A method of utilizing AIMS™ to quantify substrate / attenuator over-etch or under-etch during mask repair

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ABSTRACT

The ZEISS AIMS™ platform is well established as the industry standard for qualifying the printability of mask features based on the aerial image. Typically the critical dimension (CD) and intensity at a certain through-focus range are the parameters which are monitored in order to verify printability or to ensure a successful repair. This information is essential in determining if a feature will pass printability, but in the case that the feature does fail, other methods are often required in order to isolate the reason why the failure occurred, e.g., quartz level deviation from nominal.

Atomic force microscopy (AFM) is typically used to determine physical dimensions such as the quartz etch depth and sidewall profile. In addition the AFM is a useful tool in monitoring and providing feedback to the repair engineer, as the depth of the repair is one of the many critical parameters which must be controlled in order to have a robust repair process.

Carl Zeiss, in collaboration with Photronics-nanoFab, demonstrate the ability to use AIMS™ to provide quantitative feedback on a given repair process; beyond simple pass/fail of the repair. Using the ZEISS MeRiT® repair tool as the example, the AIMS™ technique is used in lieu of an AFM to determine if repaired regions are over-etched or under-etched; and further to predict the amount of MeRiT® recipe change required in order to bring subsequent repairs to a passing state.

MeRiT®, AIMS™, mask repair, defect repair, electron beam repair, repair yield

1. INTRODUCTION

AIMS™ is an indispensable tool for defect printability verification [1]. AIMS™ is used in manufacturing for repair verification and more specifically to determine whether or not MeRiT®-based etch or deposition repairs meet specification. The key AIMS™ plots used for repair analysis are the “Intensity Profile”, “Linewidth vs. Threshold” and “Linewidth vs. Defocus”.

An important point in AIMS™ analysis is to not only look at the results for the best focus plane but also to take into consideration the through-focus behavior. The “Linewidth vs. Threshold” plot is the primary indicator of whether a repair meets specification in each focal plane. However, if the result is out of spec the question remains; is it due to CD (lateral edge placement) of the repair or, in the case of an opaque repair, is it due to the etch depth (over-etch or under-etch)? In order to answer this question we look to the “Linewidth vs. Defocus” or Bossung plot, paying particular attention to the slope of the indicated linewidth (at target threshold) through the measured focal planes.
In this paper a technique for using the slope of the AIMS™ Bossung plot to evaluate the condition of a repair as it relates to etch depth is demonstrated. Analyzing data from four MeRiT® repairs with varying etch depths; an approximate linear correlation is established between the Bossung slope and the repair etch time. Further, from this established correlation the ideal repair time can be calculated to produce a repair with optimum through focus performance.

It should be noted that for the purposes of this experiment the end-pointing function of the MeRiT® has been disabled allowing for etches strictly based on time. The focus of the experiment is to demonstrate the technique for AIMS™ analysis of a repair and is not intended to suggest new or different repair processes for the MeRiT®.

2. Repair etch series to demonstrate analysis method and predict optimum repair process parameters

![Figure 1: Example showing pre- and post-repair SEM images for one of the programmed defect etch repairs performed in this experiment](figure)

In order to demonstrate the ability to predict the optimum repair process parameters, namely the etching time required, a series of programmed defects were etched with the MeRiT® as shown in Figure 1. The test mask is standard MoSi Embedded Attenuated Phase Shift Material (EAPSM) and the pattern is a basic line/space array with an approximate 220nm linewidth and 1:1 pitch.

As with any etching tool, a longer etch time on the MeRiT® corresponds to a deeper etch. The series of etch repairs for this experiment was started with an excessively long etch time in order to provide a known over-etch into the quartz substrate as a baseline. The etching time was incrementally decreased with each successive repair until an under-etch was reached, leaving excess attenuator material in the repair area.
Test condition 1: 280 Seconds – Known over-etch condition

AIMS™ analysis of the first test condition clearly shows a non-optimal repair. As can be seen in the “Linewidth vs. Threshold” plot (lower right pane), the repair shows poor through-focus behavior; most easily noted by the lack of an iso-focal point in the curve. Information the “Linewidth vs. Threshold” plot does not provide in a true production case is whether this is an over-etched or an under-etched repair, hence the need to look further into the AIMS™ data for more information. Shifting attention to the “Linewidth vs. Defocus” plot (lower left pane), it can be seen that the target threshold line (center black line) shows an upward (positive) slope from left to right; this is the indicator to monitor throughout the remaining test series.

Test condition 2: 240 seconds

Figure 3: Screenshot of AIMS™ 4-plot analysis for test condition 2
For test condition 2 the MeRiT® repair was performed again, this time with a reduced etch time. AIMS™ analysis shows similar results to test 1, in that there is no clear iso-focal point defined in the “Linewidth vs. Threshold” plot and there is still an upward slope to the central line in the “Linewidth vs. Defocus” plot. However, the key difference to note for test 2 is that the steepness of the slope depicted in the “Linewidth vs. Defocus” plot is reduced from that in test 1.

Test condition 3: 200 seconds

![Figure 4: Screenshot of AIMS™ 4-plot analysis for test condition 3](image)

The MeRiT® etch time was again reduced for test condition 3. AIMS™ analysis shows that the etch time is closer to that required for a perfect repair and thus closer to producing an iso-focal point in the “Linewidth vs. Threshold” plot. Even more notable is that the central line in the “Linewidth vs. Defocus” plot now has a reversed slope (negative) from the previous two etches and trends down from left to right.

Test condition 4: 190 seconds – Known under-etch condition

![Figure 5: Screenshot of AIMS™ 4-plot analysis for test condition 4](image)
For the fourth test condition the MeRiT® etch time was again reduced, creating a known under-etch condition. AIMS™ analysis shows that the “Linewidth vs. Threshold” plot moves farther away from a defined iso-focal point. Also, from the “Linewidth vs. Defocus” plot, it can be noted that the steepness of the downward slope of the central line has increased from that seen in test 3.

Extraction of the raw data from each of the “Linewidth vs. Defocus” plots in the test series was performed and confirms that the slope of the target threshold line does provide good correlation to the given etch condition.

A comparison of the slopes of each of the four test etches from Figure 6 shows the following correlation:

1) 280 seconds = slope coefficient of 7
2) 240 seconds = slope coefficient of 4
3) 200 seconds = slope coefficient of -3
4) 190 seconds = slope coefficient of -5

Figure 6: Summary of “Linewidth vs. Defocus” target threshold curves. For each etch time, the linewidth vs. defocus data for the targeted CD was plotted for comparison.
Plotting the slope coefficients extracted above with their respective etching times provides the graph shown in Figure 7. The linear regression trend line can now be used to predict the required etching time for the theoretically optimum repair. The ideal slope of the Bossung plot is 0 in this case therefore, setting the equation equal to 0 and solving for x provides this nominal etch time. An etch time of 222 seconds is calculated with the following equation:

\[
\frac{30.069}{0.1355} = 222 \text{ seconds}
\]

3. MeRiT® optimum repair based on predicted etch time

To test the proposed method for predicting an optimum repair, a final test was performed on the ZEISS MeRiT® using the etch time derived from the linear equation above (222 seconds). To have an optimized repair a clearly defined iso-focal point in the “Linewidth vs. Threshold” plot should be evident, as well as a zero slope condition in the “Linewidth vs. Defocus” plot.

Test condition 5: 222 Seconds

Figure 8: Screenshot of AIMS™ 4-plot analysis for test condition 5
Figure 8 and Figure 9 confirm the expected results of an optimized repair yielded from the predicted MeRiT® etch recipe. A clearly defined iso-focal point in the “Linewidth vs. Threshold” plot indicates a successful repair and a near zero slope in the “Linewidth vs. Defocus” plot indicates the repair depth correlates well to the nominal quartz level.

4. Reproducibility

To be viable in production the technique must be reproducible, so in order to demonstrate reproducibility a second MeRiT® etch series was completed. This second series was conducted on a different test reticle; utilizing the same attenuator material, however the pattern used for this test was a vertical line/space array. The same sequence of etch times was used; 280 seconds, 240 seconds, 200 seconds and 190 seconds.
Figure 11: Summary of test sequence #2 “Linewidth vs. Defocus” target threshold curves. For each etch time, the linewidth vs. defocus data for the targeted CD was plotted for comparison.

Figure 11 demonstrates that the slope of the threshold curves display the same trend as seen in the first test sequence which utilized the horizontal line and space features. The slope reverses between the 240 second etch and the 200 second etch just as in the first test, again indicating that the proper etching time lies somewhere in between.

Again comparing the slopes of each of the four etches from sequence #2 we establish the following correlation:

1) 280 seconds = slope coefficient of 4
2) 240 seconds = slope coefficient of 3
3) 200 seconds = slope coefficient of -2
4) 190 seconds = slope coefficient of -4

Figure 12: Trend plot for sequence #2 etch time vs. slope coefficient

And solve the linear equation for slope = 0
20.034 / 0.0892 = 225 seconds

Comparing results for optimum etch time between test #1 and test #2:

- Test #1 = 222 seconds
- Test #2 = 225 seconds
- Delta < 1.5%

While the vertical pattern in the second etch test yielded slightly different slope coefficients, the data extracted from the slopes of the Bossung plots of the two etch series provided a nominal etching time within 3 seconds of each other (<1.5% difference). This is well within the acceptable process window for a successful etch repair as demonstrated by the etches performed with these calculated times. These results demonstrate the reproducibility of the technique, therefore validating its usefulness in a production environment.

5. Conclusion

Carl Zeiss together with Photronics-nanoFab have successfully demonstrated the ability to use the AIMS™ “Linewidth vs. Defocus” or “Bossung” plot as an indicator of repair over-etch or under-etch condition. It was demonstrated that there is an approximate linear correlation between etch depth and slope of the Bossung plot and further, this linear correlation can be used to accurately predict an etching time which yields a fully optimized repair. The technique is also shown to provide reproducible results on varying pattern types.

While the technique was demonstrated using the ZEISS MeRiT® as the test repair platform, the concept applies to all methods of mask repair, where opaque material is being removed. Anecdotally, a similar linear response has been observed and is expected for MeRiT® deposition repairs. Testing is currently underway to validate these observations.

From a process development and process control perspective, the technique promises to offer significant benefits. New repair process development time could be greatly reduced, due to a minimized number of DOE repairs required; along with a diminished need for AFM feedback. Additionally, established process monitoring and control will benefit from trend analysis of the Bossung plot slope, allowing for tighter repair process control and more accurate steering to counteract possible process drift.

References

[1] “An advanced study for defect disposition through 193nm aerial imaging”, Arndt C. Duerr, Axel M. Zibold, Klaus Boehm, Advanced Mask Technology Center (AMTC), Raehnitzer Allee 9, 01109 Dresden, Germany, Carl Zeiss SMS GmbH, Carl-Zeiss Promenade 10, 07745 Jena, Germany
