Enhancing productivity and sensitivity in mask production via a Fast Integrated T+R pattern inspection and STAR*light-2*^{TM} contamination inspection on critical layers

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ABSTRACT

Transmitted Light (ddT or dbT) pattern inspection and STAR*light-2*^{TM} (SL2) contamination inspection are widely employed by mask makers in order to detect pattern and contamination defects on photomasks during the mask inspection process. However, such an approach needs a two-pass inspection to detect pattern defects and contamination defects separately.

In this paper we introduce the ***'Fast Integrated T+R and SL2'*** capability and investigate the properties of this combination of Transmitted (T) and Reflected (R) light inspection on die areas and STAR*light-2*^{TM} (SL2) on scribe areas. '***Fast Integrated T+R and SL2'*** has the capability to reduce a two-pass inspection to a single set-up and single pass inspection resulting in a substantial saving of inspection time. In addition to a throughput enhancement, '***Fast Integrated T+R and SL2'*** is able to compliment the pattern T inspection by providing additional sensitivity to detect challenging defects.

During this study we collect and analyze inspection data on a critical layer provided by the Advanced Mask Technology Center. Compared to the 2-pass individual mode pattern T and contamination SL2 inspections, a single scan '***Fast Integrated T+R and SL2'*** demonstrates the capability to capture additional real defects, improves reticle inspectability and first time success rate, and results in a significant enhancement in productivity.

Based on empirical data collected in this study, the Fast Integrated T+R and SL2 inspection is able to improve inspection throughput approximately 45% at P90.

Keywords: Mask Inspection, Productivity, Sensitivity, Fast Integrated T+R and SL2

1 INTRODUCTION

1.1 Current Inspection Strategies

Among the various reticle inspection strategies available to mask shops, KLA-Tencor's TeraScan systems offer three options: Die-to-die (pattern defect inspection with the constraint of having identical dies); Die-to-database (pattern defect inspection with reference patterns derived from database) and STARlight2 (contamination inspection with reference patterns predicted from optical properties of the reticle). For reticles with repeating dice, die-to-die and STARlight are a popular combination of mask inspections to detect both pattern defects and contamination defects.

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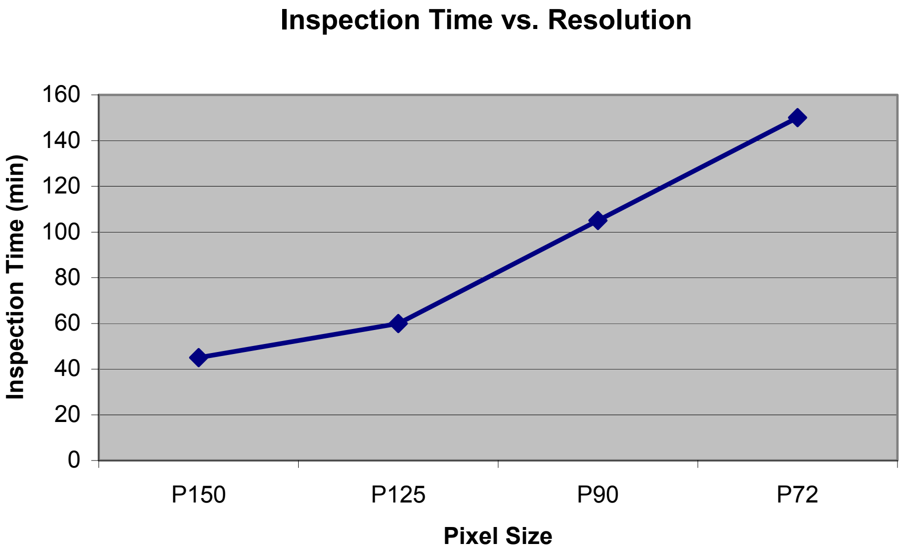
As semiconductor devices become smaller, photomask inspection requires higher resolution and smaller pixel sizes to detect critical defects. Smaller inspection pixels result in longer inspection time due mainly to the quantity of data and images to be processed, as indicated in Figure 1. As a general rule, the smaller the pixel size the higher the inspection equipment investment and the longer the inspection time. High equipment cost and slow inspection times drive the Cost per Inspection (CPI) higher. Given the fixed equipment investment, reducing inspection cycle time is a key factor to improve productivity and to reduce CPI at mask shops.



SL587 T5 (min)	P150	P125	P90	P72
ddT	45	60	105	150
ddR	45	60	105	150
SL2	45	60	105	NA

Figure 1. Inspection Time vs. Inspection Resolution
(KLA SL587 single mode of ddT, ddR and STAR*Light*^{TM} at T5 Speed)

1.2 Proposed Inspection Strategy

In this study, we propose a Fast Integrated ddTR and SL2 inspection for the mask shop in order to reduce total inspection time and to improve productivity, while providing better sensitivity than any single inspection mode. The Fast Integrated ddTR+SL2 is able to use die-to-die inspection on the die areas with both transmitted and reflected light, and SL2 inspection in the scribes and borders. This combined inspection is completed with a single scan throughput, similar to performing either the die-to-die or STARlight inspection alone. The proposed Fast Integrated ddTR+SL2 inspection provides 100% coverage of the reticle: scribes are inspected by SL2 and repeating die patterns are inspected by ddT+R as shown on the Figure 2.

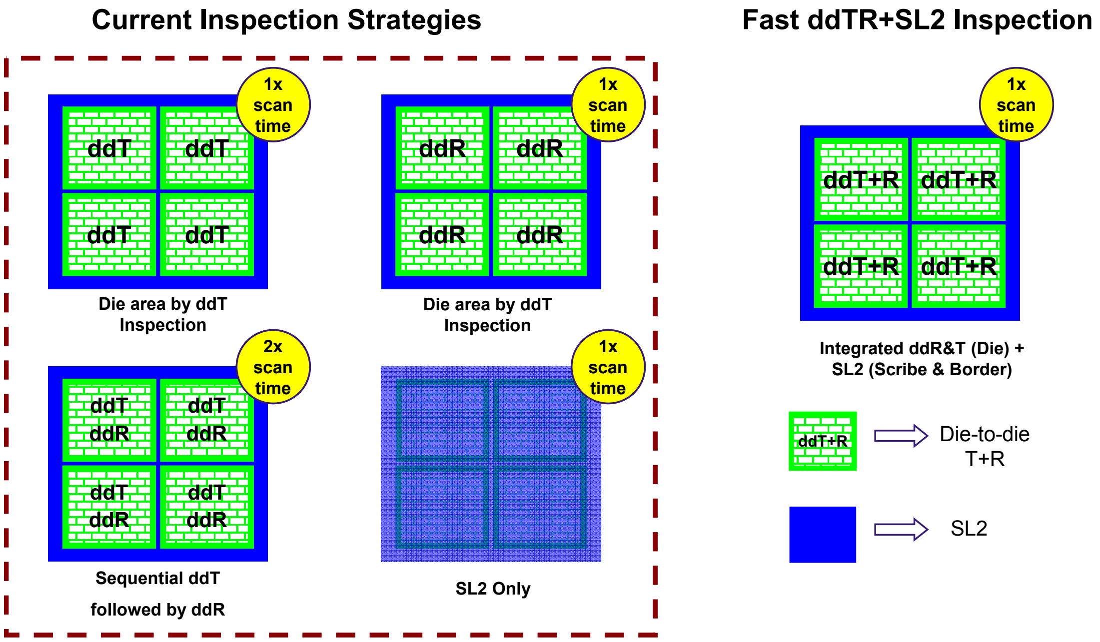


Figure 2. Fast Integrated ddTR+SL2 vs. Current Inspection Strategies

1.3 Improved Throughput

Table 1. Theoretical Improvement of Inspection Time on Fast Integrated ddTR+SL2S+B)*

	Current ddT/R+SL2		Fast ddTR+SL2(S+B)	
Resolution (Pixel)	P90	P125	P90	P125
ddT	105	60	105	60
ddR	105	60	105	60
SL2	105	60	105	60
Inspection Time (min)	210	120	105	60
Improvement %			50%	50%

Note: * SL2(S+B) is inspect STARLight-2TM on scribes and borders

The proposed inspection process applies a single pass scan to detect both contaminations (in dice and in scribe/border) and pattern defects (in dice only) at the same time. Some pattern defects in the scribes are not detected with this methodology, but should have been identified and repaired/dispositioned in an earlier in-process inspection. Compared to the current process that requires a separate inspection to detect pattern defects and another to detect contamination defects, the proposed Fast Integrated ddTR+SL2 inspection strategy can theoretically save 50% inspection time as shown on the Table 1. This throughput figure is supported by the empirical data collected in this investigation.

1.4 Sensitivity Enhancement

The die-to-die sensitivity of the Fast Integrated ddTR inspection is the better of the Transmitted light detections and the Reflected light detections. Fast Integrated ddTR improves the sensitivity on some defect categories relative to ddT or ddR individually. For example, pinhole defects and inside corner defects are typically better detected by Reflected Light. Conversely, pindot defects and outside corner defects are better detected by Transmitted Light. The Fast Integrated ddTR reports the better (smaller) of both light modes. Data are shown on the Table 2, Table 3 and Figure 3.

Table 2 - Fast Integrated ddTR Sensitivity Coverage vs. Single Inspection

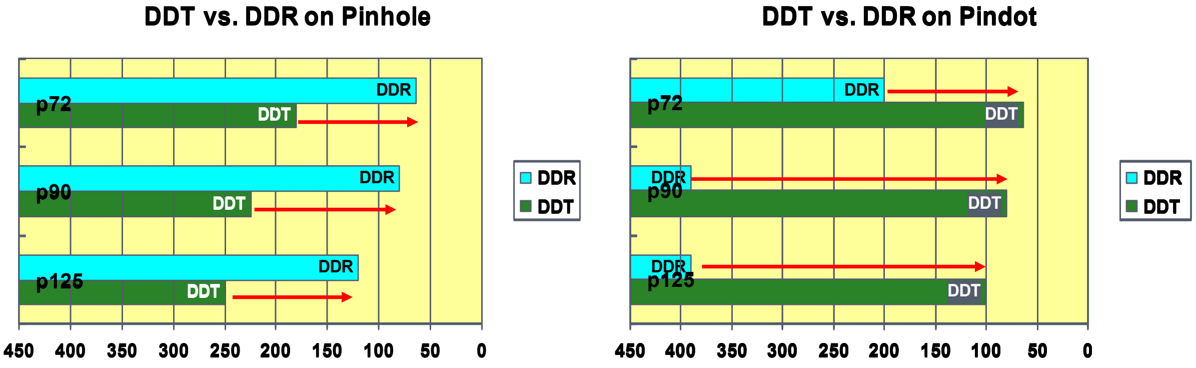
Resolution	P125			P90			P72		
Mode	ddT	ddR	Fast ddTR	ddT	ddR	Fast ddTR	ddT	ddR	Fast ddTR
Sensitivity (nm)	S3cs*	S3cs	S3cs	S2cs**	S2cs	S2cs	S2cs	S2cs	S2cs
Ext Hz Opaque	75	115	75	50	66	50	46	60	46
Ext Hz Clear	90	90	90	60	56	56	56	42	42
Ext Diag Opaq	75	110	75	50	68	50	46	60	46
Ext Diag Clear	90	85	85	64	60	60	56	44	44
Corner Inside	100	80	80	75	56	56	68	48	48
Corner Outside	70	125	70	55	88	55	48	68	48
CD	52	60	52	40	40	40	36	34	34
Line-end	45	110	45	30	65	30	26	48	26
Mis-place	40	65	40	30	42	30	22	32	22
Pindot	78	390	78	65	390	65	52	200	52
Pinhole	250	110	110	225	80	80	200	64	64

Note: *S3cs and **S2cs are test reticles

ID	Min Opaq	Min Pitch	Materials	Pattern	# of Die
S3cs	320nm	1000nm	COG (over MoSi)	Sense-Modified semi-wire	1-db, 2-dd
S2cs	260nm	800nm	COG (over MoSi)	Sense-Modified semi-wire	1-db, 2-dd

Table 3 - The Fast Integrated T+R and SL2

	ddT+R+ SL2 scribe	**ddT**	**ddR**	**SL2**
Contam Defect sensitivity in active area	High	Med	Med	Med
Contam Defect sensitivity in scribe area	Med	None	None	Med
Sensitivity to opaque defects (dots, extensions)	High	High	Med	Med
Sensitivity to clear defects (holes, intrusions)	High	Med	High	Med
Inspection time (on tested reticle)	1 Unit	1 Unit	1 Unit	1 Unit


DDT vs. DDR on Pinhole

DDT vs. DDR on Pindot

Figure 3. Pinhole and Pindot Sensitivity Comparison of ddT and ddR

2 EXPERIMENTAL DESIGN

A production photomask provided by AMTC was inspected to compare and validate real inspection performance compared to the theoretical estimates presented in this investigation. We selected this reticle because it contains different geometrical features that pose challenges for different inspection modes and contains various pattern and contamination defects that are best detected by either transmitted or reflected light.

For each reticle, we set up 4 separate inspections and compared the defect captures. The inspections consist of the following:

1) ddT only inspection (die only)
2) ddR only inspection (die only)
3) SL2 only inspection (die, scribe and border)
4) ddTR in die, SL2 in scribe and border

Because of limitations inherent to any die-to-die setup, inspections 1 and 2 only detect defects within the die boundaries. In inspection 4, to avoid excessive algorithm processing in the regions where the die-to-die and STARlight areas overlap, we created SL2 Do Not Inspect Regions (DNIR) to coincide with the die definition. This results in the SL2 algorithm only inspecting areas outside of the dice, and ddTR only inspecting inside the dice.

After completing inspections 1, 2 and 3, we combined the results of the three inspections into a new “union” inspection, which contains any defects that were captured by either inspection 1, 2 or 3. Defects captured in the “union” inspection are compared against the defects captured in the single Fast Integrated ddTR+SL2 inspection to validate our theoretical sensitivity performance. Relative setup and inspection times are also recorded to validate the throughput improvement expected with ddTR+SL2 over the sum of individual inspections.

3 INSPECTION RESULTS AND ANALYSIS

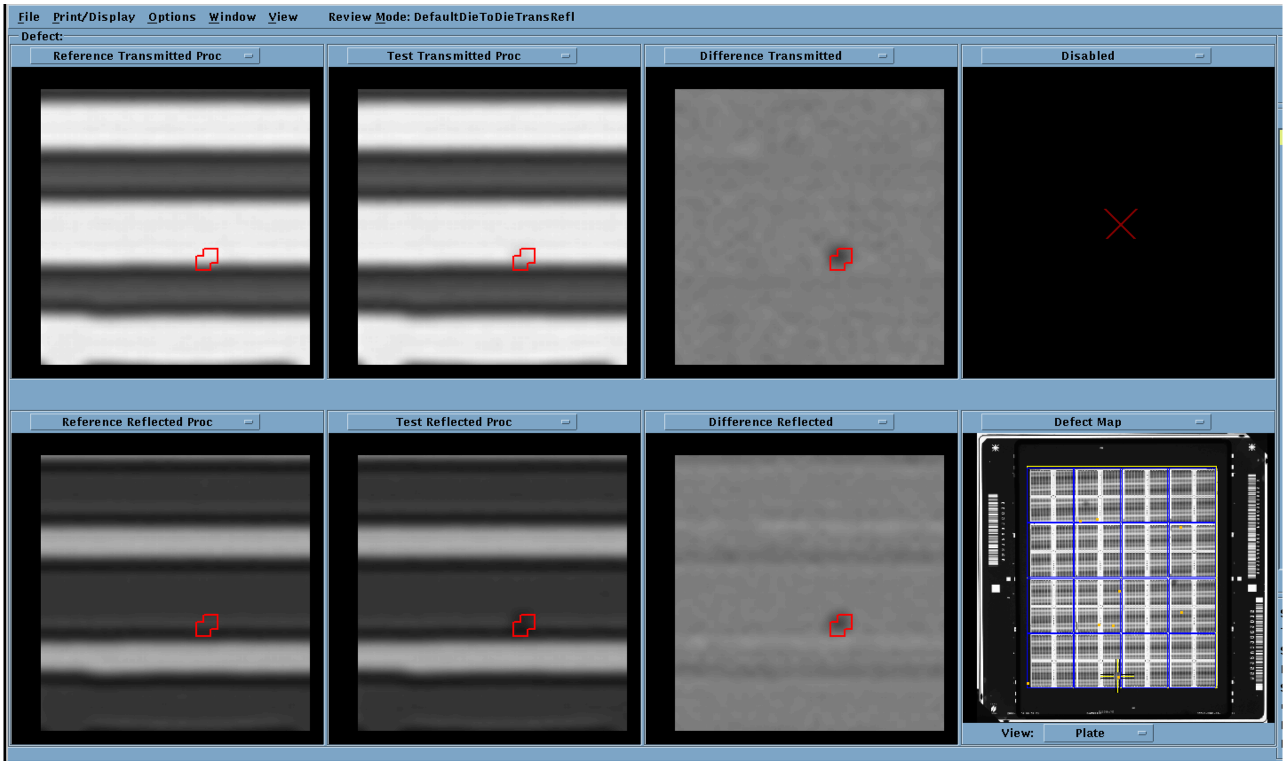
The reticle provided by AMTC is a 65nm design rule tritone reticle with light/medium OPC complexity. TABLE 4 summarizes the results of each of the individual inspections for comparison. All inspections were conducted using the same pixel size (90nm) and identical (or analogous) sensitivity settings: HiRes 1 and HiRes 3 =100, and HiRes 2 and HiRes 4=90. This ensures that the same defect sensitivity is applied in all inspections. The empirical throughput data validates our expectation that the Fast Integrated ddTR+SL2 inspection mode runs in approximately the same time as an individual die-to-die or SL2 inspection.

3.1 Discussion of Results: ddT Inspection

As expected, the die-to-die transmitted light (ddT) inspection detected primarily edge defects, opaque defects on quartz and large defects on MoSi. Since this reticle had already been through final processing, most repairable defects had been fixed and the mask had been cleaned. An example of a typical ddT detection is shown in FIGURE 4. In this inspection, both the transmitted and reflected defect images were captured in order to assist with defect disposition. Only the transmitted images, however, were used by the algorithm for defect detection. The defect pictured is a particle or pattern error on a MoSi edge. None of the defects detected in this inspection were false (system-induced due to hardware or algorithm limitations).

Table 4: Comparison of 4 Experimental Inspections

Results: AMTC Production Reticle
Algorithm 1: ddT only (UCFddT55)
Inspection view: 90nm Transmitted
Setup time: 15 min
Inspect time: 1hr 48 min
Sensitivity Settings (H1, H2): 100, 90
Total Detections: 9 defects (all real)
Algorithm 2: ddR only (UPAddR55)
Inspection view: 90nm Reflected
Setup time: 15 min
Inspect time: 1hr 48 min
Sensitivity Settings (H1, H2): 100, 90
Total Detections: 26 defects (all real)
Algorithm 3: SL2 only (UPAslTRt55)
Inspection view: 90nm Transmitted+Reflected
Setup time: 34 min
Inspect time: 1hr 53 min
Sensitivity Settings (H3, H4): 100, 90
Total Detections: 476 defects (26 real, 450 false/nuisance)
Algorithm 4: ddTR+SL2 (UHRddTR55+UPAslTRt55)
Inspection view: 90nm Transmitted+Reflected
Setup time: 35 min
Inspect time: 1hr 54 min
Sensitivity Settings (H1, H2): 100, 90
Sensitivity Settings (H3, H4): 100, 90
Total Detections: 29 defects (27 real, 2 false/nuisance)


Review Mode: DefaultDieToDieTransRefl

Defect:

View: Plate

Figure 4. ddT Inspection

3.2 Discussion of Results: ddR Inspection

The die-to-die reflected (ddR) inspection detected 26 total defects, including 8 of the 9 ddT defects from inspection 1. The one ddT defect which was not captured by ddR was a weak H2 detection. These very small defects lie below the guaranteed capture rate for the 5XX tool, and may or may not be detected in any individual inspection, depending on various hardware and environmental factors. In a reticle production environment, additional review tools such as live camera image are employed in order to determine how to disposition these types of defects. The additional defects caught by ddR and not ddT include several on-chrome defects, such as the one pictured in FIGURE 5. Similarly, there are also a few weak, very small defects detected by ddR and not by ddT. These types of detections are random occurrences and are not repeatable.

On-Chrome defects such as this contaminant that attenuates the Cr reflectivity are not detected with transmitted light. The lack of transmitted defect signature is evident in the transmitted images directly above the reflected images in FIGURE 5.

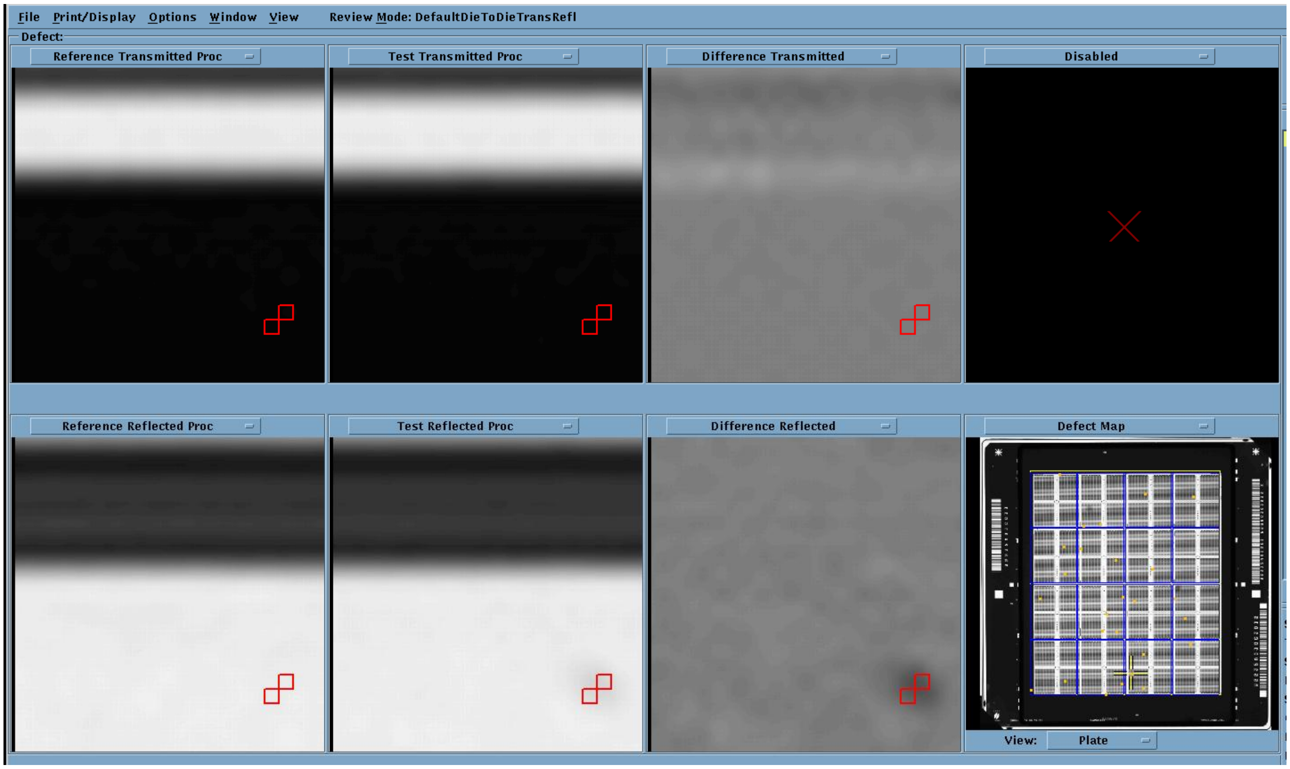
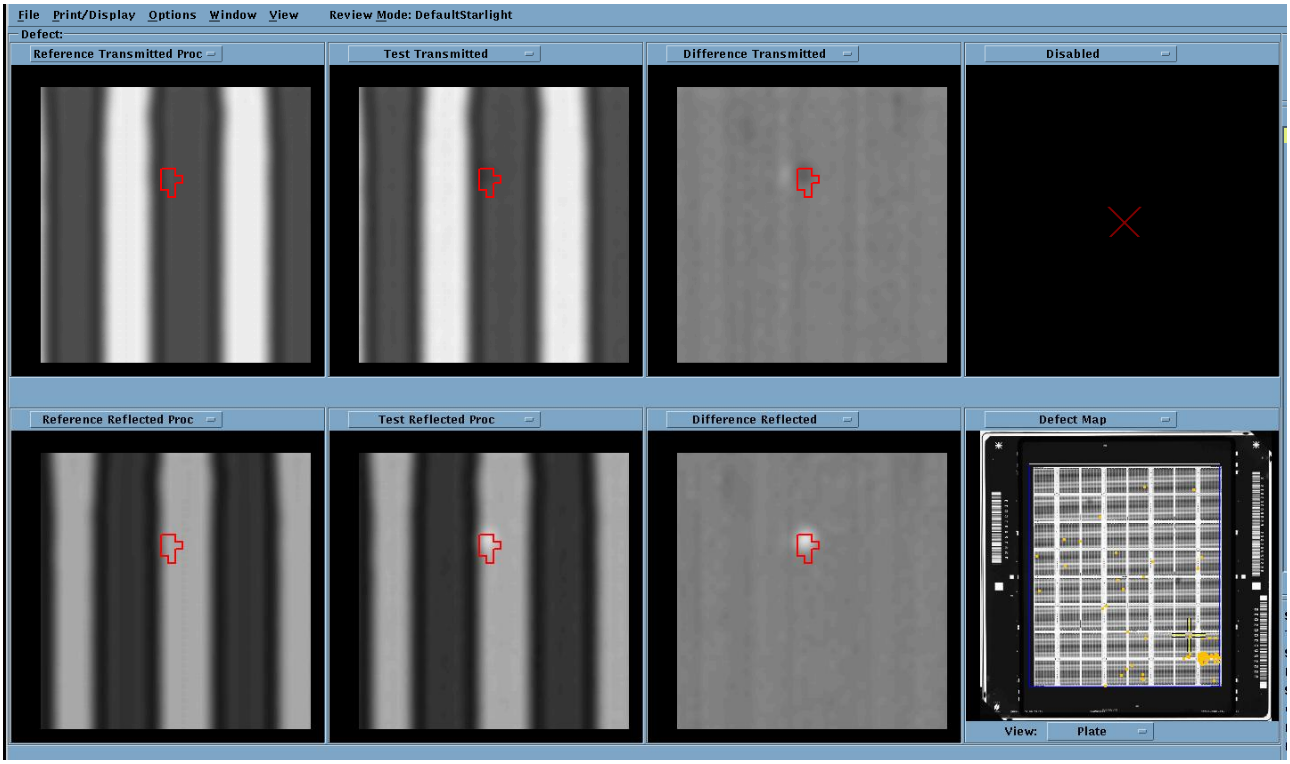


Figure 5. ddR Inspection

3.3 Discussion of Results: STARlight2TM (SL2) Inspection

The STARlight-2TM inspection uses the optical T and R images in order to render synthetic non-defective images for comparison against the optical images. Contamination in the scanned image, which does not exhibit the same optical properties as the reticle material, will not match the synthetic images in T or R. On the other hand, STARLight-2TM would ignore a pattern defect occurring in the substrate (MoSi or Chrome) because such a defect would exhibit the same optical properties as non-defective pattern. The SL2 inspection detected 26 real defects (not all are the same 26 defects as the ddR inspection) and 450 false/nuisance defects. These 450 defects are actually real phenomenon on the reticle caused by local reflectivity variation, but are generally not lithographically significant. Such undesirable detections can be mitigated by optimizing the image calibration points or by reducing the sensitivity settings. We opted to use extremely high sensitivity in order to approach the same level of defect detections in the SL2 inspections as in the die-to-die inspections. Nearly all of the 450 false defects can be quickly dispositioned by using ReviewSmart [1] [2], an automatic defect binning feature, since most of those defects occur on the same type of geometries. The remaining 26 defects represent samples of contamination occurring both within the die and inside the scribes and borders. FIGURE 6 shows an example of residual chrome (or other reflective material) on a MoSi line edge.


Review Mode: DefaultStarlight

View: Plate

Figure 6. STAR*light-2*™ Inspection

3.4 Discussion of Results: Fast Integrated ddTR+SL2 Inspection

The Fast Integrated ddTR with SL2 scribe inspection incorporates the benefits of the two individual die-to-die inspections (high sensitivity, ease of setup, few false defects) and the STARlight 2 border/scribe inspection (inspectability of non-repeating die). FIGURE 7 shows the result of the ddTR+SL2 inspection. In this inspection, 27 real defects and 2 false defects are detected. As is the case with the other inspections, there are 3 weak defects caught by this inspection that were missed by all 3 of the single-mode inspections. On the other hand, the union of inspections 1, 2, and 3, detected 12 defects (all weak, all similar detection mechanisms) that were not detected by the ddTR+SL2. This behavior is expected since weak defects are randomly detected, thus 3 individual inspections have 3x the probability of detecting any one of these weak defects. The remaining 24 defects caught in the ddTR+SL2 inspection were also caught in at least one of the individual ddT, ddR or SL2 inspections. The 450 false/nuisance defects from the SL2 inspection were not detected because this region is inspected by the ddTR algorithm, and the DNIR is applied for SL2. The defect shown in FIGURE 7 is an on-Quartz contaminant that is not detected by either of the individual die-to-die inspections because it resides in the scribe.

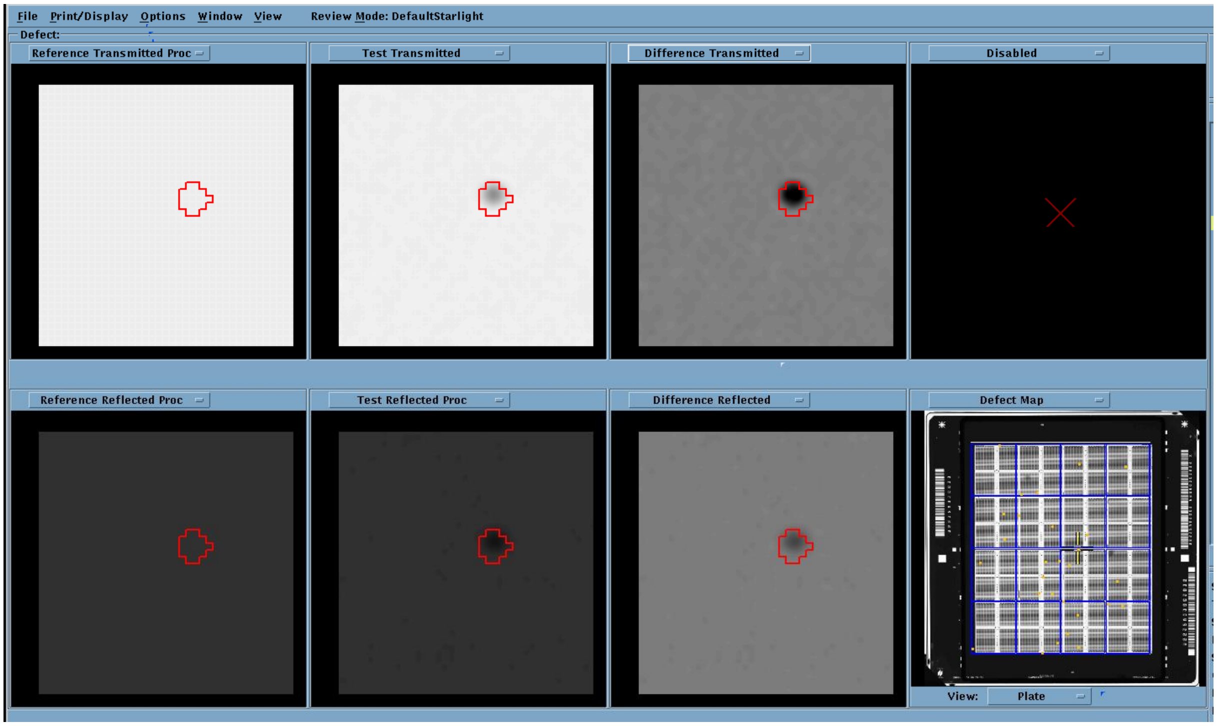


Figure 7. Fast Integrated ddTR+SL2 (scribe and border) Inspection

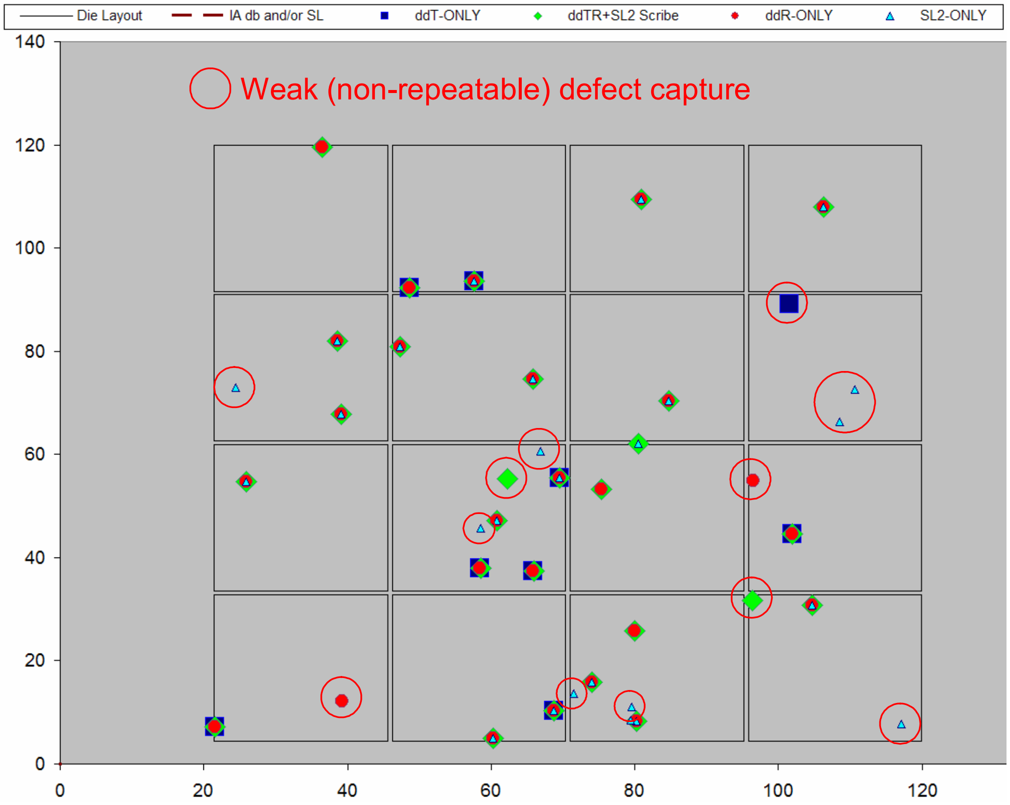


Figure 8: Spatial Distribution of Defects detected by 4 Inspections (Only real defects are reported)

Figure 8 is a defect map, which overlays the defect locations from each of the individual inspections (ddT, ddR, SL2 and ddTR+SL2). Most of the defects detected by any of the single mode inspections were also caught by the combined ddTR+SL2 inspection mode. A small number of random weak defects are also represented as single detections and are annotated in circles. The reason these real, very small defects are not consistently detected has been explained in this paper. For simplicity, we filtered out the 450 nuisance detections from the comparison so only the real contaminants/pattern defects are represented. Table 5 summarizes the inspection and setup time for each of the inspections performed in this investigation and highlights the relative time saving associated with the Fast ddTR+SL2 inspection approach.

Table 5: Comparison of Inspection Cycle Time

Plates	**AMTC Reticle**		
SL587 T5 (min)	Inspection Time	Setup time	Total Cycle Time
ddT only	108	15	123
ddR only	108	15	123
SL2 Only	113	34	147
Fast ddTR+SL2	114	35	149
2-pass ddT/ddR+SL2	221	49	270
Fast ddTR+SL2	114	35	149
Improvement	48%	29%	45%

4. CONCLUSION

Fast Integrated ddTR and SL2 enhanced productivity by reducing inspection cycle time by 45% as shown on Table 5. In addition to the throughput improvement, Fast Integrated T+R and SL2 shows a sensitivity advantage compared to single mode ddT or ddR.

The inspection strategy of Fast Integrated ddTR and SL2 incorporates advantages of two individual ddT and ddR inspections on repeating die, such as high sensitivity, ease to setup and few false defects, and the STARlight-2TM advantage of inspectability on non-repeating die. The Fast Integrated ddTR and SL2 inspection significantly reduced false defects compared to SL2 single mode (from 450 to 2) because the problematic region is inspected by the ddTR algorithm and a DNIR is applied for SL2. All of the significant defects detected by either the individual ddT, ddR or SL2 inspections were also detected by the ddTR+SL2 inspection. The only defects that were not detected are extremely small weak defects that are not reliably captured even when the same inspection is run multiple times. Similarly, the Fast Integrated ddTR+SL2 inspection also captured two weak defects that were missed by all three of the other individual inspections.

Using Fast Integrated ddTR and SL2 can be the right inspection strategy for mask makers because it offers improved useable sensitivity as well as simultaneous pattern and contamination inspection capability. Fast Integrated ddTR and SL2 provides full coverage of reticles, enhances inspection sensitivity, captures additional real defects, improves inspectability on complicated patterns and significantly enhances productivity compared to a conventional 2-pass inspection strategy.

References:

[1] - Improvement in defect classification efficiency by grouping disposition for reticle inspection, 25th Annual BACUS Symposium on Photomask Technology. Proceedings of the SPIE, Volume 5992, pp. 78-85 (2005)

[2] - Implementation of reflected light die-to-die inspection and ReviewSmart to improve 65nm DRAM mask fabrication, 25th Annual BACUS Symposium on Photomask Technology. Proceedings of the SPIE, Volume 5992, pp. 58-68 (2005)

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