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## ***Phase Shift Focus Monitor (PSFM)***

### **PSFM Demo Procedure**

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**Note: Analysis, setup, graphics and results shown in this document use**

**'Weir PSFM' Software**

***Weir PSFM is provided and recommended by Benchmark for PSFM and Phase Grating (PGM) analysis. Ask or see <http://www.benchmarktech.com/Weir.htm> for details.***

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## Introduction

### Physics

Benchmark's Phase Shift Focus Monitors employ phase-shift mask (PSM) technology developed by IBM Corporation. The technique is based on the asymmetric imaging exhibited by structures that shift phase ( $\phi$ ) by a value other than  $180^\circ$ . The basic focus monitor pattern consists of three narrow chrome lines equally spaced. At nominal focus, the overlay error for this bar-on-bar structure is zero in both X and Y. When a focus error exists, the phase-shifted half of the pattern moves relative to the unshifted part; the resulting overlay error is a direct measure of the focus error.

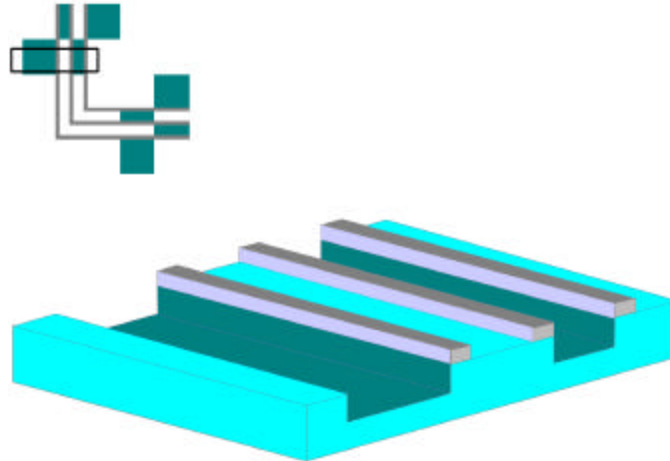


Figure 1: Cross-section of a PSM Mark

Positive defocus shifts the image toward the shifter and negative defocus shifts the image away from the shifter. The phase-shifted lines can be arranged in a box-in-box pattern which can be measured using an overlay tool. The box-in-box offset moves linearly with defocus and is zero only at best focus.

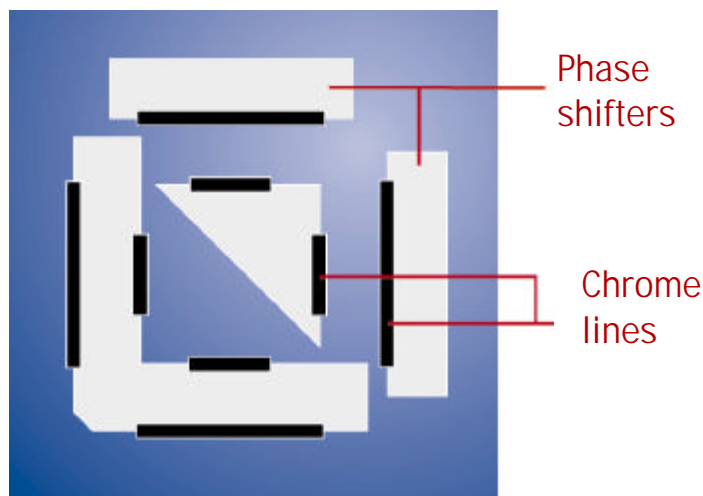


Figure 2: Phase Shifted Lines arranged in a Box-in-Box pattern

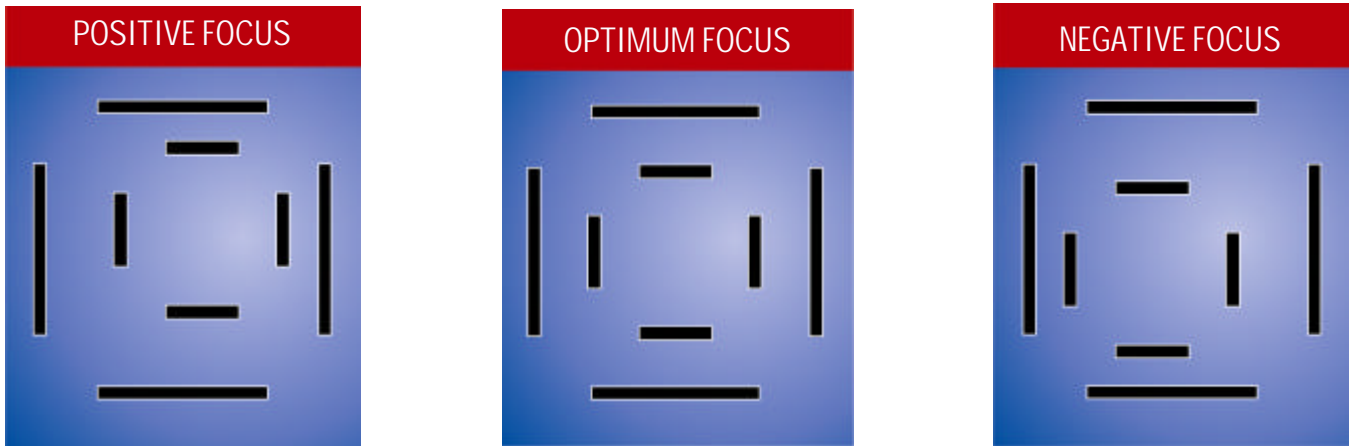


Figure 3: Overlay Shift versus Defocus

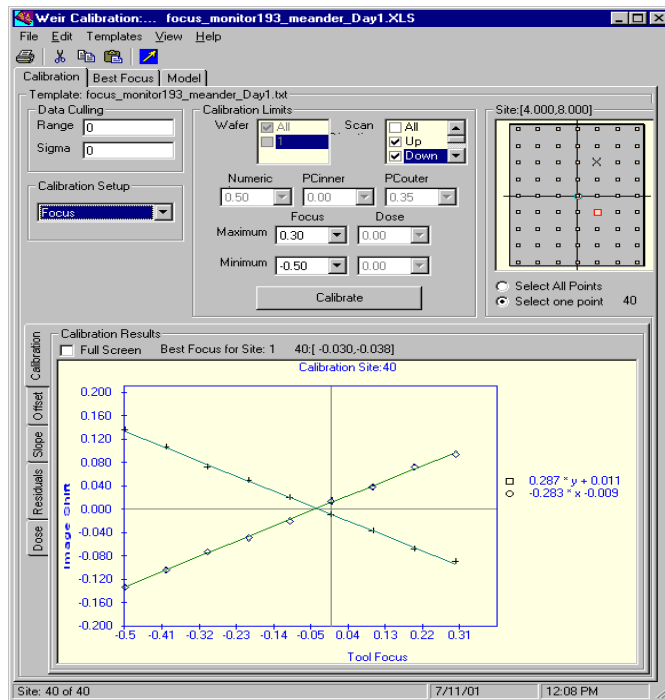
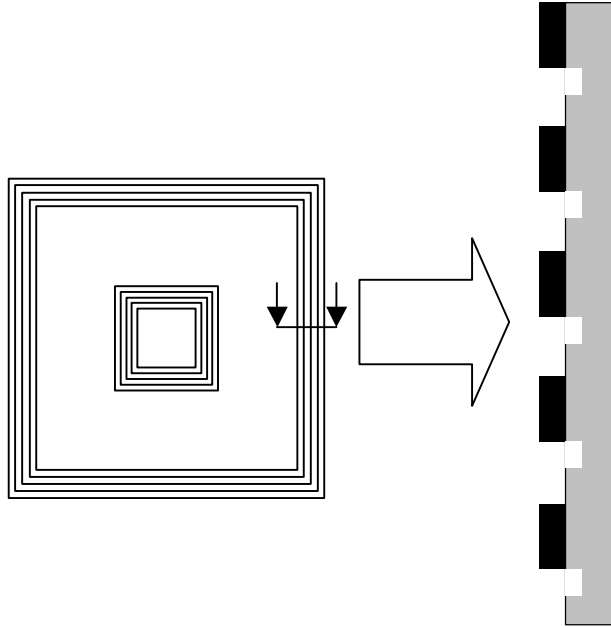


Figure 4: Calibration Lines (Overlay Shift versus Defocus) plotted using Benchmark's Weir PSFM Software

The Phase Shift Technology when employed on diffraction gratings leads to a greater sensitivity to focus. This technology is patented by Advanced Micro Devices (AMD). The grating pattern consists of equally spaced Chrome lines with 0 and 90 degree phase shifted region between them. The grating pattern imaging can be understood as an interference pattern arising out of the 0<sup>th</sup> and +/-1<sup>st</sup> order diffraction components. The higher orders are not captured due to the limited lens aperture. The

PGFM grating structure only gives rise to the 0<sup>th</sup> and +1<sup>st</sup> order component. The -1<sup>st</sup> order is cancelled out. This leads to a 2 beam interference which is asymmetric with respect to the vertical axis. The metrology pattern consists of two concentric boxes composed of these phase gratings. The image is centered only at zero focus and tends to shift with defocus.



**Figure 5: Phase Grating Mark**

Sensitivity of PGFM is almost 2.5 times that of the PSFM method. However, the range over which the calibration curve is linear is smaller than PSFM. Hence, it is better suited for measurement of tighter focus distributions so that the reduced linearity range is not a concern. The reticle has been demonstrated to be particularly useful for the evaluation of 193 nm scanners.

## **Highlights**

- ?? High Precision: better than  $\pm 9\text{nm}$  3 sigma
- ?? Extremely fast
  - Focus measured with existing overlay metrology tools
  - No Focus matrix required
  - Eliminates need for several wafers to be exposed
  - Employs automated data acquisition using presently available metrology tools
- ?? Complete lens / tilt stage / wafer chuck characterization
  - Focus
  - Chuck (Stage) Tilt X, Y
  - Platen (Reticle) Tilt X, Y
  - Field Curvature, IFD
  - Astigmatism
- ?? Is fully compatible with nearly all lithography systems
- ?? Data insensitive to exposure dose
- ?? Demo reticle for 193 nm, 248 nm, and 365 nm are available

## Reticle Layout

### ***193 nm Demo Reticle***

#### **Salient Features (193 nm)**

- ?? Matrix: 13 x 17
- ?? Pitch (at 1X): 2 mm
- ?? Field Size (at 1X): 26 mm x 34 mm
- ?? PSFM (Iso-line) Feature Sizes (at 1X): 100, 110, 120, 130, 140, 150, 170, 190 nm
- ?? PGFM (Grating) Feature Sizes (at 1X): 200, 250, 300 nm
- ?? Recommended Feature for Measurement: Site A or B shown in Zoom 2.
- ?? Compatible with all 193 nm exposure tools (ASML, Canon, Nikon, SVGL) with 4X reduction
- ?? There is a 4X/5X reduction reticle also available. Please contact Benchmark Technologies to get layout details.

### Layout (193 nm)

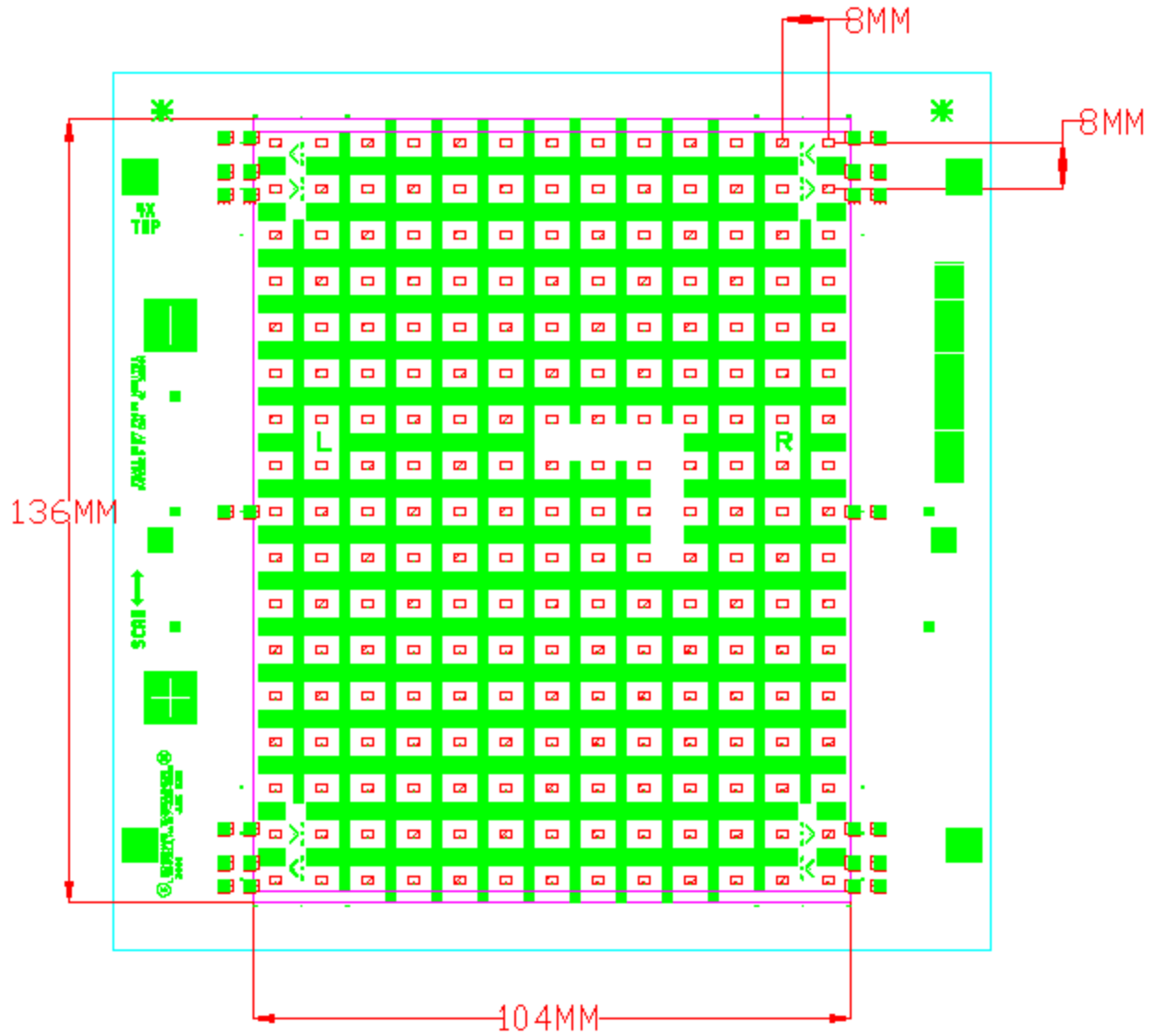


Figure 6: 193 nm Reticle Layout (Zoom 1)

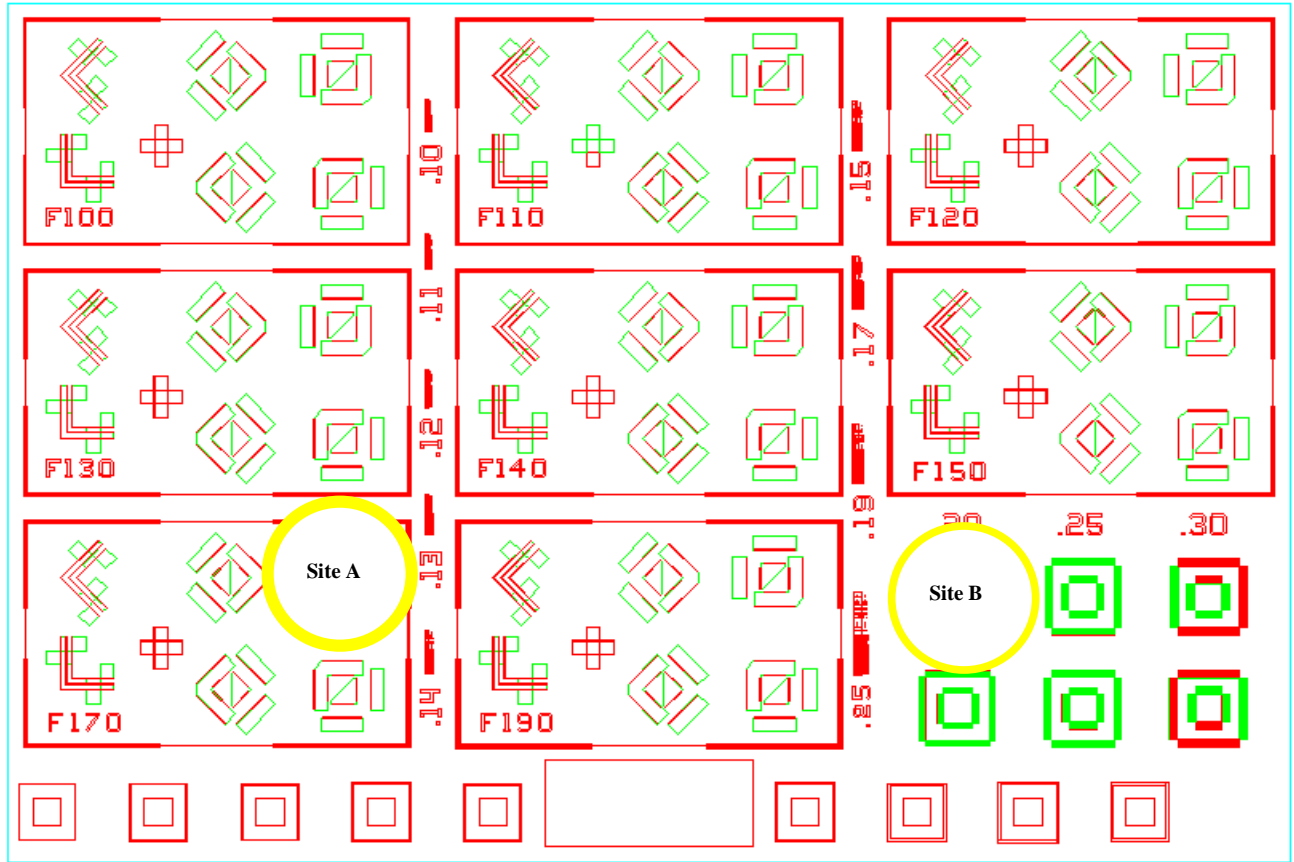
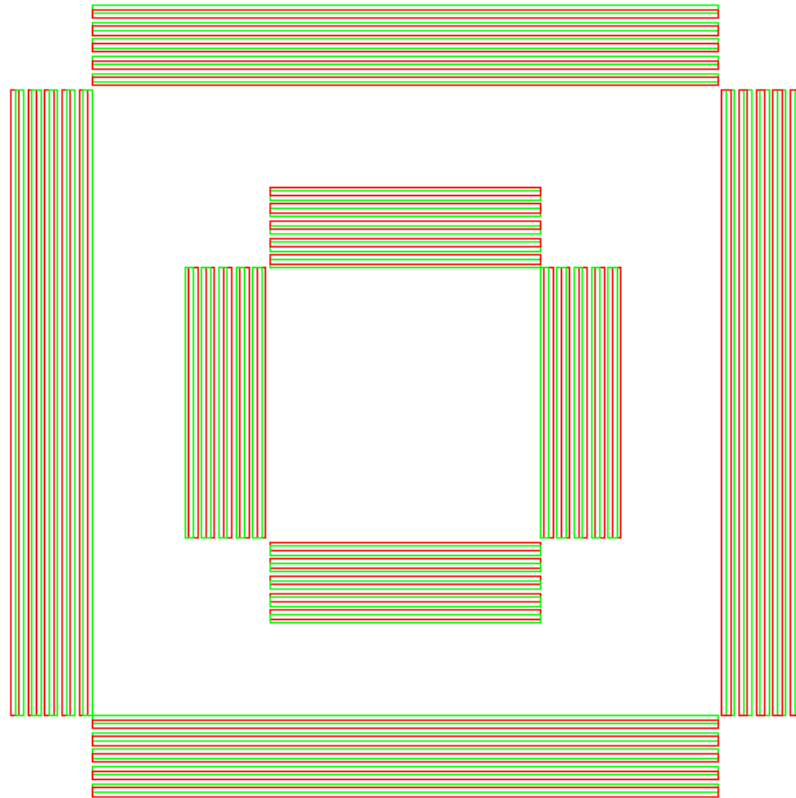


Figure 7: 193 nm Reticle Layout (Zoom 2)



**Figure 8: 193nm Reticle Layout (Zoom into Grating)**

## **248 nm Demo Reticle**

### **Salient Features (248 nm demo)**

- ?? Matrix: 13 x 17
- ?? Pitch (at 1X): 2 mm
- ?? Field Size (at 1X): 26 mm x 34 mm
- ?? PSFM (Iso-line) Feature Sizes (at 1X): 100, 110, 120, 130, 140, 150, 170, 190 nm
- ?? PGFM (Grating) Feature Sizes (at 1X): 200, 250, 300 nm
- ?? Recommended Feature for Measurement: Site A or B shown in Zoom 2.
- ?? Compatible with all 248 nm exposure tools (ASML, Canon, Nikon) with 4X reduction.
- ?? There is a 4X/5X reduction reticle also available. Please contact Benchmark Technologies to get layout details.



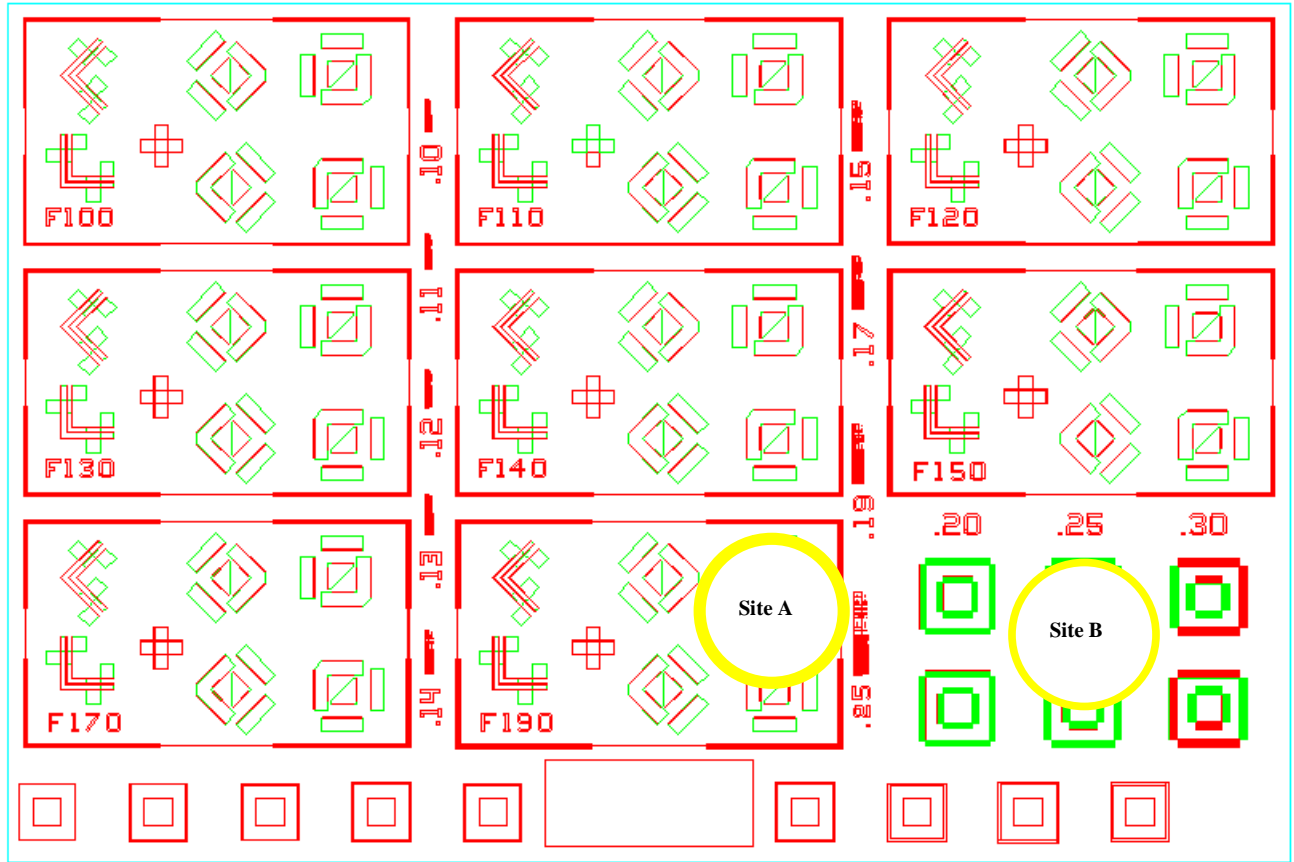


Figure 10: 248 nm Reticle Layout (Zoom 2)

## **365 nm Demo Reticle**

### **Salient Features (365 nm demo)**

- ?? Matrix: 11x 13
- ?? Pitch (at 1X): 2 mm
- ?? Field Size (at 1X): 22 mm x 26 mm
- ?? PSFM (Iso-line) Feature Sizes (at 1X): 160, 180, 200, 240, 280, 320, 360, 400 nm
- ?? PGFM (Grating) Feature Sizes (at 1X): None
- ?? Recommended Feature for Measurement: Site A or B shown in Figure 2.
- ?? Compatible Tools: All 365 nm exposure tools (ASML, Canon) with 5X reduction ratios

### Layout (365 nm demo)

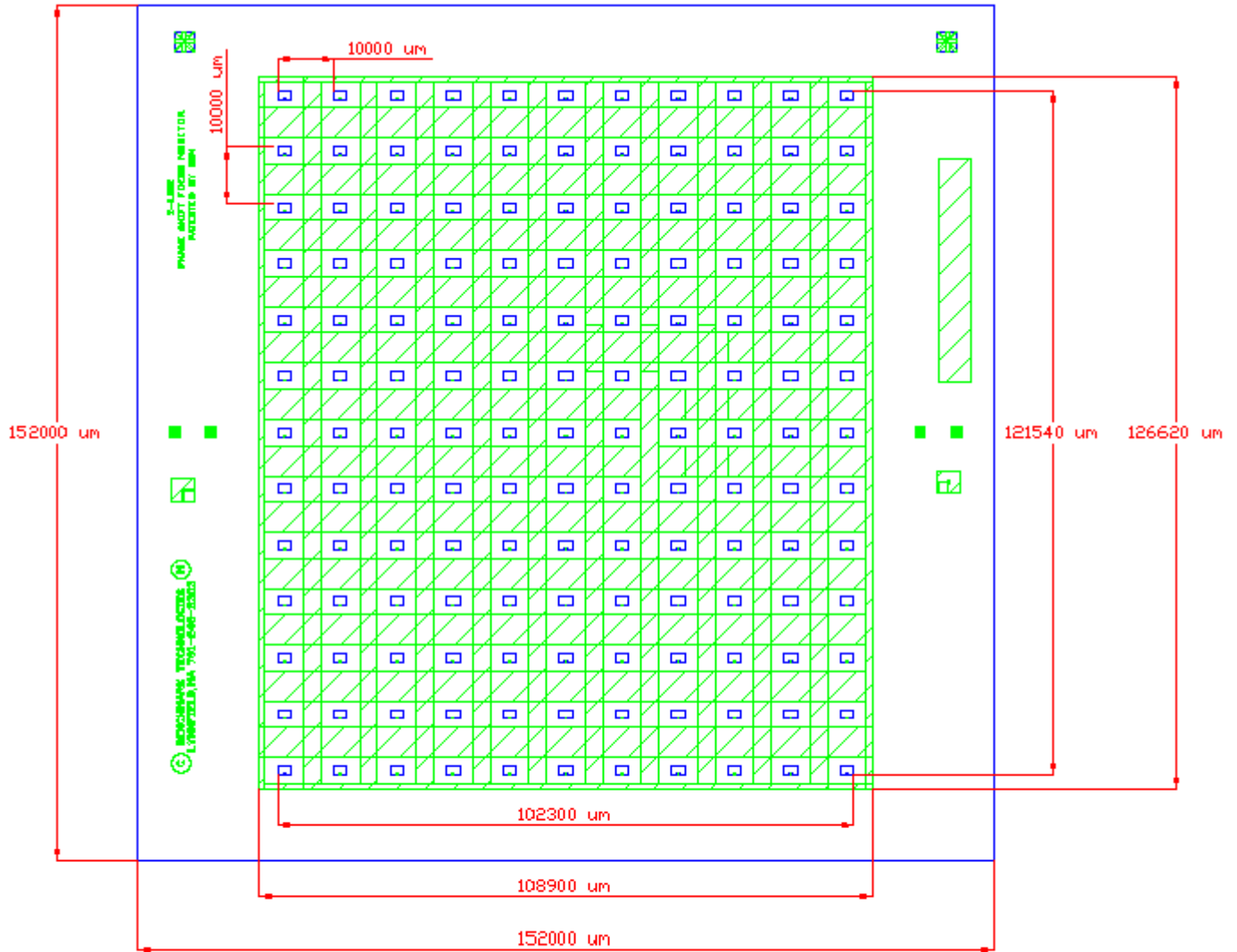


Figure 11: 365nm Reticle Layout



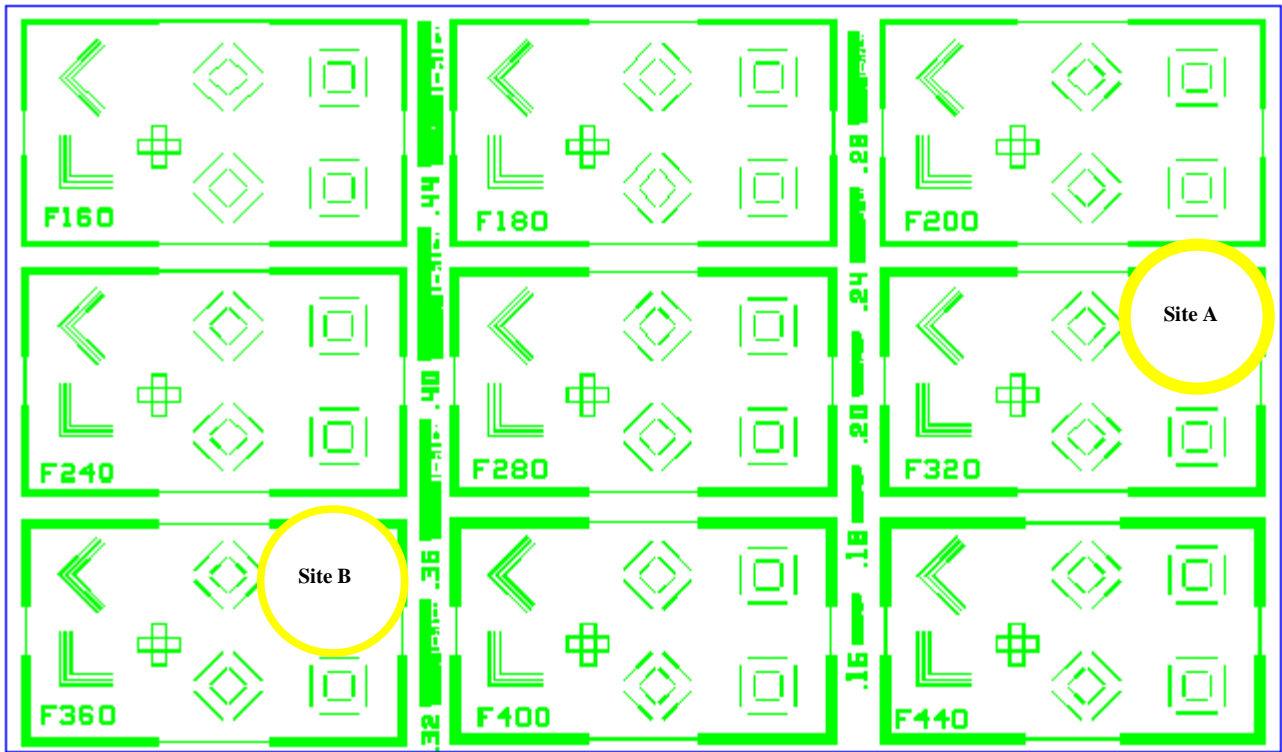


Figure 12: 365 nm Reticle Layout (Zoom 2)

## **436 nm Demo Reticle**

### **Salient Features (436 nm demo)**

- ?? Matrix: 11x 11
- ?? Pitch (at 1X): 2 mm
- ?? Field Size (at 1X): 22 mm x 26 mm
- ?? PSFM (Iso-line) Feature Sizes (at 1X): 160, 180, 200, 240, 280, 320, 360, 400 nm
- ?? PGFM (Grating) Feature Sizes (at 1X): None
- ?? Recommended Feature for Measurement: 400 or 440 nm
- ?? Compatible Tools: All 436 nm exposure tools (ASML, Canon) with 5X reduction ratios

*Please note that the reticle layout is similar to 365nm with only an 11 x 11 matrix.*

## **Day 0: Exposure Tool Settings and Choosing a Resist**

### **Illumination Settings**

We recommend using the 'normal' illumination mode

### **Numerical Aperture (NA)**

Choose a production setting, probably around 0.6 or 0.7

### **Partial Coherence (Sigma)**

Select a fairly coherent illumination.

### **Resist**

Should be thin, high contrast, and positive. Use BARC if possible. We recommend that you use a normal production recipe (where thickness is monitored regularly). Typically customers select a gate level recipe as a starting point.

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

### **Wafers**

Use flat or ultra-flat wafer

# Day 1: Finding Best Exposure

## Data Collection

Expose a focus/exposure matrix as shown below. Reduce the field size to 2 mm x 2 mm (or 6 mm x 6 mm) so as to expose only the center site. This way we can fit several focus/exposure matrices on a single wafer.

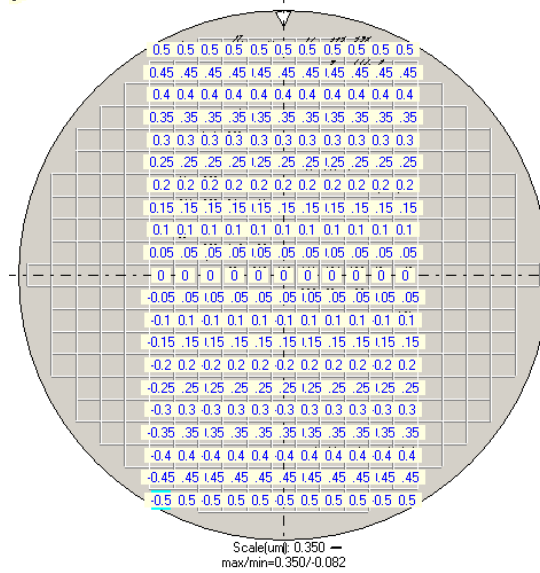


Figure 13: Focus Matrix Shown Above (Screens by Weir PSFM)

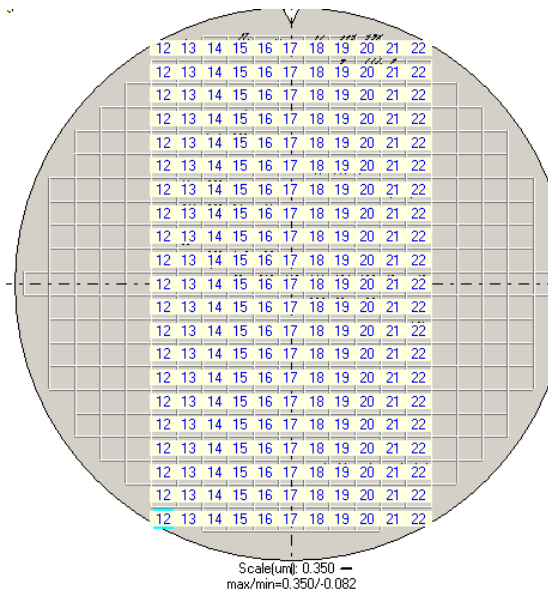
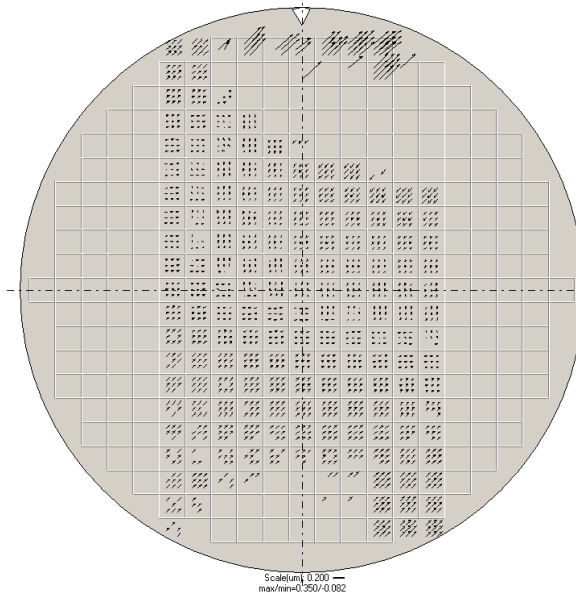


Figure 14: Exposure Matrix Shown Above

Focus changes from  $-.50\ \mu\text{m}$  to  $+.50\ \mu\text{m}$  in steps of  $.05\ \mu\text{m}$  (or  $-1.0\ \mu\text{m}$  to  $+1.0\ \mu\text{m}$  in steps of  $.1\ \mu\text{m}$ ).  
Exposure changes from  $1.25\ \text{E}^0$  to  $1.75\ \text{E}^0$  in steps of  $.05\ \text{E}^0$  (or  $1.0\ \text{E}^0$  to  $2.0\ \text{E}^0$  in steps of  $.1\ \text{E}^0$ ).

Measure the recommended feature (refer to Reticle Layout Section to pick the right feature to measure) using an overlay tool.



**Figure 15: Measured Data from an Overlay Tool**

## Analysis

Please send the data to Benchmark Technologies for analysis of data. We will use TEA's 'Weir Software' for analyzing the data. There are 3 criteria by which the best exposure can be chosen. We will analyze all methods and send you a report.

At best exposure the focus calculations should not vary much with small changes in exposure. Customers have chosen two ways to arrive at this:

1. *Slope of Calibration Line* is plotted against *Exposure*. At best exposure the curve is flattest. That is, small changes in exposure will not change calibration slope appreciably.

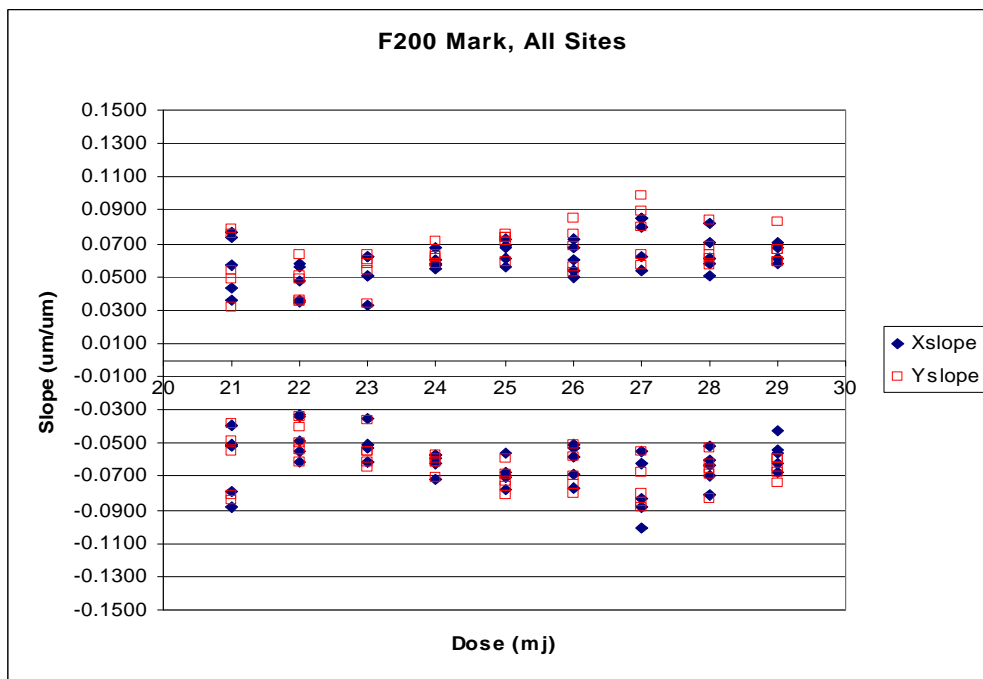


Figure 16: Calibration Line Slope versus Exposure Dose

2. *Range of Linearity* is plotted against *Exposure*. That is, at best exposure the calibration line can be used even for large changes in focus.
3. *Uncertainty/Nonlinearity* (3 sigma deviation of calibration line from straight line) is plotted against *Exposure*. That is, small changes in exposure will still yield a straight line.

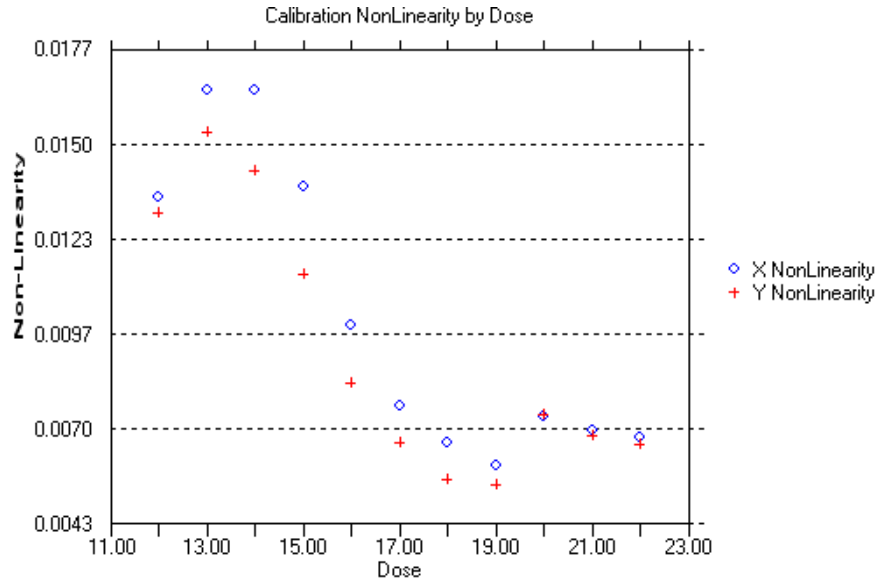


Figure 17: 3 Sigma Non-linearity versus Exposure Dose

4. *Best Focus* is plotted against *Exposure*. Anticipated behavior is to have BF change with dose, but be constant and stable over the valid exposure range. BF range across each field should also be minimal in the optimum dose range.

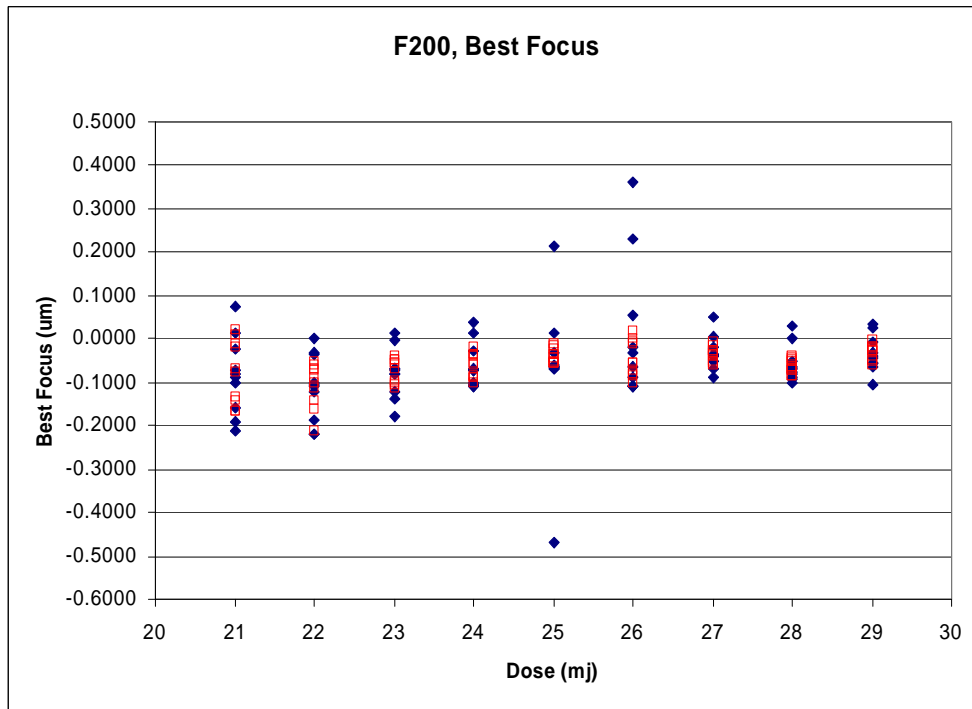


Figure 18: Best Focus Calculated versus Exposure Dose

## Day 2: Finding Lens / Tilt Stage Characteristics

### Data Collection

Expose a focus matrix as shown below. Select a field size that exposes the entire exposure area of the lens. You could increase the step size by 1 mm to increase the scribe line width by 1 mm.

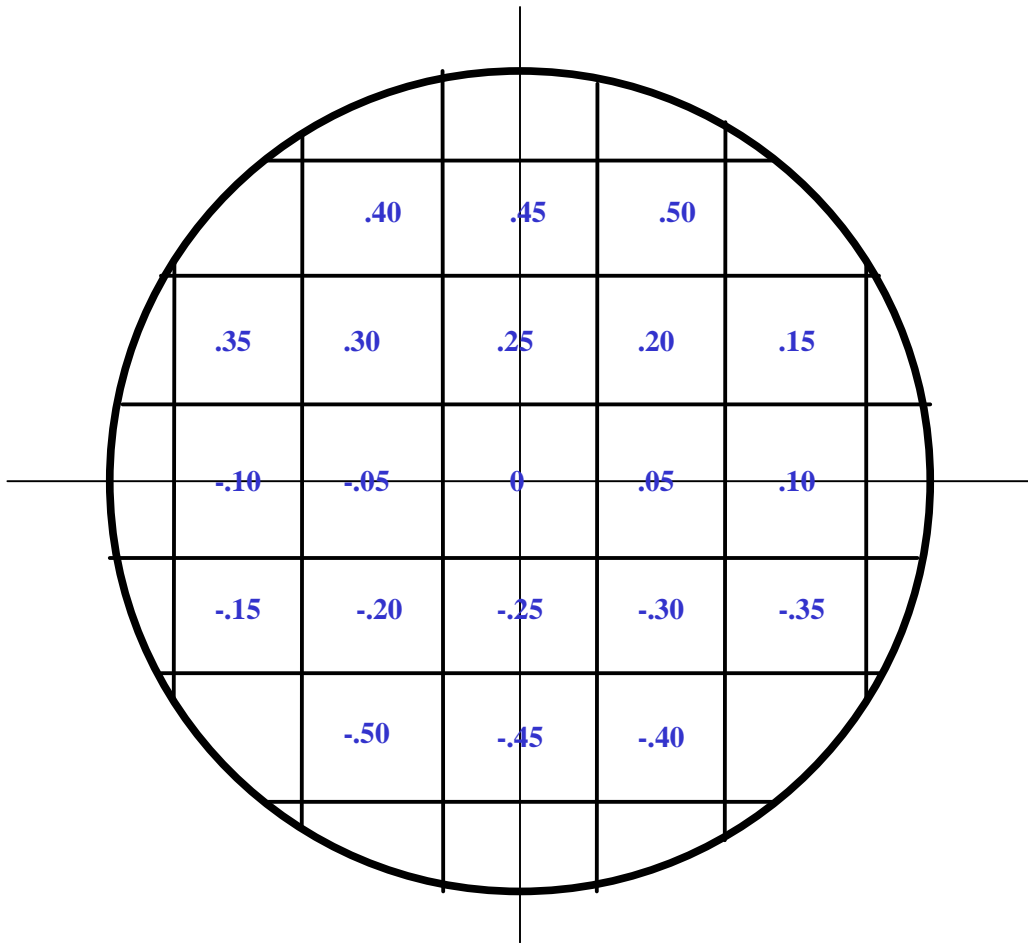


Figure 19: Focus Matrix Layout

Focus changes from  $-0.50 \mu\text{m}$  to  $0.50 \mu\text{m}$  in steps of  $0.05 \mu\text{m}$ . Alternatively you can choose focus range of  $-1.0 \mu\text{m}$  to  $+1.0 \mu\text{m}$  in steps of  $0.10 \mu\text{m}$ .

Aberrations generated by a Stepper (Step and Repeat Systems) are symmetric and radial in nature. Metrology time can be conserved by measuring patterns located on irregular arrays as shown below. However, if you have the time we recommend sampling all the locations in the field.

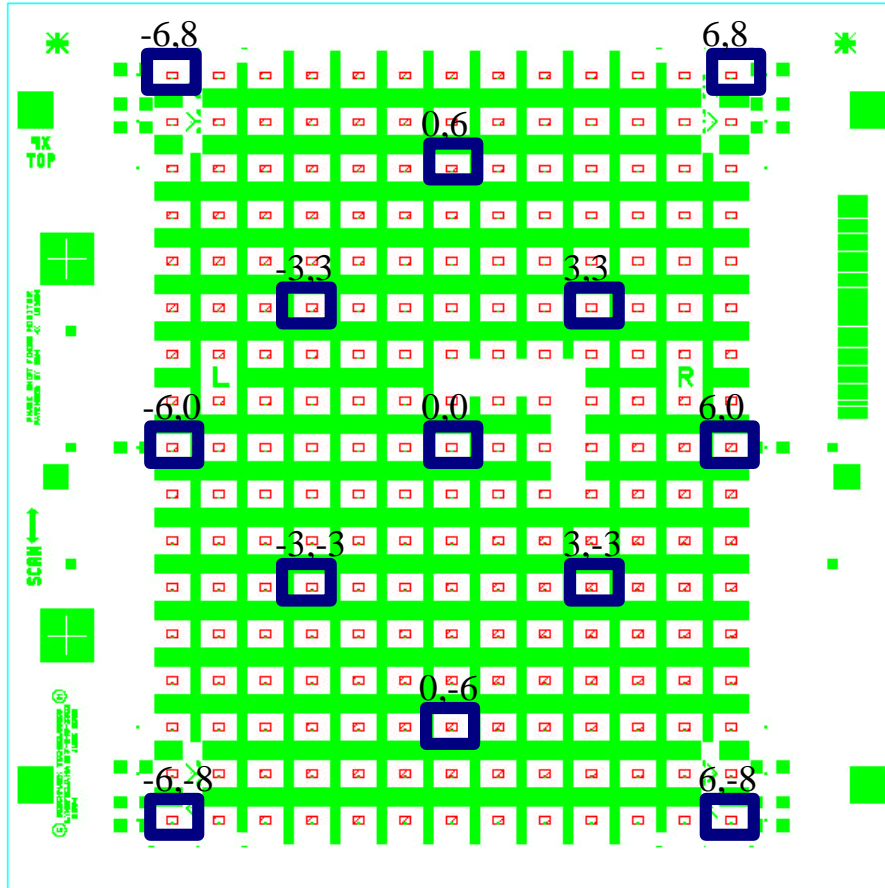


Figure 20: Recommended Measurement Location for a Quick Analysis of Steppers (radial sampling)

Aberrations generated by a Scanner (Scan and Repeat Systems) occur along Cartesian axes. This is because the lens aberrations are restricted to the horizontal slit. The slit is then scanned vertically. Metrology for a Scanner therefore should maximize the sampling locations along rows and columns as shown below. However, if you have time we recommend sampling all locations in the field.

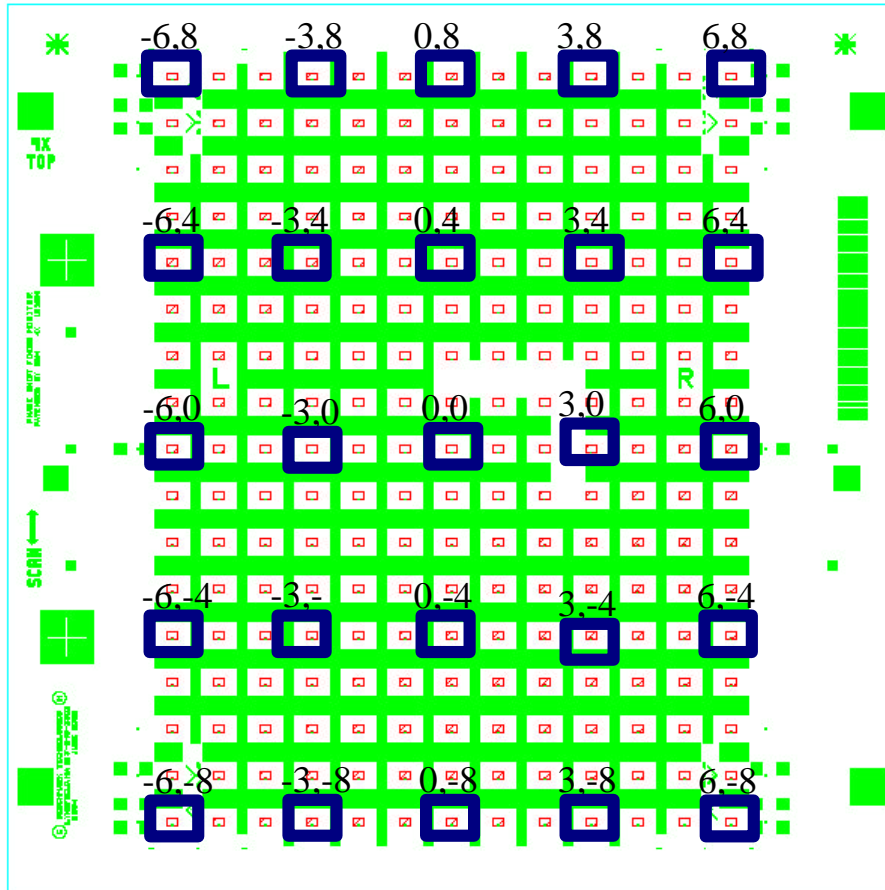


Figure 21: Recommended Measurement Locations for a quick analysis of Scanners (Cartesian Sampling)

## ***Analysis***

Please send the data to Benchmark Technologies for analysis of data. We will use TEA's 'Weir Software' for analyzing the data. There are several results which are generated using this test which are briefly summarized here.

1. *Calibration Line* (Overlay offset versus Focus) for every point in the reticle. This data will be used in 'Day 3: Finding Wafer/Chuck Characteristics
2. *Best Focus, Stage Tilt X&Y* evaluated from the best average plane fit through all measured data points.
3. *Lens Astigmatism* at every point in the field. Evaluated from difference in X versus Y offset (of the box in box pattern)
4. *IFD (Image Field Deviation)* is the focus residual left after removing best focus and stage XY tilts which are correctable components of the image focus. IFD is essential a fingerprint of lens focus aberrations.
5. *Scanner Slit Curvature*
6. *Scanning Stage Curvature*

## Day 3: Finding Wafer / Chuck Characteristics

### Data Collection

Expose a wafer at fixed focus and exposure as shown below. Choose the best exposure and best focus which you calculated on Day 0 and Day 1. Select a field size that exposes the entire exposure area of the lens. Make sure all dies to the edge of the wafer are exposed as shown below.

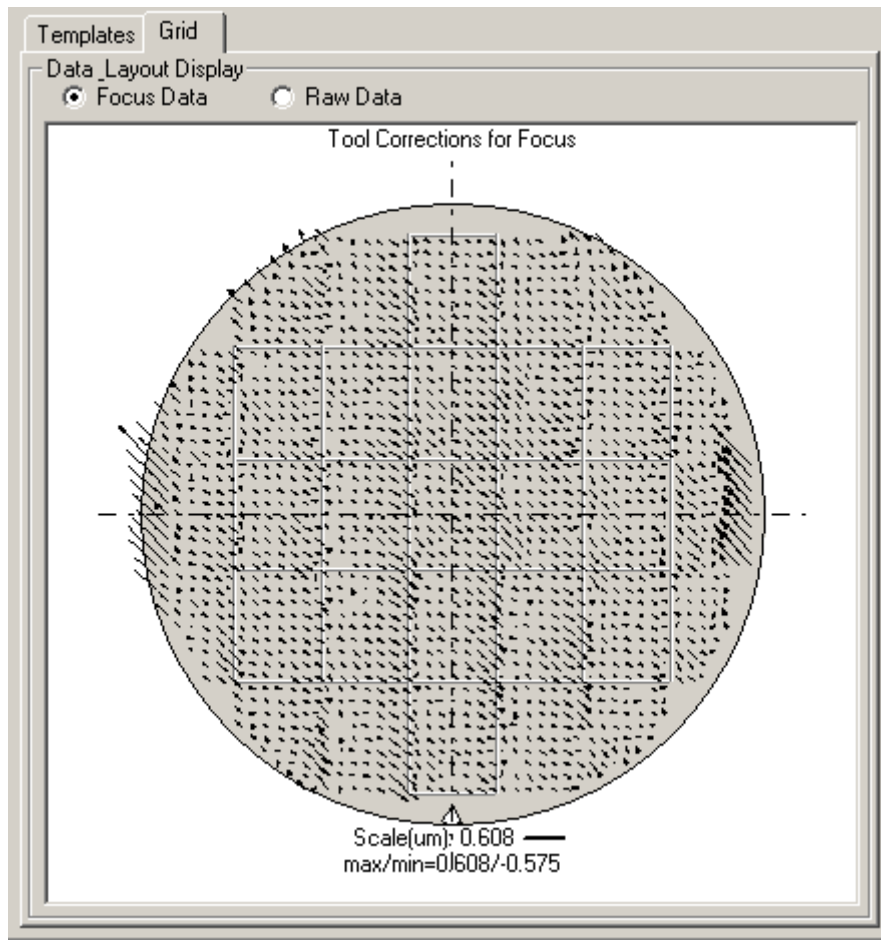


Figure 22: Collecting Entire Wafer Data

Collect overlay data for all points in the field all the way to the edge of the wafer.

## ***Analysis***

Please send the data to Benchmark Technologies for analysis of data. We will use Weir PSFM Software for analyzing the data. There are several results that will be generated using this test which are briefly summarized here.

1. *Wafer Piston and Wafer tilt X&Y*. The software has a proprietary method to isolate tilt contributions by wafer/chuck versus reticle/platen.
2. *Wafer Bow, Wafer Trifoil, and Wafer Pentode*. 300 mm wafer process effects often cause higher order wafer overlay aberrations (3<sup>rd</sup> order aberrations, such as Somberero effect, are sometimes noticeable). These can be modeled using the software.
3. *Wafer Edge Effects*. Obtained by comparing edge dies to center dies
4. *Stage Stepping Direction Effects*. Obtained by comparing alternate rows.
5. *Slit Scanning Direction Effects*. Obtained by comparing alternate dies.
6. *Lens heating effect during wafer exposure*. Obtained by comparing dies exposed in the beginning to those exposed at the end.