Functional tolerancing using full surface metrology

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Abstract

This paper highlights two examples of the use of full surface metrology to allow for functional tolerancing of components in the areas of Extreme Ultra-Violet (EUV) lithography (reticle characterization) and Deep Ultra-Violet (DUV) precision lens manufacturing (lens holder metrology). For both examples, the measurement of the full surface is a key enabler to understanding the critical characteristics to control and tolerance for functionality or performance. Interferometric techniques are used to provide high resolution and accurate measurements for both examples. Subsequently, this data can be used to identify the features of the surface characteristics that contribute to the end functionality and provide a means for deterministic correction or compensation.

functional tolerancing, full surface metrology, EUV, lens cell assembly, DUV, photomask, reticle

1. Introduction

For decades, progression of technology in many fields such as semiconductor electronics, communications, automotive, alternative energy, and aerospace and defence have traditionally pushed manufacturing with continuous tightening of tolerances on component fabrication. System-level error budgets allow smaller allotments to subsystems and components, frequently resulting in tolerance reductions on components. In many instances, these tolerance reductions are comprehensive and add significant stresses to cost and manufacturability. Intelligent review of a component's tolerances can determine which features (size, shape, surface finish, etc.) are important for functionality; provided those features can be well-characterized, increased effort in manufacturing or assembly can be used to meet stricter system level requirements without tighter tolerances.

2. Case I: EUV Photomask Overlay Compensation

With the transition to reflective lithography for the use with extreme ultraviolet (EUV) light in scanner systems, including the use of electrostatic chucking, the surface form of the reticle now has a direct and significant impact to the wafer's resulting overlay. Flatness errors resulting in degradation to the overlay performance are characterized as either in-plane distortions (IPD) or out-of-plane distortions (OPD) [1].

To meet the current overlay budget for the 13 nm node, reticles would require 8 nm P-V flatness in order to achieve the final 1.4 nm overlay. This level of flatness is lower than the industry is currently able to consistently produce. The implementation of flatness compensation, either at reticle write or at the scanner, has the potential to alleviate these single digit specifications.

The methodology outlined in this case utilizes the current industry standard for reticle measurement [2], but proposes the use of compensation methods to increase overlay performance without having the added cost of reticles polished to single digit nanometres. With the adoption of such a scheme we show that it is possible to use current levels of reticle flatness and still achieve final overlay requirements.

2.1. Proposed Flatness Methodology

In the case of write compensation, blank flatness data is fed-forward to the reticle write tool and the pattern is shifted to offset the flatness related errors. In the case of scanner corrections, the flatness of the reticle post-write is corrected by translation of stages within the scanner system itself [3].

The algorithm developed in this study was used to determine the level of flatness that can be tolerated and still meet the specified overlay requirements (**Figure 1**). Key factors taken into consideration for the final compensation algorithm used in our predictive analytics are as follows.

- Reticle bending during clamping including location of neutral surface, backside slope calculation method, clamping forces, and opportunity for torsion
- Spatial frequency transfer from reticle backside to frontside during clamping (referred to as "backside bandpass")
- Gravity compensation methods for vertical free state reticle blank measurement
- OPD contribution from non-telecentricity of scanner as well as differences in slit geometries
- Polynomial fitting of clamped reticle flatness as it relates to write tool and scanner correction capabilities
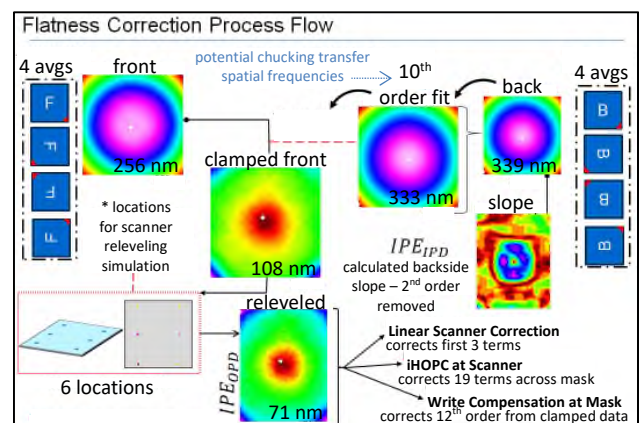

Figure 1. Flatness compensation capability proposed analysis.

By segmenting the reticles shape into correctionable and non-correctionable components, it is then possible to identify topographies which must be addressed by process development vs. those which can be compensated for using current correction capabilities.

2.2. Survey Results

Using a survey of production photomask blanks, we evaluated the image placement budget under the current specifications, and those same blanks image placement performance with the implementation of a compensation scheme(**Figure 2**) [4].
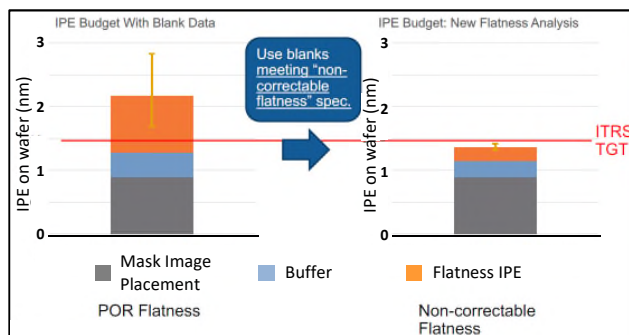

Figure 2. Survey of blanks failing current flatness spec vs. same blanks with compensation applied (residual "non correctable" flatness graphed on right).

3. Case II: DUV Lens Cells/Opto-Mechanical Assemblies

Optical performance of DUV lithography or inspection lenses often have strict requirements on RMS wavefront errors and wavefront asymmetries. Manufacturing of lens holders (cells) and assembly of the components into the final assembly often introduce stress into the optical components which can adversely affect wavefront errors or birefringence, even with micrometer-level tolerances. Standard methods for alleviation to the stress and strain in a lens cell assembly can include kinematic flexure mounts, compliant adhesives, or tighter tolerances on the lens holder geometries. These methods often involve additional or expensive manufacturing steps or complex assemblies which ultimately contribute added cost.

This case describes a methodology for using full surface interferometric measurements of the mechanical surfaces of the lens cells to minimize the resulting stress and strain of the completed opto-mechanical assembly [5]. Full surface measurements of the mating surfaces of cells at the time of manufacture provide a prescriptive assembly procedure for meeting system level specifications without a decrease in tolerance of the component.

3.1. Proposed Methodology

Specifications of the mechanical cells are traditionally prescribed as maximum deviation such as Total Indicator Runout (TIR), which as a single scalar value lacks any potential for functional tolerancing. Using the full surface measurement data, information related to the low order shapes can be quantified and complimentary components selected for mating surfaces, ultimately minimizing the systems strain (and resulting wavefront error). In many cases this allows for the relaxation of mechanical component specifications and reducing costly testing and rebuild time.

Topographic information of the mating surfaces is collected by measuring each components face using a large aperture, grazing incidence Fizeau interferometer. The results are then filtered using Fourier transform, Zernike polynomials or some

combination of both to extract the low order errors of each contacting surface. In an initial survey of cell surfaces it was found that the most common low order topographic errors were two-lobe, three-lobe, and radial taper. From this data, the coefficients of the mating surfaces are calculated, and their appropriate phase changes (rotations) prescribed; in essence nesting the surfaces in a fashion which minimizes the resulting strain transferrable to the final system assembly (Figure3).
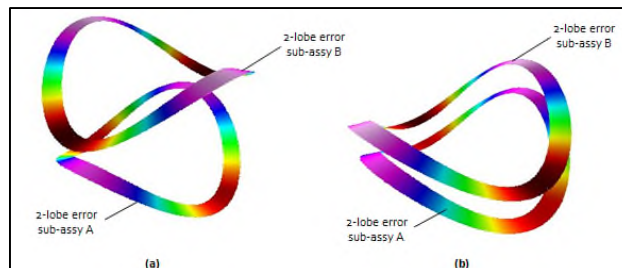

Figure 3. (a) Interferometer results showing non-optimal rotation 2-lobe form errors of subassembly A and B and **(b)** optimal rotation results of subassembly A and B. **(b)** shows the "nesting" of the errors on the sub-micrometer level to minimize strain transfer to the optical elements.

3.2. Results

A lens assembly with 16 mechanical components is first assembled with random orientation (clocking) of the mechanical components and then again after the mechanical cells are characterized using the method described above. The transmitted wavefront is measured after both build iterations using a bespoke DUV interferometer where the imaging performance can be characterized for RMS errors in addition to a number of standard Zernike estimates for optical path deviations (OPD) from a perfect spherical wavefront. **Table 1** below shows the improvement in RMS and astigmatic performance from use of deterministic alignment of the imperfect mechanical surfaces of the lens holders without any improvements made to optical or mechanical tolerances.

Table 1. RMS and astigmatic OPD improvement from measurement method

	RMS OPD	ASTIG OPD
random cell clocking	4.7 nm	4.4 nm
deterministic cell clocking	2.8 nm	1.8 nm

4. Conclusion

Two examples of full surface metrology for functional tolerancing of flatness for EUV reticles and lens holder assemblies are given. Both examples exemplify the use of measurement analysis to support next generation applications while avoiding tighter tolerances. Understanding the important characteristics for functionality and applying deterministic compensations or corrections are sufficient for system-level improvements.

References
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