CHUCK INDUCED DEFORMATIONS IN EUV MASK SUBSTRATE METROLOGY

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INTRODUCTION
Specifications for photomask blanks for extreme ultraviolet lithography (e.g., SEMI spec P37-1102 [1]) call for flatness and thickness variations as low as 30 nm peak to valley. These photomask blanks are ~ 150 mm square and 6.25 mm thin, frequently made from fused silica or other low expansion materials. The area of the mask reserved for handling is limited to a narrow band, typically less than 5 mm wide outside a defined “quality area.” The flatness specifications apply to an “unconstrained” substrate; hence the metrology must be performed either:

- Using a chuck that introduces deformations which can be absorbed in the measurement uncertainty budget (a few nm (k=1)); or
- With subtraction of the chuck induced deformations, which must therefore be repeatable and amenable to validation.

We have adopted the second option in a metrology tool for automated measurement of masks. After a brief description of the salient features of the tool, we describe a method for separating chuck induced errors from mask blank flatness.

RETICLE FLATNESS METROLOGY TOOL
Figure 1 is an overview of the tool. The optical system comprises a 100 mm nominal aperture laser Fizeau interferometer which feeds an in-line 100-225 mm beam expander. Standard 300 mm transmission and return flats (TF, RF) are in custom, ISO Class 1 clean room compatible mounts on a Z-axis rail to allow cavity length to be adjusted as required. The optical axis of the system is tilted 2 degrees from horizontal.

Reticles to be measured are removed from the SMIF pod by the robot and placed, horizontally, on the reticle frame. The frame rotates and then slides between the TF and RF so that the surfaces of the reticle are normal to the optical axis. In this configuration, a transparent reticle gives multiple interference patterns. The interferometer light source is tuned over a range of 150 GHz and, through implementation of Fourier Transform Phase Shifting Interferometry [2] (FTPSI), the instrument reports a number of parameters including surface flatnesses, wedge, index, homogeneity, thickness variation, and slopes. The dominant, time invariant sources of uncertainty in the flatness measurements are the calibrations of the TF and RF and the chuck induced deformations.

FIGURE 1: Overview of metrology tool (top) and close up (lower) showing the robot loading a reticle blank

TF AND RF CALIBRATION
The TF and RF are calibrated using an N-position areal 3-flat test[3,4]. A third kinematically mounted flat, capable of rotation about its optical axis, can be used as either the TF or RF. The calibration is performed in-situ to
eliminate uncertainties associated with remounting the flats.

A simple, routine, sanity check of the calibration is to sum the calibration files for the TF and RF and subtract from an independent measurement of the cavity. Figure 2 shows the results of one such test, clearly characterized by a L-R flip error leading to LR anti-symmetry in the (very small) difference.

FIGURE 2: Calibration check; difference is 1.1 nm PV, 0.14 nm rms

RETICLE FEA

In the measurement position, the reticle is supported on two points located on the edge of reticle (and in front of the center of gravity) and on 3 points outside the quality area on the back. There is an additional location on one of the vertical edges (Figure 3) to maintain a repeatable mounting location. The predicted deformations are symmetric, and show very little difference between “front” and “back” surfaces (Figure 4).

FIGURE 3: Reticle frame (chuck) showing constraint locations

FIGURE 4: Predicted (16.7 nm PV) chuck induced deformations over the test aperture (top) and the difference (lower) between predicted deformations of front and back surfaces (0.7 nm PV).

The problem with simply subtracting the predicted deformations arises from the part aspect ratio (~25:1) and the support locations. Small differences between the modeled and actual contact conditions result in differences in deformation that exceed the target measurement uncertainty.

MEASUREMENT OF DEFORMATIONS

An obvious approach to separating chuck induced deformations from the real part surface is to invoke the same kind of algorithms that were used to calibrate the TF and RF. Lindquist et al[5] considered chuck induced deformation in the measurement of reticles using an Abramson interferometer. They use three measurements of the reticle at 0, 90° and 180° – plus matrix flips and rotations in the manner of Ai et al[6]. This process has different error propagation than a four position test[3], but the same blindness to rotationally invariant terms and to terms that are harmonic in 4kθ, where k is a positive integer.

Clearly, we can make 4 measurements of the reticle in a conventional 2 surface Fizeau
geometry, rotating $90^\circ$ between measurements. The average of these four measurements contains the chuck-induced error (or at least the repeatable portion thereof), plus any rotationally invariant and $4k\theta$ flatness errors in the reticle.

It may be reasonable to argue that a 3 point chuck (plus edge supports) is unlikely to produce a $4\theta$ term in the part; it is less easy to argue that no quadratic term (or any other term symmetric about the center of the part) can be produced.

Using FTPSI, we measure independently the cavity between the TF and the first surface of the reticle and between the second surface of the reticle and the RF. Now, consider the case where two measurements are made with the reticle reversed (about a line perpendicular to the optical axis) – as shown very schematically in Figure 5. As measured in the two cavities, the sign of the figure error of the reticle does not change (for the sign convention that the OPD increases for decreasing gap between the “reference” surface and the reticle surface). The chuck induced deformations, however, have opposite signs in the two cavities. Hence – in 2 dimensions -- this looks like a classic reversal[7]; in practice, the reticle coordinates are flipped about either X or Y. As implemented in the tool at Zygo, the flip is about the Y axis.

The TF and RF are calibrated separately. We assume:
- The chuck design provides repeatable locations and forces;
- The reticle is symmetric (in terms of mechanical properties) about the optical axis; and
- The measured surface error of a reticle is well described as a linear superposition of its “freeform” shape and the chuck induced form errors.

Now we can perform the four position test as discussed above and get an estimate ($E_1$) from the TF/reticle cavity of the chuck induced deformations:

$$E_1 = \frac{1}{4} \left[ (TF + P) + (TF + P_y) + (TF + P_{xy}) + (TF + P_{xy}) \right] - TF_{cal}$$

where $P$ refers to the reticle (part). After reversing the reticle we get a second estimate ($E_2$) from the reticle/RF cavity:

$$E_2 = \frac{1}{4} \left[ (RF + P) + (RF + P_y) + (RF + P_{xy}) + (RF + P_{xy}) \right] - RF_{cal}$$

where the prime ‘ indicates the flip. Hence:

$$E_2 = PRI + P4k\theta(x,y) - \text{chuck}$$

The chuck induced errors change sign because of the sign convention used. The half the difference ($(E_1-E_2)/2$) gives the chuck induced error including only those $4k\theta$ terms in the reticle which are not symmetric about the flip-axis:

$$\frac{E_1 - E_2}{2} = PRI + P4k\theta_{odd}(x, y)$$

FIGURE 5: Schematic of the reversal showing a reticle with a quadratic error with higher order chuck induced errors superimposed.

An alternate algorithm (derived from [3]) rotates the data sets back to their original orientation, averages, and then subtracts from data taken at the original orientation. This has the effect of setting the $4k\theta_{odd}$ term in the estimate of the chuck error to zero. In practice, the asymmetric $4k\theta_{odd}$ terms are negligible.

RESULTS

Figure 6 shows the measured “quality” area from two surfaces of a reticle. Figures 7 and 8 show two evaluations of the chuck induced deformations made using two different reticles with significantly different surface shapes. The rms of the difference between these maps is 1.02 nm. Differences between repeated maps of
the chuck induced deformations made using the same reticle are within 0.4 nm rms.

Figure 9 shows the difference between the predicted and the measured chuck induced deformations based on the average of 4 evaluations using 2 different reticles. We fit the data of Figure 9 to a quadratic (2nd order Legendre polynomial) which we used to correct the predicted chuck induced errors. The unfit residual from this procedure is 0.5 nm rms and is easily identified as arising from shearing the high slopes at the edge of the reticles used.

SANITY CHECKS?
Procedures involving manipulating multiple data sets to generate correction files always carry with them the risk of, for example, a sign error which results in highly repeatable but biased results. In this case, there are two simple sanity checks.

FIGURE 6: Surfaces of one of the reticles used in evaluating the chuck induced deformations

FIGURE 7: Estimated chuck induced deformations

FIGURE 8: Estimated chuck induced deformations

FIGURE 9: Difference between measured and modeled chuck induced deformations
First, if all the calibrations are correct, a simple flip test (where the part is measured sequentially with respect to the TF and RF) should give the same result. Figure 10 shows the standard deviation (pixel by pixel) for 8 such flip tests taken after the tool was installed at the customer’s site. The consequence of the high velocity downward air flow in the test cavity is all too apparent. Despite this, the mean of the standard deviation map is 1.03 nm.

A second, somewhat fortuitous, sanity check is the measurement of a reticle with surface flatness errors of the same order of magnitude as the chuck induced errors (Figure 11). Clearly, there is no suggestion in this data of the characteristic shape of the modeled chuck induced deformations or of the experimentally derived correction to it.

CONCLUDING REMARKS
The specifications for the flatness metrology tool briefly described in this paper included a requirement that no contact be made with either surface of the reticle within the “quality area”. One design goal was that the chuck induced deformations be highly repeatable, so that they could be subtracted from the raw measurement result.

This paper has presented a simple procedure for separation of the chuck induced errors from the “freestanding” surface flatness errors. The measurements confirm that small differences between the assumed and actual contact conditions lead to large differences between modeled and measured chuck deformations. These improved assessments of the chuck induced deformations were necessary to meet the target uncertainty in measuring reticle flatness (as specified in [1]) less than 12 nm (k=2).

REFERENCES