Single Pass Die to Database Tritone Reticle Inspection Capability

Bryan Reese, KLA-Tencor Corporation, Austin, Texas, USA
Jan Heumann, AMTC, Dresden, Germany
Norbert Schmidt, KLA-Tencor Corporation, Dresden, Germany

ABSTRACT

Tritone reticle designs present many challenges for both photomask manufacturers and defect inspection equipment suppliers. From a fabrication standpoint, multi-write and process steps for tritone layers add levels of complexity and increased cost not encountered with most traditional binary (two tone) masks. For inspection tools, the presence of three distinctive light levels presents a challenge for algorithms originally designed to inspect gray scale data between two tones (black and white): especially for database transmitted light modes.

While most die-to-die and STAR*light*™ inspections on tritone reticles produce successful results using binary algorithms, database inspections typically require two separate recipes to reveal all lithographically significant defects. With this dual-inspection technique, DNIR (Do Not Inspect Regions) are often added to eliminate the presence of third tone (typically Chrome) features: a process that adds considerable time to recipe creation. Additional workarounds when using binary inspection algorithms include implementing special light calibration techniques during setup in an effort to minimize nuisance defects caused by the presence of a third tone.

As a result of these workarounds, reticle throughput is either reduced or sensitivity compromised when using binary database inspection algorithms on tritone reticles. This paper examines the benefits of using a tritone database inspection algorithm from both productivity and sensitivity standpoints as compared to results obtained from using the aforementioned workarounds and existing binary inspection modes. The results and conclusions contained within are based on data obtained from standard test vehicles and a variety of tritone production reticles.

Keywords: tritone, reticle, database, inspection

MOTIVATION FOR STUDY

Using conventional binary database patterns to inspect tritone reticle images presents an obvious data discrepancy. Unlike a die-to-die tritone inspection where both Reference & Test images each contain three distinct light levels, database inspections where reference data contains only two tones will produce an excessive amount of false defects. This outcome is especially true when inspecting 193nm EPSM reticles illuminated by 365nm or 257nm laser light sources. As a result, two main workarounds have been implemented by many mask suppliers over the past several years to circumvent this challenge.

The first technique to get around this issue involves using a DNIR (Do Not Inspect Region) placed around any chrome feature present in the IA (Inspection Area). By eliminating chrome patterns, the third tone is removed from the optical image allowing conventional binary database algorithms to be used. While this technique does eliminate the extra tone, the trade-off with this approach is two-fold. The first and most obvious concern is that any features within a DNIR border are not inspected. While most chrome structures of a simple tritone reticle appear only in the scribe and border locations, some chrome patterns may be part of the primary design and must be inspected to ensure they contain no defects.

The other trade-off to consider when using DNIRs is that the process of adding them to a recipe can be very time consuming. The extra steps needed to implement DNIR locations during recipe creation can reduce productivity. While some DNIR borders can be defined using offline database images, it is common practice to identify DNIR locations while the reticle is loaded on the Inspection Station. This method is often times preferred since the live

Photomask Technology 2006, edited by Patrick M. Martin, Robert J. Naber,
Proc. of SPIE Vol. 6349, 63493L, (2006) · 0277-786X/06/$15 · doi: 10.1117/12.686121

camera image (in transmitted light mode) clearly reveals the dark chrome patterns to include within the DNIR. However, this approach takes away valuable inspection time from the reticle inspection tool further impacting overall productivity.
The second workaround involves lowering the transmitted light level of the shifter material using Inspection Station software to create a pseudo-binary optical image. As indicated by the arrow in Figure 1A, shifter material normally produces a "gray" transmitted light level not present in conventional binary (two-tone) database images. Forcing the shifter light level to a lower (darker) value, as indicated by the arrow in Figure 1B, creates a pseudo-binary image compatible with dual-tone binary database patterns. The result of this "Modified Light Calibration" technique is that both shifter and chrome features appear dark when viewed with transmitted light. As such, no DNIRs are needed since both shifter and chrome features have nearly the same dark tone compatible with binary database patterns.

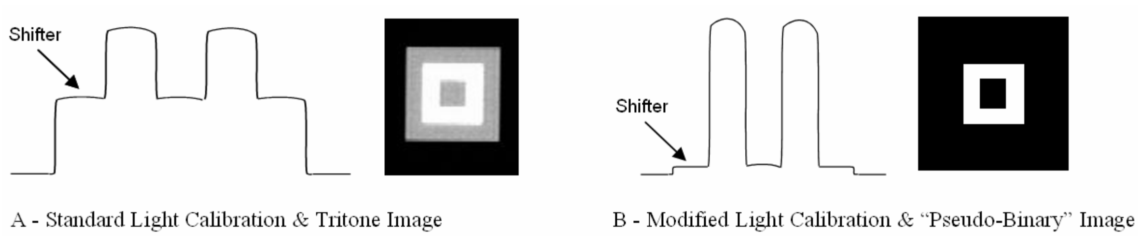


Figure 1 – Transmitted Light Profiles

The main disadvantage of this workaround is that there is a loss of sensitivity at the chrome and shifter interface. The lack of dynamic range between these two layers, as indicated by the arrow in Figure 1B, reduces image contrast to a point where defects, such as residual chrome on the shifter surface, are not detected. Other defect types not found using this workaround include residual chrome on shifter/quartz edges and chrome pinholes that expose shifter material.

Whether using the DNIR or Modified Light Calibration approach, there is an inevitable tradeoff in either throughput or sensitivity that must be addressed as part of any thorough inspection program. These limitations associated with using a binary database workaround to inspect tritone reticles require an additional inspection for either the DNIR areas or the shifter/chrome regions creating an overall dual-pass strategy. It is because of these limitations with either workaround that a single-pass tritone database solution was evaluated with the findings posted in this paper.

THEORY OF OPERATION

To implement the tritone database capability on the KLA-Tencor TeraScan™ (5XX Series) product line, two important changes were made. First, database images needed to differentiate the individual tones associated with first and second write level data preps. The second fundamental change was with the release of a new database algorithm that could process tritone pattern data to perform alignment, image calibration, and defect detection operations.

A conventional binary database image is shown in Figure 2A. Compared to a tritone reticle optical image (Test) in Figure 2B, the tone mismatch described in the previous section becomes quite apparent. However, when light levels for both first and second level write patterns are maintained, a database tritone (dbTt) Reference image can be created as shown in Figure 2C. This exact match between the dbTt (where "T" stands for transmitted and "t" for tritone) Reference data (Figure 2C) and tritone reticle optical image (Figure 2B) eliminates the need for either DNIR or Modified Light Calibration workarounds.

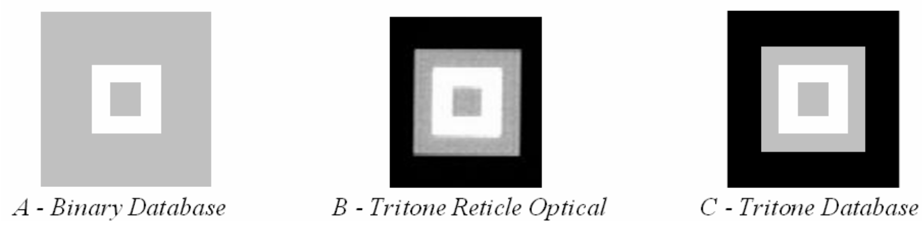


Figure 2 – Tritone Reticle Transmitted Light Images

Creating tritone Reference database images involves a two-stage dataprep process. To begin with, both 1st and 2nd level pattern files are prepped individually. As shown in Figure 3, these two independently prepped levels are then merged together to produce one tritone database pattern file using the KLA-Tencor TeraPrep™ system. The end result is a Reference database image containing three separate tones that can be directly compared to a tritone optical image.

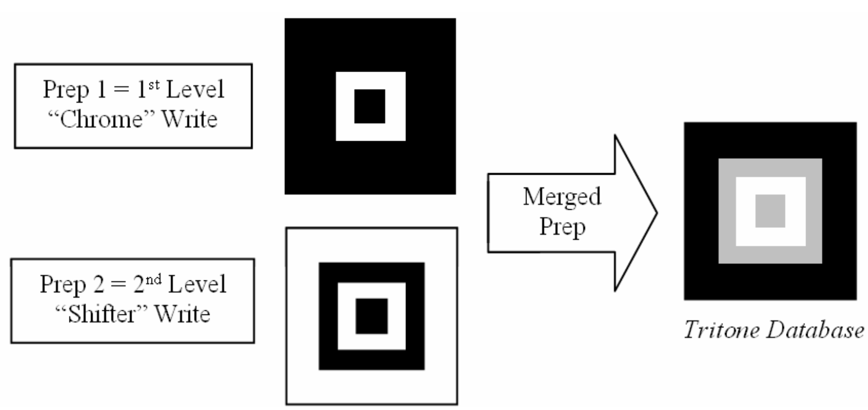


Figure 3 – dbTt Dataprep & Merge Process

In addition to changes in the dataprep system, a new tritone database inspection algorithm was developed. With this algorithm, a single-pass database inspection strategy for tritone reticles can be achieved. The dbTt algorithm performs bias and rounding routines similar in concept to the Image Calibration capability found on previous generation binary database algorithms to adjust the Reference image for process induced pattern changes.

Three new detector categories are introduced in the UCFdbTt45 algorithm to accommodate defect detection among three tones. The Hi-Res1 (pattern) detector includes the following new groups:

- Clear Chrome Edge: Cr/Qz edge detector
- Chrome Halftone Edge: Cr/MoSi edge detector
- Triple Point: detector for regions where Cr/MoSi/Qz patterns appear in the vicinity of each other

As with other algorithms, defects found during a dbTt inspection are sorted into various bin categories for Defect Review. A portion of the algorithm Setup menu showing the dbTt detectors is shown in Figure 4. Similar to other 5XX detector sliders, a threshold setting of 100 provides maximum sensitivity while a value of zero effectively disables that detector.

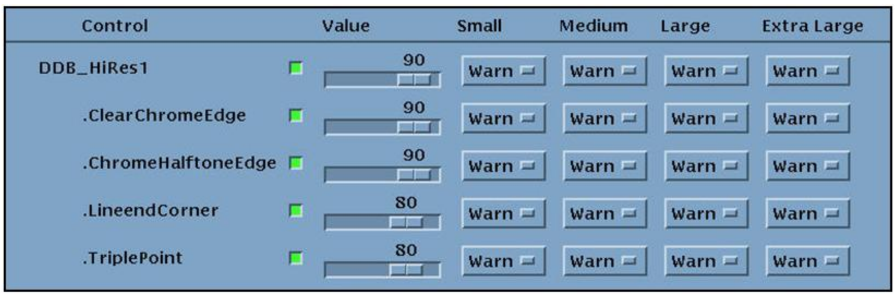


Figure 4 – Portion of the dbTt Algorithm Menu

EXPERIMENTAL

Evaluating the capability of the dbTt inspection mode was divided into two main sections: 1) test reticle performance and 2) production reticle performance. From these two study groups, both sensitivity and throughput measurements were obtained providing initial information regarding the performance of the dbTt mode.

Test Reticle Performance – Sensitivity Comparison
The SPICA200V6.2 is a test mask used to validate the sensitivity and false defect performance for the 150nm, 125nm, and 90nm views for 5XX pattern inspection modes. Since this 193nm EPSM (6%) tritone mask contains both Shifter/Quartz and Chrome/Shifter/Quartz programmed defect arrays, capture rate capabilities for both binary and tritone database inspection modes could be compared. In this paper, P125 and P90 inspection view performance was evaluated using both binary and tritone database modes.

Ideally, both binary and tritone database inspection modes should have the same defect capture rate. Theoretically, however, it is understood that there would be a slight loss of sensitivity with the dbTt mode. This phenomenon is due to the reduced dynamic range (less image contrast) inherent with any tritone inspection mode as depicted in Figure 1A. For both binary and tritone database modes, the P125 inspection view (125nm pixel size) was used to inspect the 320nm region of the SPICA200 mask while P90 (90nm pixel size) performance data was obtained from the 260nm test structures.

Production Reticle Performance – Throughput Comparison
For production reticle evaluation, two simple (no chrome in the active area) tritone masks were selected to measure the throughput advantage of single-pass dbTt performance as compared to results from both dual-pass binary database inspection strategies. As shown in Figure 5, the first case study uses a 65nm node tritone reticle to obtain single-pass dbTt results to compare against dual-pass results using the Modified Light Calibration workaround for the P90 view. The second test includes a 90nm tritone reticle to measure single-pass dbTt performance against dual-pass inspection efforts with the DNIR workaround for P125.

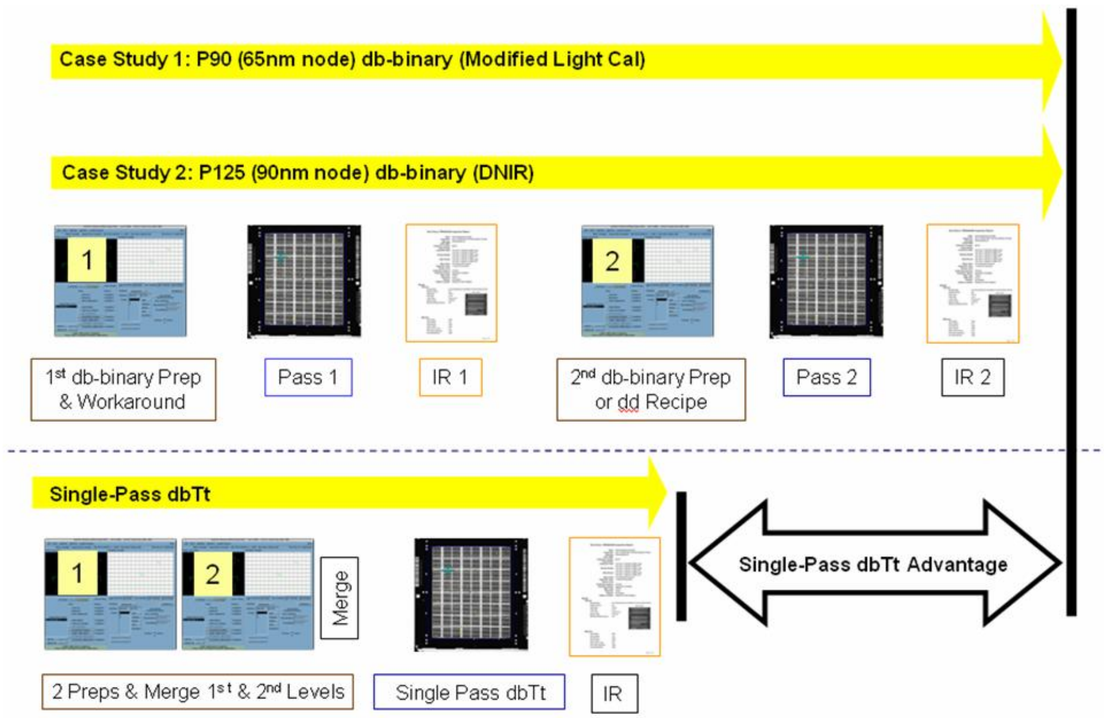


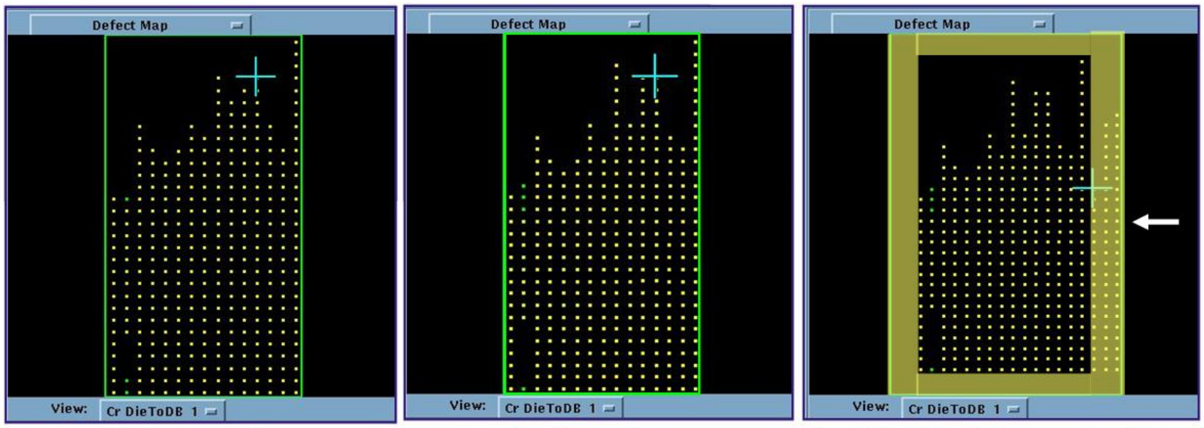
Figure 5 – Throughput Comparison Overview

For all throughput measurements, the TeraScan™ was configured as a T4 system which indicates a specific image computer configuration. IA sizes were approximately 100mm X 115mm for all inspection modes.

RESULTS

Test Reticle Results –Sensitivity Comparison

P125 Results: The 320nm region of the SPICA200 was inspected ten times in the EPSM programmed defect array using the UCFdbT45 binary database algorithm. These results produced an average defect count of 340 as indicated in Figure 6A. Using the UCFdbTt45 tritone database algorithm, the same "EPSM Only" region was again inspected 10 times generating an average defect count of 333 detections as shown in Figure 6B. As anticipated, there was a slight loss of sensitivity (7 counts on average) with the dbTt inspection mode as can be observed when comparing Figure6A with Figure 6B. Both sets of data were obtained using maximum sensitivity settings for the Hi-Res1 and Hi-Res2 detectors.



A - dbT-binary = 340
EPSM Only IA

B - dbTt = 333
EPSM Only IA

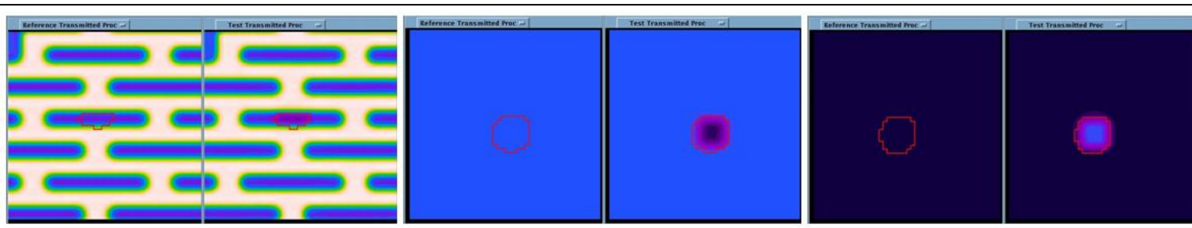
C - dbTt = 400 *(67 Chrome Area Defects)*
EPSM & Chrome Areas

Figure 6 – P125 SPICA200 Results

It should be noted that defects found by the dbT-binary mode (Figure 6A) that were not captured by dbTt (Figure 6B) included fewer pinholes (2nd column from the left) and edge defects located within the smallest extents of the programmed defect grid. The "gap" in pinhole detection for both results is typical with any transmitted light inspection algorithm and is commonly addressed using alternate inspection modes as described in a previous publication [1]. No false defects were observed in any of these P125 runs.

Figure 6C contains dbTt results with the "EPSM Only" IA extended to include "Chrome on Shifter" programmed defects located in the far-right 3 columns. These 10 sequential inspections produced an average defect count of 400 also using the maximum sensitivity settings for the Hi-Res1 and Hi-Res2 detectors. This total includes the 333 "EPSM" detections (Figure 6B) in addition to 67 Chrome-on-Shifter programmed defects. The shaded overlay added to Figure 6C (see arrow) indicates the expanded IA that includes all three Chrome, EPSM, and Quartz materials and does not appear on the 5XX GUI.

Figure 7 contains three Reference & Test images; one from each of the three columns located in the Chrome-on-Shifter programmed defect array. It should be noted these types of defects are not consistently found when using the Modified Light Calibration workaround to inspection tritone reticle using a binary database and is discussed further in the "Results" section.



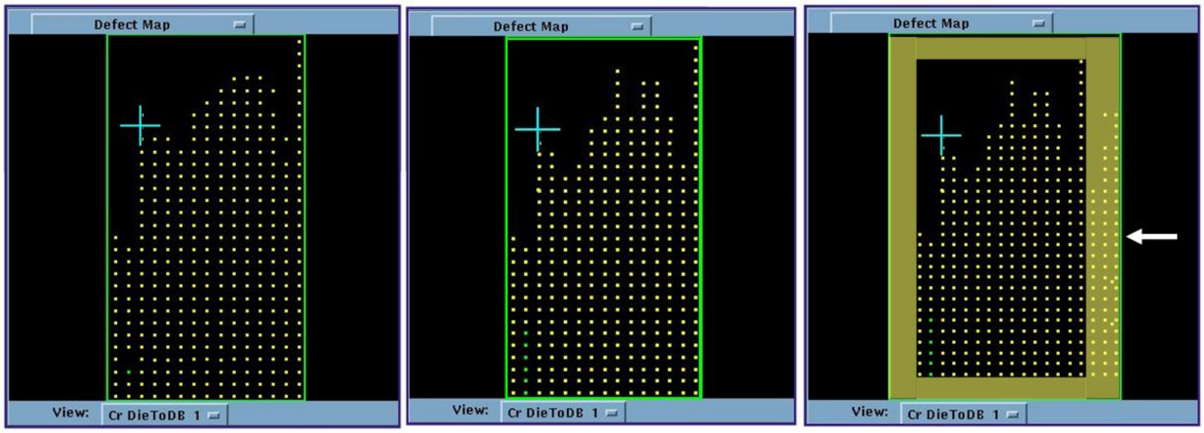
Column R Defect
Chrome on EPSM Edge

Column S Defect
Chrome Spot on EPSM

Column T Defect
Pinhole in Chrome (Exposed EPSM)

Figure 7 – Transmitted Light Chrome in EPSM Defect Images

P90 Results: The 260nm region of the SPICA200 was inspected 10 times using the UCFdbT45 binary database algorithm resulting in an average defect count of 347 detections as shown in Figure 8A. Using the UCFdbTt45 algorithm and tritone database, the same inspection area was inspected 10 times and produced an average defect count of 337 detections as shown in Figure 8B. As anticipated, there is a slight loss of sensitivity (10 defects on average) using the dbTt inspection mode as can be observed when comparing Figure8A with Figure 8B. Both "EPSM Only" data was obtained using maximum sensitivity settings for the Hi-Res1 and Hi-Res2 detectors.



A - dbT-binary = 347
EPSM Area Only

B - dbTt = 337
EPSM Area Only

C - dbTt = 407 *(70 Chrome Area Defects)*
EPSM & Chrome Areas

Figure 8 – P90 SPICA200 Results

Figure 8C contains dbTt results with the "EPSM Only" IA extended to include "Chrome on Shifter" programmed defects located in the far-right 3 columns. These 10 sequential inspections produced an average defect count of 407 also using the maximum sensitivity settings for the Hi-Res1 and Hi-Res2 detectors. This total includes 337 "EPSM" detections (Figure 8B) in addition to 70 Chrome-on-Shifter programmed defects. The shaded overlay added to Figure 8C (see arrow) indicates the expanded IA that includes all three Chrome, EPSM, and Quartz materials and does not appear on the 5XX GUI. No false defects were observed in any of the P90 runs.

Figure 9 provides specific insight into the types of defects found by the dbT-binary mode but not detected by dbTt due to the reduced dynamic range. Although no thorough investigation has been performed, the general conclusion by the authors of this paper is that these defect types are not lithographically significant for most wafer fab requirements. Most binary database inspections typically require slightly reduced sensitivity settings on production reticles to intentionally ignore non-critical defects similar in size and location to those presented here.

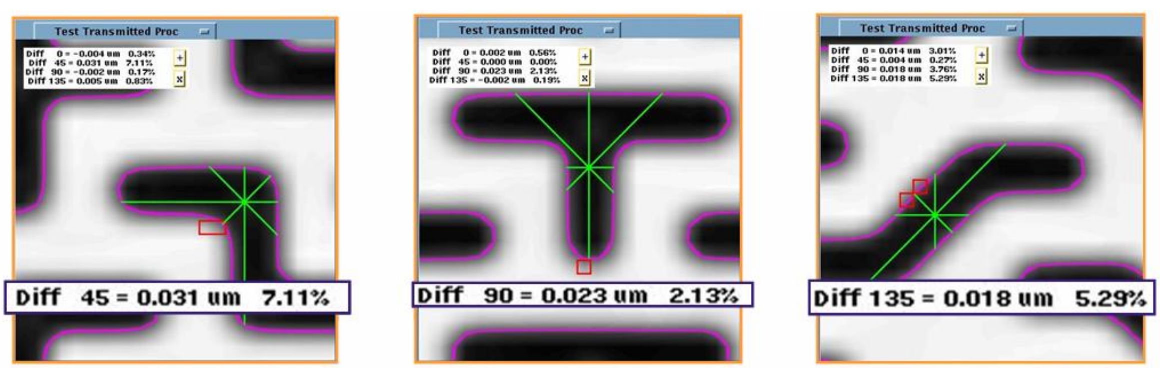


Figure 9 – P90 SPICA200 dbT-binary Defect Images (not found by dbTt)

Production Reticle Results – Throughput Comparison

Case Study 1 – *P90 dbTt vs. db-binary MLC (Modified Light Calibration) Results*

The inspection comparison results for this reticle are provided in Figure 10 with values rounded to the nearest whole minute. The total throughput needed for the dual-pass inspection, as seen in the top row of the chart, was 395 minutes. By comparing this data against the single-pass dbTt results of 230 minutes, the throughput advantage of the dbTt inspection mode can be seen. Data from the various Inspection Steps are contained within the table of Figure 10 and were used to generate this chart.

P90-65nm	Recipe 1	Cal 1	Insp 1	Recipe 2	Cal 2	Insp 2	*Total*
db-MLC	6	31	176	9	12	161	395
dbTt	16	29	185	0	0	0	230

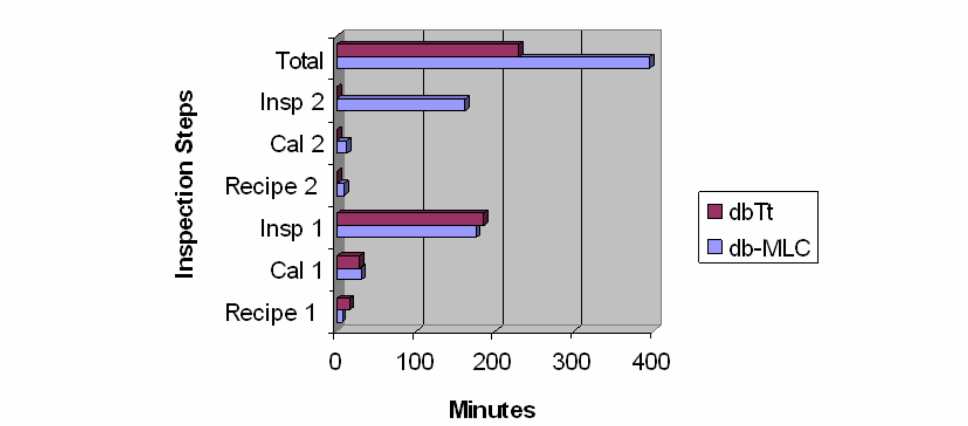


Figure 10 – P90 Results (dbTt vs db-binary Modified Light Cal)

The "Recipe 1" results reveal dbTt taking 10 minutes longer to create for the initial setup period (16 minutes vs. 6 minutes). This is due to the extra steps necessary to produce the merged tritone database file. The "Cal 1" segment includes Plate Alignment, Light Calibration, and Image Calibration routines which were virtually the same for both modes (2 minute difference). Total inspection time "Insp 1" for both modes was similar as well (within 10 minutes of each other).

The "Recipe 2" category was zero minutes for the dbTt since a 2nd inspection was not required using this single-pass strategy which is also the case for the "Cal 2" and "Insp 2" entries. By using the dbTt single-pass solution, a second inspection is not required which is the primary advantage of this inspection mode. The second set of data for the db-MLC inspection strategy was obtained from a die-to-die transmitted light inspection (161 minutes) needed to capture chrome or contamination defects on MoSi not found using the MLC workaround.

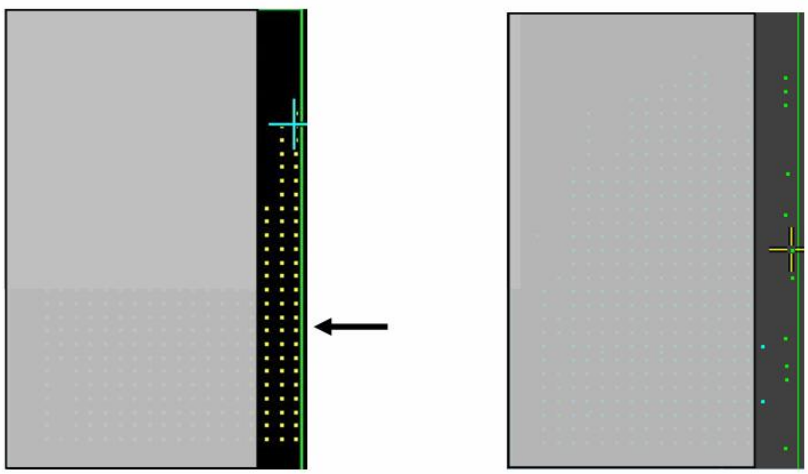
During this experiment, it was observed that the Defect Review period was essentially the same for both single and dual-pass strategies and therefore these results are not included for the sake of clarity. It should be noted, however, that additional time and resources are needed to manage two IRs associated with the dual-pass inspection strategy for a single tritone reticle. Ensuring both sets of IR coordinates are provided to defect repair tools requires special attention by mask manufacturers since this is normally a single-step procedure.

Another potential glitch with using the dual-pass inspection strategy for tritone reticles is with production floor management software normally designed to interface with one inspection output file such as an AutoPrint IR text file. Ensuring two IRs are tracked by such software may require some sort of manual intervention or programming modifications to such a software system. The extra time needed to administer these "post-inspection" steps was relatively complicated to measure precisely but is pointed out in this results section as additional points to consider regarding the dual-pass inspection strategy.

One final item worth mentioning regarding the creation of merged dbTt pattern files has to do with pattern polarity of the first and second level write layers. Attention must be given to the selection of correct polarity (positive or negative) during dataprep to match the lithography process used on the reticle (positive or negative resist). If either layer contains the wrong polarity for the type of resist used, a reverse tone image can be generated in the dbTt merge file causing problems during Image Calibration or excessive defects during inspection.

Modified Light Calibration: Chrome on Shifter Sensitivity Loss

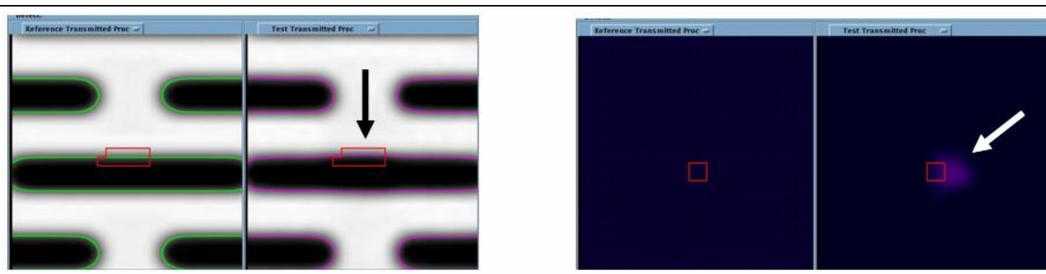
Figure 11B reveals a sensitivity problem when using the Modified Light Calibration workaround. The non-shaded region (see arrows) reveals a capture rate difference for Chrome-on-EPSM (Shifter) programmed defects within Columns R, S, and T. When compared to the dbTt results in Figure 11A, it becomes apparent the db-binary inspection mode (involving the Modified Light Calibration workaround) does not provide a complete inspection solution for inspecting tritone reticles. The results in Figure 11 clearly illustrate the need for a second inspection (hence the dual-pass strategy) when attempting to inspect tritone reticles with the db-binary inspection using the Modified Light Calibration workaround.



A - dbTt Mode   B - db-Binary (Modified Light Calibration) Mode

Figure 11 – Chrome-on-EPSM Capture Rate Comparison

As stated previously in this paper, the low contrast between Chrome and Shifter materials (refer to Figure 1B) produced from this workaround creates sensitivity performance for Chrome on Shifter program defects that is very unreliable. Figure 12 reveals some of the inconsistently detected defects from this method. It should be emphasized no defects in Column S (Chrome Spots on EPSM) were found using the db-binary mode with the Modified Light Calibration workaround.



Column R Defect
Chrome on EPSM Edge

Column T Defect
Pinhole in Chrome (Exposed EPSM)

Figure 12 – db-Binary (Modified Light Calibration) Defect Types Not Consistently Captured

It should also be pointed out that the actual “Column R Defect” in Figure 12 can not be seen since both chrome and shifter materials are reduced to nearly the same black level when viewed with transmitted light (see dark arrow). Refer to the “Column R Defect” in Figure 7 to compare how this “Chrome on Shifter Edge” programmed defect test image appears when using the dbTt mode.

The “Column T Defect” in Figure 12 also reveals poor image contrast for exposed shifter defects as indicated by the white arrow. Refer to the “Column T Defect” in Figure 7 to compare how this programmed defect test image appears when using the dbTt mode.

Case Study 2 (P125) – *P125dbTt vs. db-binary Results (DNIR)*
The inspection comparison results for this reticle are provided in Figure 13 with values rounded to the nearest whole minute. The total throughput needed for the dual-pass inspection, as seen in the top row of the chart, was 279 minutes. By comparing this data against the single-pass dbTt results of 144 minutes, the throughput advantage of the dbTt inspection mode can be seen. Data from the various Inspection Steps are contained within the table of Figure 13 and were used to generate this chart.

P125-90nm	Recipe 1	Cal 1	Insp 1	Recipe 2	Cal 2	Insp 2	*Total*
db-DNIR	31	29	90	12	28	89	279
dbTt	15	30	99	0	0	0	144

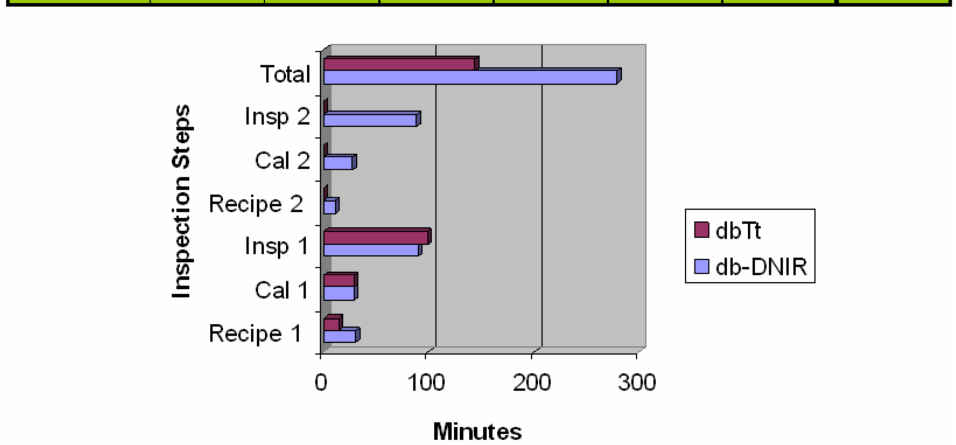


Figure 13 – P125 Results (dbTt vs db-binary DNIR)

The “Recipe 1” results reveal dbTt taking 16 minutes less to create for the initial setup period (31 minutes vs. 15 minutes). This is due to the extra steps necessary to define the DNIR portion of the recipe. The “Cal 1” segment includes Plate Alignment, Light Calibration, and Image Calibration routines which were virtually the same for both modes (1 minute difference). Total inspection time “Insp 1” for both modes was similar as well (within 9 minutes of each other).

The “Recipe 2” category was zero minutes for the dbTt since a 2nd inspection was not required using this single-pass strategy which is also the case for the “Cal 2” and “Insp 2” entries. By using the dbTt single-pass solution, a second inspection is not required which is the primary advantage of this inspection mode. The second set of data for the db-DNIR inspection strategy was obtained using a transmitted light db-binary inspection (89 minutes) needed to augment the dual-pass inspection strategy for this tritone reticle which inspected the border and scribe areas with DNIRs for the main pattern die.

It was observed that both Dataprep and Defect Review segments were essentially the same for both single and dual-pass strategies and therefore these results are not included for the sake of clarity. It should be noted, however, that additional time and resources are needed to manage two IRs associated with the dual-pass inspection strategy for a single tritone reticle. Ensuring both sets of IR coordinates are provided to defect repair tools requires special attention by mask manufacturers since this is normally a single-step procedure.

Another potential glitch with using the dual-pass inspection strategy for tritone reticles is with production floor management software normally designed to interface with one inspection output file such as an AutoPrint IR text file. Ensuring two IRs are tracked by such software may require some sort of manual intervention or programming modifications to such a software system. The extra time needed to administer these "post-inspection" steps was relatively complicated to measure precisely but is pointed out in this results section as additional points to consider regarding the dual-pass inspection strategy.

CONCLUSIONS

In conclusion, the dbTt mode provided a single-pass solution offering a throughput advantage over db-binary results on tritone production reticles. As measured in the first case study using the P125 inspection view, the improvement was a factor of 1.93 (144 minutes for dbTt single-pass) compared to 279 minutes using the dual-pass db-binary (Modified Light Calibration) approach. For the second case study, the P90 view performance revealed an improvement factor of 1.72 times (230 minutes for dbTt single-pass) vs. 395 minutes for the dual-pass db-binary (DNIR) strategy.

When comparing single-pass sensitivity performance, dbTt consistently found the "Chrome-on-Shifter" programmed defects that db-binary inspections (using the Modified Light Calibration workaround) did not detect when the IA included Columns R, S, and T. The defect types found in this region include chrome-on-shifter edge defects as well as residual chrome spots on shifter and chrome pinholes (with exposed EPSM). Any thorough inspection strategy using a binary database approach using either workaround to inspect tritone reticles will require a 2nd inspection to find these types of potentially yield limiting defects.

Based on data presented in this paper, the dbTt mode was found to be slightly less sensitive to certain defect types when compared to db-binary inspection results on the SPICA200 tritone test reticle. The two categories that reveal a capture rate performance difference are pinhole and on-edge/line-end defects. However, as discussed in the Results section, the db-binary mode also did not detect all pinholes present in the 193nm EPSM programmed defect array. Both inspection strategies require an additional inspection strategy, such as a reflected light solution, to eliminate the "pinhole gap" effect inherent with transmitted light inspections on 193nm EPSM masks.

With respect to dbTt performance for on-edge and line-end type defects, the differences occurred with the smallest programmed defect sizes and are not generally considered to be lithographically significant for most wafer fab requirements. Data used to support this claim include edge and line-edge defect measurements ranging in size from 18nm to 23nm as shown in Figure 9. In general, most binary database inspections typically require reduced sensitivity settings for production reticles to intentionally ignore small defects similar in size and location to those shown in Figure 9. However, a detailed printability study of these and other defect types not detected by the dbTt mode which are commonly found on production reticles is being considered for future work.

REFERENCES

[1] A. D. Vacca, D. Taylor, *Comprehensive defect detection featuring die-to-database reflected light inspection*, BACUS Symposium on Photomask Technology, 2004