13 points-per-field. The sites are located to maximize the number of measurements for each radius from lens-center.

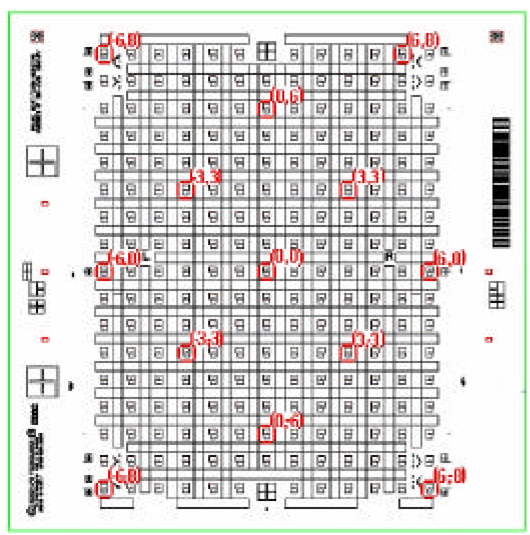


Figure 5: Focus Monitor with 13-sites measured for Stepper characterization

Scanner-Slit/Scan Characterization

Scanner aberrations occurs along the Cartesian axes.this is because the lens aberrations are restricted to the horizontal slit. The slit is then scanned vertically.

Metrology for a scanner should therefore maximize the number of measurements located on Cartesian rows and columns as shown in Figure 6. A 5x5 array, as shown in this figure, is a good minimum metrology setup for quick scan analysis and template calibrations.

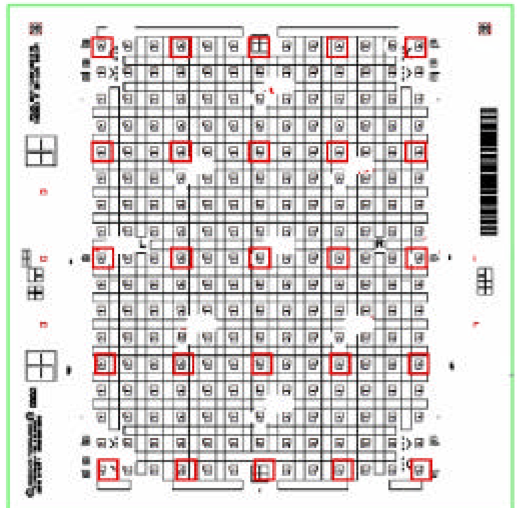


Figure 6: Focus monitor with 25 sites in a 5x5 array. This is a base layout optimized for scanner characterization.

Fixed Focus Metrology

Fixed-focus experiments desire to discover the variation of focus across the entire wafer. In doing so, you will also want to be able to discriminate between Wafer and lens (slit-scan) induced aberrations.

Weir PSFM can be used for this analysis method. Follow the basic layouts described in the previous section on “Focus Calibration Metrology”.

Focus variation can be subtle when studying it’ s variations across the wafer. The basic metrology arrays described in the previous section can be easily increased to resolve finer structure in the lens. For example, the 5x5 array of Figure 6 could be increased to an 11x11 array.

Remember that the focus-groups are located on 2 mm centers.

Basic Analysis Techniques

Initial Dose Optimization

PSFM calibrations will exhibit a small 2nd order sensitivity to dose. Calibrations however respond more strongly in their range of variation or calibration noise across the exposure field. The optimum dose is therefore where the PSFM calibration is insensitive to small changes in dose. There are three easy methods of selecting the proper dose setting. The first method uses a simple plot of overlay as a function of Dose. The second and third methods are more exact and require the user of the Weir PSFM interface.

Wafer Exposure and Layout

1. Ranging initial dose
   a. expose one Focus-dose (FEM) wafer with 11x11mm step size with field bladed to 10x10mm. Greatest response is achieved with higher coherence.
   b. Set energy steps at 0.5mj and defocus steps at 0.05 um process
   c. Conduct SEM measurements on "500" grating. This grating has 250nm chrome lines
   d. Measure across energy (along row) at field center
      i. Mark is clearly labeled as mid-row and mid-column at the center focus step.
2. Dose Analysis Layout for Weir PSFM
   a. Measure overlay through focus for the best energy determined above plus two more energy columns left and right from the nominal energy. Multiple mark sizes (F200, F180 etc) can be selected.
      i. You will not see significant differences between marks of the same size but different tone.
   b. Measure nine (9) points per field across the 10x10 mm field described above.
   c. Determine the best energy for the test as being the one with largest defocus response at best conditions using any or all of the methods described below.
      i. the response "image shift-defocus" slope should be ~0.25 um/um.
   d. When looking at multiple marks, use the mark that contains the greatest slope and the least across-field noise.
      i. **Note**: Weir PSFM should be used to perform the calibrations. Calibration offset, slope and "Best Focus" for each site and exposure setting will be saved in the "Calibration" spreadsheet of the data. You can then analyze dose response using either the Weir PSFM tabs described below or by using the Excel plotting features of the spreadsheet.
   e. When optimum dose and feature has been determined, generate a new calibration FEM using more points per field and covering the maximum exposure area.
      i. Scanners require more points per field because of the variations derived from slit and scan travel as well as lens aberrations.
   f. Import the calibration data, using optimum dose, into Weir PSFM software for analysis of the aerial image. The Calibration can also be saved for future fixed-focus focus-conversion of across-wafer focus variations.

Best Dose Analysis Methods

Note: If a dataset contains Exposure-dose information, then two additional tabs appear on the "Calibrate Too Focus" or Calibration interface; the tabs are labeled "Dose" and "NonLinearity" as shown in Figure 8.

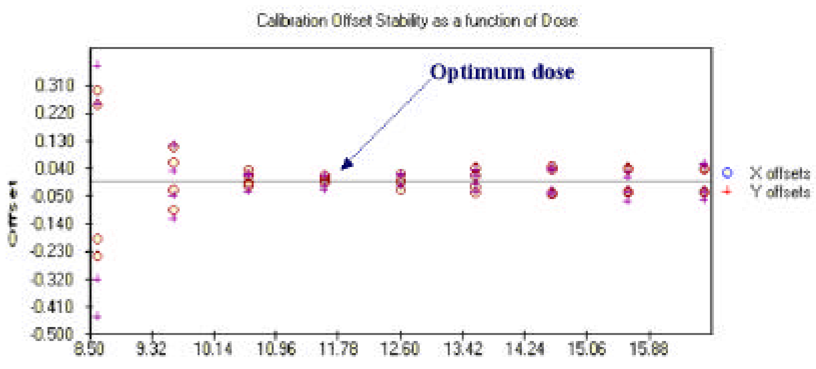


Figure 7: Weir PSFM plot for determination of optimum dose

1. Overlay verses dose
   a. Expose a dose matrix and measure the PSFM "overlay". The optimum dose will be at the center of the "flat" region over which image-shift is insensitive to small changes in dose.
   b. This method is less accurate than method #2 but easy to plot. This method is recommended for users of older instruments.
2. Calibration slope verses dose, Figure 7 (Dose Tab).
   a. Requires calibration of multiple sites located on the field. Fields are exposed in a full focus-exposure matrix.
   b. Plot the calibration offset or slope as a function of dose. Select the dosage that results in the minimum amount of "spread" in the coefficient settings. The Weir PSFM software automates the plotting of these charts in the PSFM Calibration interface.
3. Calibration nonlinearity verses dose, Figure 8 (Nonlinearity Tab)
   a. Plots the RMSS (nonlinearity) values of the calibration curve residuals as a function of dose.
   b. Look for a relatively "flat" range of RMSS values, the lower the better. In Figure 8, the selected exposure value will be 19 mj or 20 mj. The 19 mj value has a lower nonlinearity but, in general, the overall region of identical response seems to lie from about 18 to 22 mj. 20 mj has an added benefit in that the x-y axis difference in performance is no longer present.
   c. PGM calibration will be more sensitive to nonlinear behavior. Ensure that the range of focus values does not extend beyond the functional range of the PGM pattern, thereby increasing the nonlinear response at large focus offsets. You can easily limit the calibration range by using the Weir PSFM focus range controls.

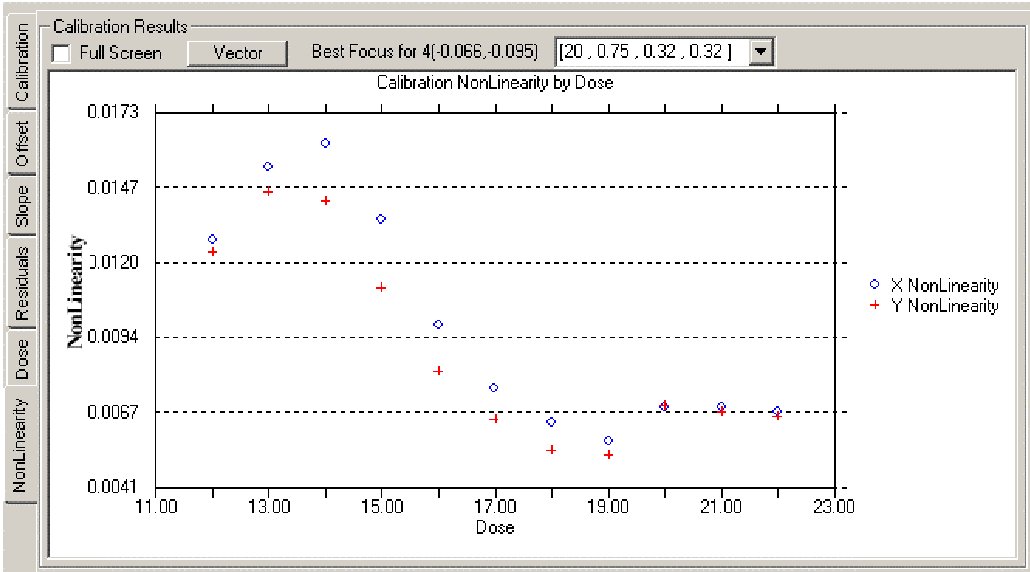


Figure 8: The calibration nonlinearity value determines optimum dose for PGM or PSFM exposure.

Note: *Use the Weir PSFM software to import the overlay metrology. The data will now reside in a Weir spreadsheet. At this point, you can use the Calibration functions of Weir PSFM – next section – to plot a Calibration Offset curve as shown above or simply use the spreadsheet plotting functions to plot overlay verses dose.*

Defining an Exposure Layout

Setting up a Serpentine Focus Variation

In this section we will go through a step-by-step account, illustrating how the exposure values of a focus-dose matrix array can be specified using the automated layout controls of the Weir Main screen. We want to specify a serpentine variation in focus across the wafer starting at 0.6 microns defocus in the lower left and stepping from right-to-left in 0.1 um incrments. Follow the text boxes illustrated in Figure 9.

Note: Values will be added to ALL wafers of the data set unless you first manually select an individual wafer from the "Wafer" drop-down control.

1. Use the File/Open menu to select and import the data.
2. Select the "Layout" tab.
3. Press "Draw" to display the previously-centered array.
4. Change the "format" to "Serpentine"
5. Change "fo" (initial focus) to 0.6 and and "Step" to –0.1
6. Double-click on the outer die, selecting it as the origin.
7. Select the relative location and travel direction of the array you will be filling. In this case, click the origin button located as shown. For this location, fields to the left and then upward of the origin die (step 5) will be filled in.

8. Click on “Update” to fill in the array values. Then click “Save” to save the data to the “Layout” spreadsheet.

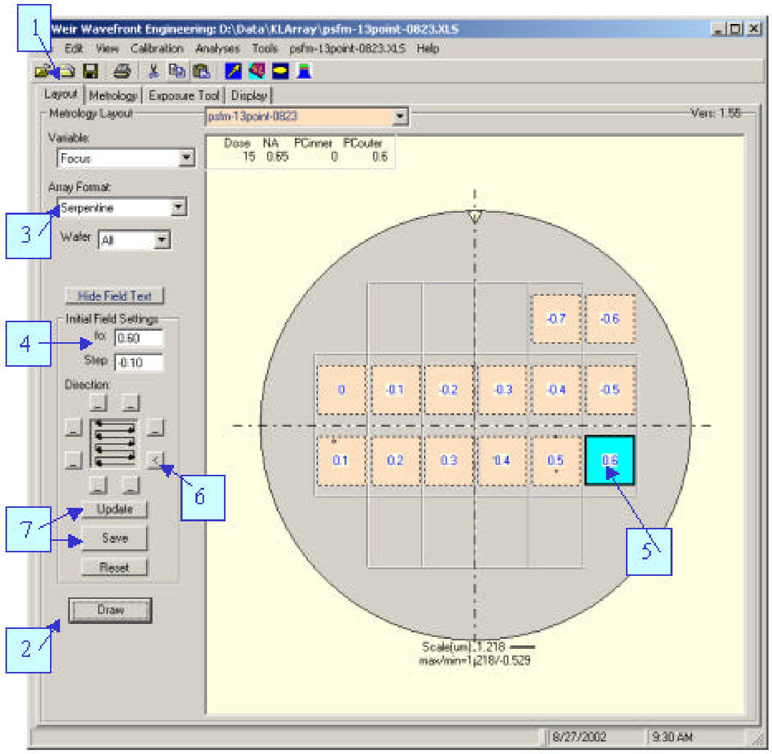


Figure 9: Specifying Focus-variation layout.

Adding a Constant Partial Coherence Value to the Array

Now that we have set up the focus, we desire to specify a constant Sigma or Partial Coherence (PC) for all die in the data set. Note that if PC varies from wafer to wafer, you need to first select the appropriate wafer ID from the dropdown list. Refer to Figure 10 for this exercise.

Select the “PC_outer” variable

✍✍ *Note PC inner is used to define “ring” and other apertures.*

Change the “format” to “Constant”

Change “PC” (initial sigma) to 0.63.

✍✍ "Step" will automatically change to 0 because of the "Constant" setting.

✍✍ With Constant settings, it is not necessary to set an origin die.

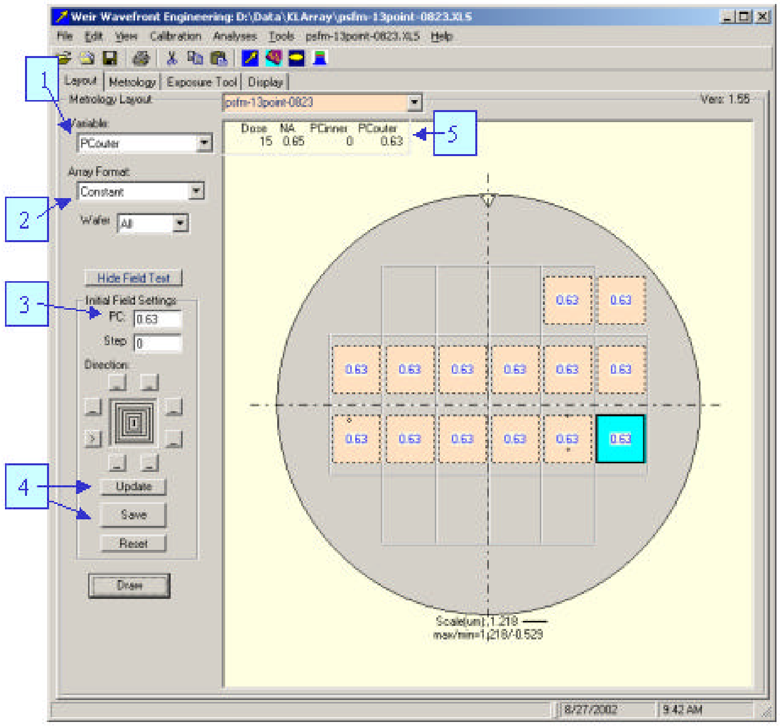


Figure 10: Specifying constant Partial Coherence in the layout.

Click on "Update" to fill in the array values. Then click "Save" to save the data to the "Layout" spreadsheet.

Check that the Dose, NA etc values are correct. You can reset these values in the same manner as this by changing the "Variable" field. This field will add additional rows as additional-unique values are added to the array.

Focus Monitor Reticle calibration

In the previous section, we loaded a focus matrix data set and defined the layout of the focus matrix. Next select the "Calibraiton/ Calibrate Tool Focus" menu option to access the screen of Figure 11.

When the Weir PSFM Calibration interface first appeared, the data defaulted to an analysis of a single site in the center of the field. The field center is typically the best-behaved portion of the exposure for calibrations. We then moved to test the field’ s four corners by double-clicking each site – or single-click to select and then press calibrate.

The lower right corner, site #63, yielded the two poor measurement points for the 22 mj dose shown in Figure 11. We examined the extent of poor-metrology values and selected a Range Cull setting of 0.011 um by noting the distance of each from the best fit curve and the ordinate scale of the graph. A few simple, single point calibrations using these approximate values and noting the number of cull points in the graph title will quickly allow you to select a reasonable cull values. Performing the single-site analysis again yielded the calibration curve of Figure 11. Selecting the “All Sites” radio button, below the field-layout graphic, and pressing the “Calibrate” command completed the calibration. Weir automatically calibrated all sites of the reticle for all exposure combinations. The results are stored in a single Weir PSFM Calibration template.

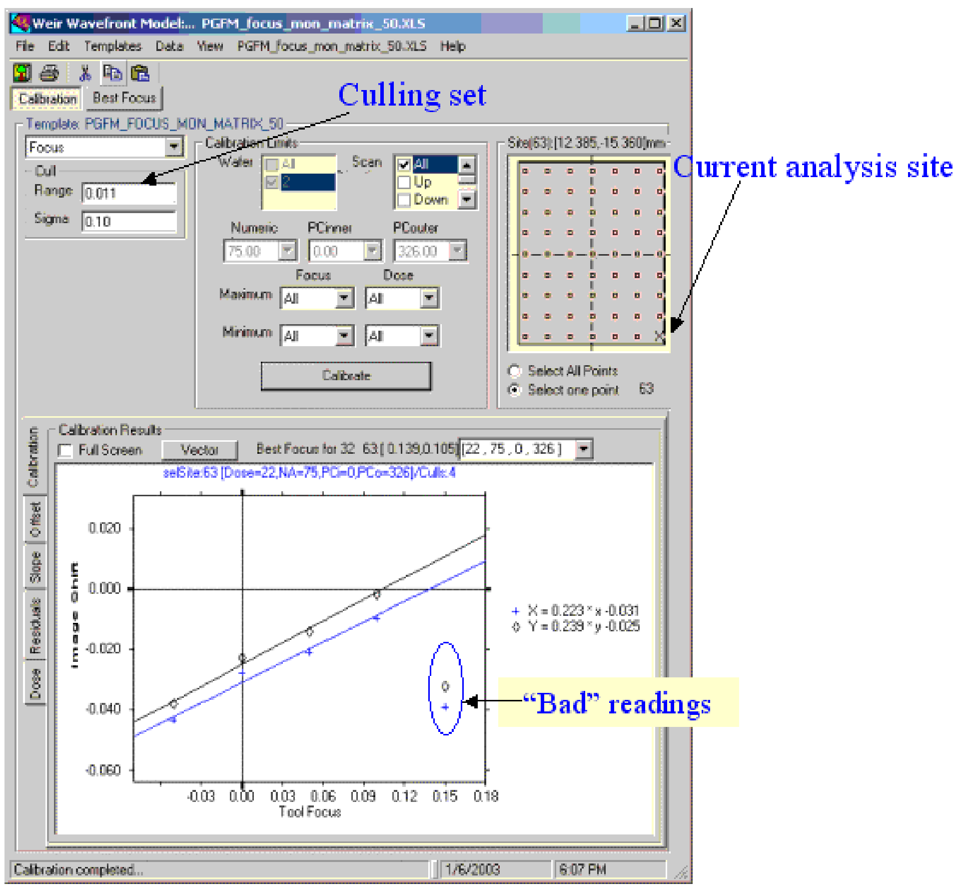
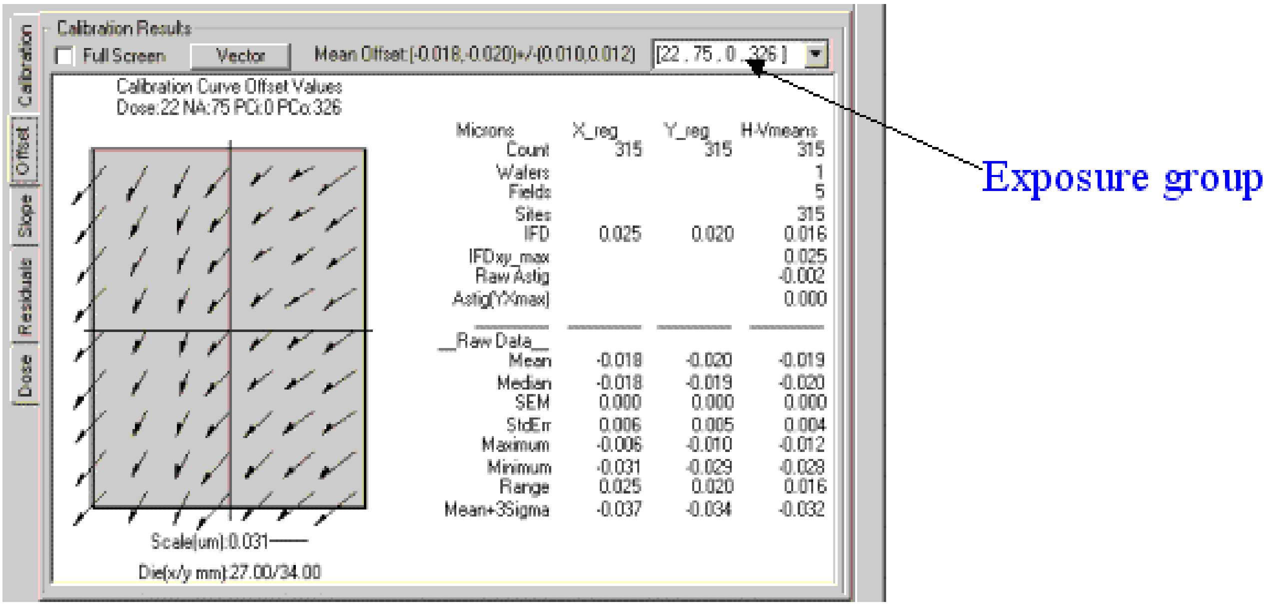


Figure 11: Corner Site Calibration for cull settings

Validate the Calibrations

After a full-field calibration, the uniformity of the coefficients as they are computed across the whole reticle should be checked. These next few steps yield information on the health of the metrology, the quality of the setup ranges, the effectiveness of culling and some hints about the performance of the aerial image.

Click the Offset tab to view a vector plot of the calibration offset variance from site-to-site on the reticle. Figure 12 shows the offsets for the 22 mj dose. We can now easily view this same graphic for other dose values by selecting each exposure from the exposure-group drop-down control located on the upper right of the graph.



Microns	X_reg	Y_reg	H-Vmeans
Count	315	315	315
Wafers			1
Fields			5
Sites			315
IFD	0.025	0.020	0.016
IFDxy_max			0.025
Raw Astig			-0.002
Astig(YXmax)			0.000
__Raw Data__			
Mean	-0.018	-0.020	-0.019
Median	-0.018	-0.019	-0.020
SEM	0.000	0.000	0.000
StdErr	0.006	0.005	0.004
Maximum	-0.006	-0.010	-0.012
Minimum	-0.031	-0.029	-0.028
Range	0.025	0.020	0.016
Mean+3Sigma	-0.037	-0.034	-0.032

Figure 12: Viewing calibration offsets across the reticle field.

The statistics displayed show the offset data population for every site on this display. "X" offsets range from –6 nm to –31 nm, close matching those of the Y axis.

Best Focus Analysis

Select the "Best Focus" tab and begin the analysis by clicking on the "Calculate" command button or any one of the display tabs to the left of the graphic. Weir PSFM will begin the model sequence automatically. We could also have selected to restrict the analysis by using the exposure check-boxes at the top of the window.

At this point you should save the calibration template. Use the "Template/Save" menu item to save the new calibration under a name that is the same as your current data set.

Fixed Focus Analysis

In the previous section we calibrated a Focus Monitor reticle using a focus-dose matrix on a horizontal slit scanner. In this section we will examine the focus performance of that same scanner across a whole wafer. We will be using the Calibration template stored in the Weir Template Library to convert the PGFM overlay to focus data

Conversion of overlay data to focus

We used the template stored in the last application example for data conversion as shown in Figure 13. This fixed-focus dataset contains only one exposure-dose = 20 mj. Notice that the template stored in the library contained many more potential templates. The conversion sequence in Wier

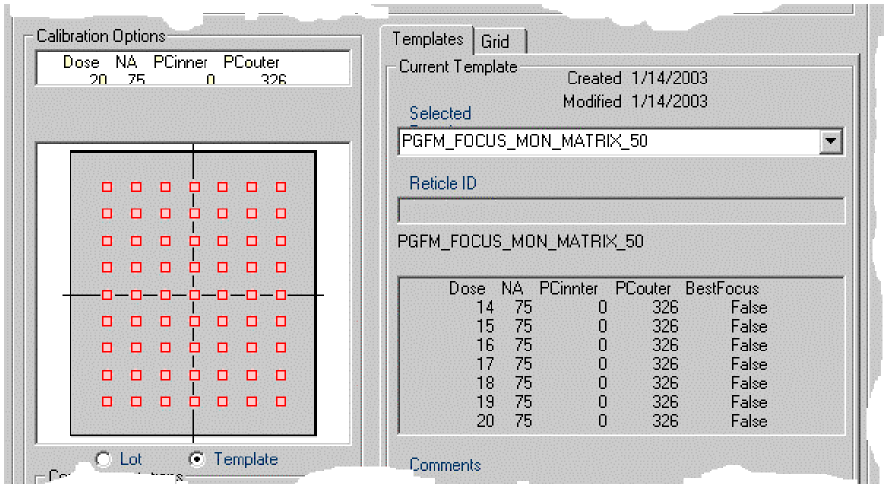


Figure 13: Calibration template selection for conversion to focus

PSFM will select the proper conversion based on the four exposure criteria; Dose, NA, Pcinner and PC outer. You can override any of these criteria during template selection by using the check-box elements located below the template/Lot field layout screen. These check boxes can be seen in the lower left corner of Figure 14.

The Cull Analysis command button was used to display a histogram of the candidates present in the raw overlay data for data culling, see the inset histogram of Figure 14. The goal is to achieve a population on this histogram that has a uniform distribution without the long "tail" shown to the left of the inset. Quite simply, selecting 3.0 sigma as a cull value removes 24 data points; the number culled by each method is shown in blue to the right of the "Sigma" and "Range" cull entry fields on the upper right side of Figure 14. The resulting converted focus data, plotted as a vector plot, is displayed by Weir in the graphic window in the figure.

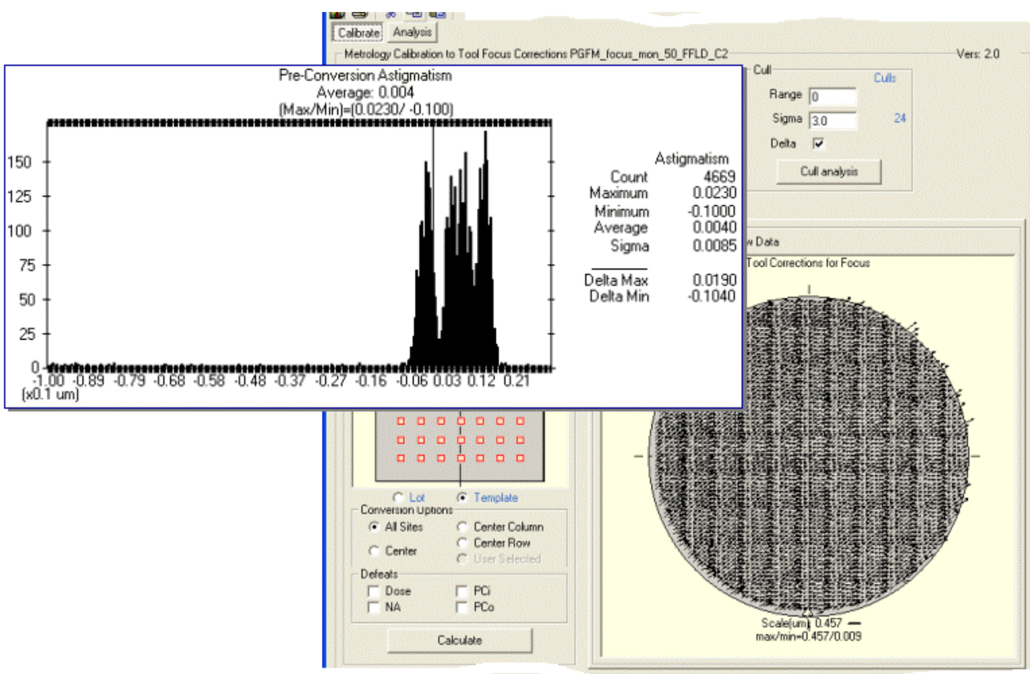


Figure 14: Weir Analysis Uniformity conversion screen with data-culling histogram (inset).

Precision and Error Budget

Selecting the "Precision" tab located to the left of the graphic area summarizes the full-wafer focus precision of the data set. The chart of Table 1 is calculated from the raw focus data and saved in the "Precision" spreadsheet tab.

The Range of focus values along the slit exceeds that of the scan by almost 0.1 micron. This is good because it implies that the scan is not contributing excessively. The overall one-sigma lot precision is (X,Y) = (44,25) nm. The variation within the field, row and column seems to account for the majority of the errors.

Site variation for slit and scan are approximately equal. Variations in this metric would indicate changes in focus from field-to-field for the same site.

IntraField focus varies more for variations within the slit (X-focus) than along the scan. This would indicate that most of the variation is going to occur across the lens-slit rather than be inflicted by the scan. The design of the scan system is to average out errors in the scan or Y-axis.

InterField variation is constant for both axes, indicating very good field-to-field autofocus control.

	Slit	Scan	Zmean
_____	_____	_____	_____
Average	0.143	0.081	0.112
Range	0.401	0.277	0.277
Precision	_____	_____	_____
Lot	0.044	0.025	0.031
Field	0.040	0.022	0.027
Site	0.024	0.018	0.021
IntraField	0.032	0.011	0.017
InterField	0.018	0.013	0.015
Column	0.036	0.019	0.026
InterColumn	0.019	0.010	0.010
Row	0.039	0.020	0.025
InterRow	0.015	0.009	0.012

Table 1: Full-Wafer Focus Precision & Error Budget

Column precision reflects variation within each column of data. We can see it is about equal in value to the Row variation for both axes. The variation is also consistent for the direction, X or Y. This indicates stability in both axes. Both inte-rColumn and InterRow variation suggest greater changes along the slit than along the scan axis.

In summary, this is a very well behaved system. We' ll see the majority of the focus variation occurring from field-to-field. This could be because of wafer, film or stage-height variation. The Stage and slit are properly aligned with the majority of focus error occurring along the X-focus or slit direction. This may be lens or aerial image limited. Finally, the row-to-row and column-to-column is almost identical. This would indicate a properly set up scan-system without variations due to scan direction or from wafer-edge effects.

Raw Focus Analysis

You can see statistics and various graphics including histograms, vector and contour plots of the raw focus data. Turn off all wafer and field models using the controls on the "Models" tab of the Analysis screen. Select the Contour graphic radio button and press the "Wafer" tab to the left side of the graphic window to see the data. Figure 15 displays how the average focus contour varies across the wafer.

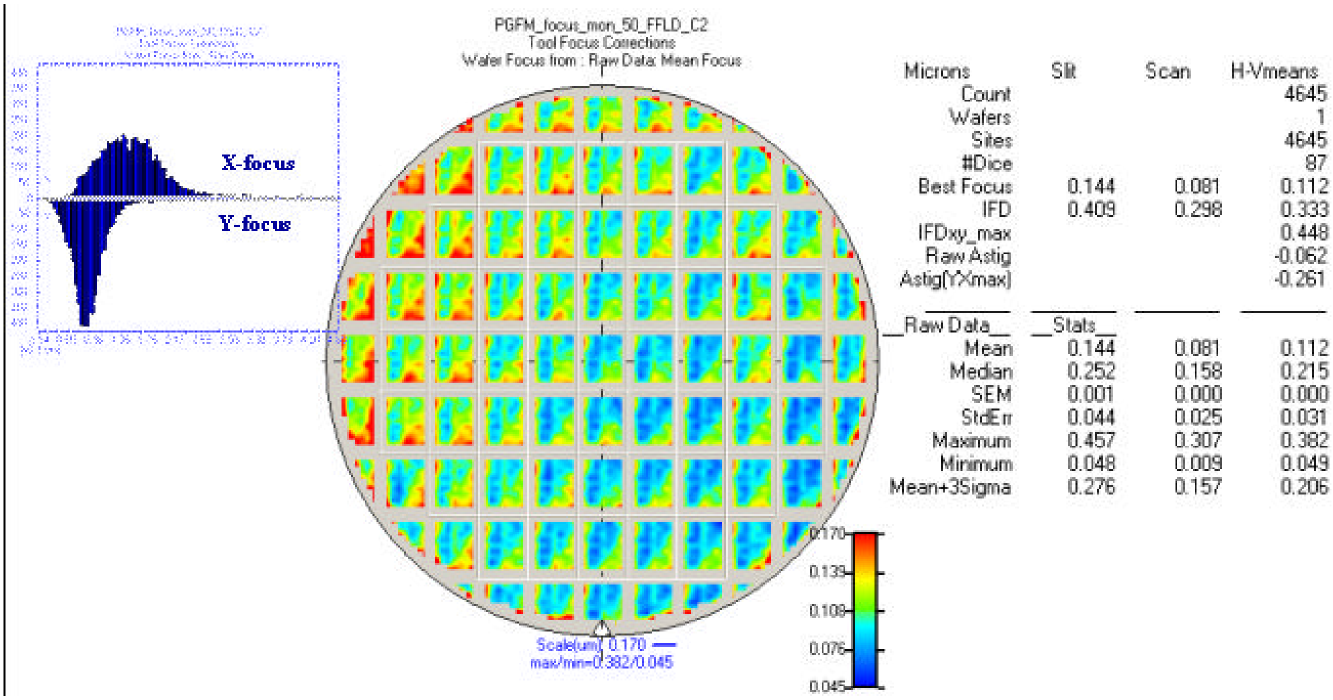


Figure 15: Average focus variation of raw focus metrology across the wafer.

A comparison of the X and Y-focus histograms on the inset of Figure 15 illustrate that, as predicted by the precision analysis of the previous section, there is significantly more spread in the X focus population than in Y. The data exhibits an average focus of 112 nm, with astigmatism of –62 nm. This tool is losing 333 nm simply to focus variation across the field and wafer. The variation of focus for vertical lines, or X-focus values, is even greater displaying a total IntraField Deviation (IFD) of 409 nm.

Note particularly the fine-structure variation, causing a bead-like column of focus on the left side. The high focus "red" areas of the upper-left side of the wafer suggest the presence of wafer tilt.

Focus errors across the wafer are composed of:

?? Systematic Errors from

?? Wafer tilt and bow

?? Field offsets (piston) and any rotational effects

?? Row (lens-slit) and column (slit-scan) systematic errors and

?? Residuals errors from

  ?? Wafer substrate

  ?? High order variations

  ?? Local bumps, dirt etc.

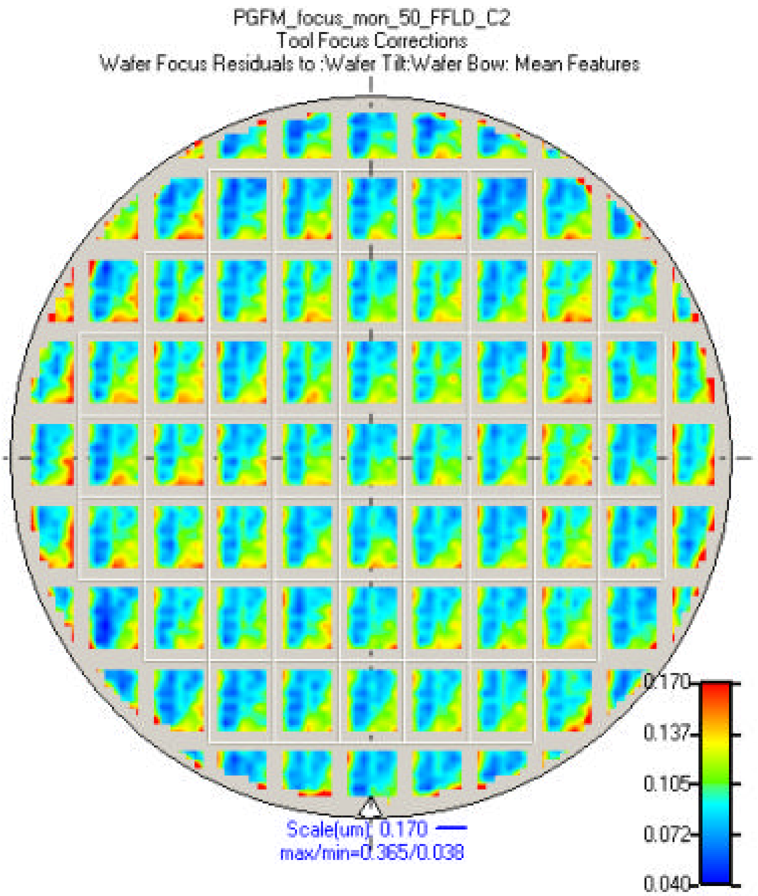
  ?? Scan-variations

  ?? Reticle pattern errors

  ?? Metrology systematic errors and

  ?? Random exposure and metrology noise.

The first obvious items to remove will be the effects of wafer or film flatness. This is easily performed in Weir PSFM by turning on the modeling of the wafer and, optionally, the field analysis. Next, select only the wafer coefficients – Tilt and Bow -- for viewing. This will change the graphic of Figure 15 to look like that of Figure 16 when you display it using the "Wafer Residuals" tab.



Microns	Slit	Scan	H-Vmeans
Count			4645
Wafers			1
Sites			4645
#Dice			87
Best Focus	0.144	0.081	0.112
IFD	0.409	0.298	0.333
IFDxy_max			0.448
Raw Astig			-0.062
Astig(YXmax)			-0.261
	Model		
Wafer	Slit	Scan	Ave.
XTilt(urad)	-0.135	-0.100	-0.117
YTilt(urad)	0.081	0.076	0.079
Bow(um/cm2)	0.000	0.000	0.000
	Model		
Field	Slit	Scan	Ave.
BF(Fitted)	0.097	0.118	0.108
Tilt(um/cm)	0.012	-0.009	0.002
Tilt(urad)	1.228	-0.851	0.188
Astigmatism			0.021
Curv(um/cm2)	0.031	0.022	0.026
IFDresid(um)	0.409	0.298	
Residuals	Stats		
Mean	0.144	0.081	0.112
Median	0.252	0.158	0.215
SEM	0.001	0.000	0.000
StdErr	0.044	0.025	0.031
Maximum	0.457	0.307	0.382
Minimum	0.048	0.009	0.049
Mean+3Sigma	0.276	0.157	0.206

Figure 16: Average raw-focus variation after wafer error removal.

Figure 16 displays an improved rendition of the average-focus perturbations across the wafer. We could have performed a similar analysis by turning on both wafer and field modeling but selecting only the field coefficients for display and then pressing the "Wafer" display tab. This method however leaves out a lot of information for it only displays the systematic field errors of offset (piston), tilt and bow.

When we examine the residuals by pressing the "Wafer Residuals" tab, the wafer systematic errors are removed and everything else is thrown into the summary and display. The focus uniformity, independent of wafer systematic tilt and bow, is now read in the Residual statistics at the bottom of the figure. Optimum focus, based on raw data, is therefore at 112 nm and it exhibits again a total of –62 nm of Astigmatism. The IFD of the tool is still at 333 nm; in short the systematic components do not change by much because the wafer-induced errors of this ultra-flat substrate are not dominantly contributing to the focus error budget.

In spite of the lack of wafer-error contribution, there is much to be learned. For example we can begin to see some wafer or film sub-structure appearing in the lower right quadrant of the substrate that is too random or high-order to be modeled by the wafer model. The across-field focus variation is also more apparent now as are the effects of the wafer's edge on focus. The field exhibits some interesting fine structure that can be seen with greater clarity in Figure 17.

Figure 17 is easily plotted by selecting the “Field Resids” tab on the screen. A spreadsheet, “Surf_FieldResids” is generated when the contour is plotted.

Hint: reduce the size of the overall plot area to shorten display time during field plotting.

Here the average field of mean-focus values contains a vertical ridge of bumps traveling up the field a –6 mm from field center. The full contour of this structure can be seen using either the Weir 3D or the Excel surface plot on the data stored in the “Surf_FieldResids” spreadsheet. This column of bumps is most likely the result of the travel of the slit-scan stage during exposure.

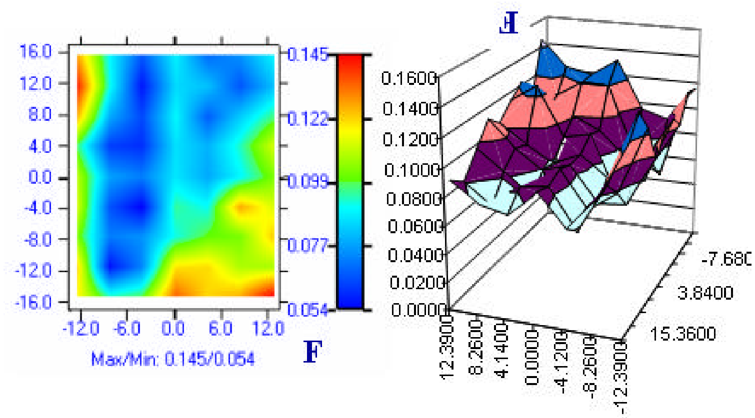


Figure 17: Average mean-focus field and Excel 3D plot. Note “F” label for orientation in each plot.

This average field correlates not only in general contour but also focus-range with the Best Focus calculation of the aerial image found in the previous section. This field view contains additional fine-structure introduced by the wafer and scan system not seen in the Best Focus calculation. Note that both this fixed-focus analysis and the Best Focus calculation of the image exhibit a columnar trench at –6 mm and a low-focus drift of this area to the upper right corner of the exposure.

Acknowlegement

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