Field results from a new die-to-database reticle inspection platform

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ABSTRACT

A new die-to-database high-resolution reticle defect inspection platform, TeraScanHR, has been developed for advanced production use with the 45nm logic node, and extendable for development use with the 32nm node (also the comparable memory nodes). These nodes will use predominantly ArF immersion lithography although EUV may also be used. According to recent surveys, the predominant reticle types for the 45nm node are 6% simple tri-tone and COG. Other advanced reticle types may also be used for these nodes including: dark field alternating, Mask Enhancer, complex tri-tone, high transmission, CPL, etc. Finally, aggressive model based OPC will typically be used which will include many small structures such as jogs, serifs, and SRAF (sub-resolution assist features) with accompanying very small gaps between adjacent structures. The current generation of inspection systems is inadequate to meet these requirements. The architecture and performance of the new TeraScanHR reticle inspection platform is described. This new platform is designed to inspect the aforementioned reticle types in die-to-database and die-to-die modes using both transmitted and reflected illumination. Recent results from field testing at two of the three beta sites are shown (Toppan Printing in Japan and the Advanced Mask Technology Center in Germany). The results include applicable programmed defect test reticles and advanced 45nm product reticles (also comparable memory reticles). The results show high sensitivity and low false detections being achieved. The platform can also be configured for the current 65nm, 90nm, and 130nm nodes.

Keywords: ArF, 45nm, 32nm, reticle, defect, inspection, sensitivity, OPC, SRAF

1. INTRODUCTION

The current generation of reticle defect inspection systems has provided excellent performance for current IC manufacturing through the 65nm logic node, thus, ensuring defect free reticles to the industry (including the comparable memory nodes). These systems have been effective in finding critical reticle defects during reticle manufacturing to ensure high quality defect free reticles, and further, finding critical reticle defects, such as crystal growth and haze, which occur during reticle use, thus protecting wafer fabs from catastrophic yield losses.

However, the current generation of reticle defect inspection systems has inadequate optical imaging resolution and inadequate database modeling for the 45nm and 32nm logic nodes considering the small features and defects. This inadequacy typically results in high false detections and insufficient sensitivity to meet the needed quality requirements.

KLA-Tencor has developed a new reticle inspection platform, TeraScanHR, with the following improvements as compared to the prior TeraScanTR platform: (1) higher optical imaging resolution to better resolve small features, (2) higher precision database modeling to better represent small OPC in die-to-database inspection, and (3) higher speed image processing for higher productivity especially when using integrated modes (e.g. transmitted + reflected). The new TeraScanHR platform is based upon the field proven TeraScan family of systems introduced in 2003. The TeraScanHR platform can also be configured for the current 65nm, 90nm, and 130nm nodes.

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The technical aspects of the TeraScanHR platform are discussed, along with selected results from the field testing of two of the three beta systems; located at Toppan Printing in Japan, and the Advanced Mask Technology Center in Germany. The testing used applicable programmed defect test reticles to measure defect detection sensitivity, along with a large set of product and product-like reticles from the 90nm to the 32nm logic nodes to assess both sensitivity and inspectability when using the available pixel sizes (72/90/125nm) – also the comparable memory nodes. All three beta systems are currently being used for advanced production. Several pilot systems have also been shipped and are currently in field qualification, while manufacturing operations at KLA-Tencor are ramping for full production.

2. RETICLE INSPECTION DEVELOPMENT

KLA-Tencor introduced the original TeraScan platform in 2003 with die-to-die capability for the 90nm node. Since then, KLA-Tencor has further developed the TeraScan family to include: die-to-database capability, 65nm node capability, reflected light capability, and STARlight capability; the most recent platform being the TeraScanTR.

To serve the 45nm node advanced production requirements and 32nm node development requirements, KLA-Tencor has recently developed the TeraScanHR platform with higher performance and new capabilities. Following past practices, this platform can be configured as a variety of different models which are intended to cost effectively inspect reticles from the 130nm node to the 32nm node. In this way, a reticle manufacturer, or wafer fab, can purchase just the capability needed at the time, and then upgrade as more capability is needed in the future. A typical TeraScanHR system is shown in Figure 2-1 (note that the three electronic racks may be remotely located).

The new TeraScanHR platform continues KLA-Tencor's tradition of high resolution imaging for high performance reticle inspection. This technique uses significantly higher resolution imaging of the reticle than the wafer lithography system, thus allowing direct inspection of both the primary structures and the sub-resolution structures to ensure a high quality reticle. Furthermore, since the inspection is done at high resolution where actinic wavelength is less important, a single wavelength system can provide good performance inspecting reticles from a variety of lithographic wavelengths.

The new TeraScanHR has been designed for advanced production inspection of reticles for approximately the 45nm logic node and the 55nm half-pitch memory node. This includes typical binary (COG), 6% EPSM (including simple tri-tone), and dark field alternating PSM reticles. To provide the highest quality inspection, the system supports both transmitted and reflected light inspection modes which can be easily integrated into a single inspection.

The new TeraScanHR platform has been shown to have capability for development of 32nm logic reticles and approximately 45nm half-pitch memory reticles using the new 72nm pixel. Further, capability extensions are in development for more aggressive RET, such as Mask Enhancer, complex tri-tone, and chromeless. Finally, the platform has larger pixels with faster scan times which are intended for the 65nm logic node up to the 130nm node (also comparable memory nodes).

The development program has completed the internal testing phases using several prototype systems, as well as the field beta testing phase with three beta systems located at leading-edge reticle manufacturers. Several pilot systems have been shipped and are undergoing field qualifications, and K-T’s production line is currently ramping.
3. TECHNOLOGY

3.1. Image Acquisition

A simple block diagram of the TeraScanHR image acquisition subsystem is shown in Figure 3-1 with the changes from the previous TeraScanTR platform indicated. The TeraScanHR uses a high resolution microscope and linear sensor architecture with both transmitted and reflected illumination paths.

Referring to the top of the diagram, the illumination source is a 257nm wavelength continuous wave (CW) laser (>5500 hours lifetime). There is an Active Beam Steering subsystem to compensate for beam drift and to reduce laser replacement time. The Transmitted Illuminator has several different configurations that can be selected by the user at runtime. Two illuminator configurations are currently implemented: standard contrast for COG and EPSM reticles, and phase contrast for quartz etch reticles such as alternating, Mask Enhancer, chromeless, etc.

The phase contrast mode provides improved imaging contrast to quartz phase defects (bumps and divots) allowing for higher defect sensitivity. Transmitted illumination is the traditional mode used for inspection.

The reticle is inspected with the pattern surface down. The air bearing stage scans the reticle in one axis for continuous image pick-up, and then indexes in the other axis after each swath to provide a serpentine inspection path.

The custom designed objective images the reticle surface through the zoom lens onto the imaging sensor. The zoom lens allows different pixel sizes to be selected by the user at runtime; this provides faster scan times when a less sensitive inspection is desired – four pixel sizes are available depending upon the model (72, 90, 125, and 150nm). Image pick-up is done with a time-domain-integration (TDI) sensor which offers high speed continuous image pick-up at much lower light levels than a conventional CCD linear sensor.

The system also includes a reflected illumination optical path for reflected light inspection. Since the system uses a single imaging sensor, a switching device is used to select between transmitted and reflected illumination. This switching device is fast enough to switch illumination modes on a swath by swath basis during the inspection to allow an integrated inspection using both transmitted and reflected illumination (integrated T+R mode). Since each illumination mode has the best performance for different classes of defects and different geometry types, the integrated T+R mode provides the highest quality inspection.

To achieve the needed performance level, the development project redesigned several of the optical modules as indicated by the blue color and dashed boxes in Figure 3-1. The primary change was to provide a higher NA capability to resolve smaller lines, OPC, and defects (approximately 1.2x higher NA than the previous 90nm pixel TeraScanTR platform). The higher NA supports the new 72nm pixel. Additionally, the quality of the optical elements has been improved for better imaging uniformity to reduce false detections associated with small OPC.

The Autofocus subsystem uses a separate beam to maintain proper focus on the reticle surface throughout the inspection considering reticle surface flatness, tilt, vibration, thermal effects, etc. The TeraScanHR platform includes a new autofocus subsystem (AF2) which provides the necessary precision for the higher NA optics which has lower depth of
focus. The new autofocus subsystem uses an advanced pre-mapping technique which has improved capability to maintain proper focus, especially when inspecting reticles with significant topology such as the quartz etch types. To further improve imaging performance, the stage has been modified to achieve lower vibration levels.

At the bottom of Figure 3-1 are shown high resolution transmitted and reflected images of a binary reticle. Note that the sub-resolution clear serifs are fully imaged and clearly visible, thus allowing defects on the serifs to be readily detected directly and noted by the operator for proper repair. An oversize clear serif defect is present and visible in both the transmitted and the reflected images, whereas, a particle on the dark material is also present but is only visible in the reflected light image (dark spot).

As with lithography systems, slight amounts of mechanical or optical error will reduce overall system performance. Therefore, the new TeraScanHR platform was designed with opto-mechanical components capable of the most stringent inspection mode (72nm pixel die-to-database reflected light). The system can be configured into several models which are all built with substantially the same base hardware, therefore, a lesser model (e.g. 150nm pixel die-to-die) can be readily upgraded to a higher performance model (e.g. 72nm pixel die-to-database). This upgradeability allows a user to purchase a less capable model initially and then readily upgrade to a more capable model later when the need arises, thus optimizing capital expenditure.

3.2. Image Processing

Figure 3-2 shows a simple block diagram of the TeraScanHR image processing subsystem with changes from the previous TeraScanTR platform indicated. The Tera Image Supercomputer is a fully programmable and scalable multi-processor architecture using high-speed processors.

The transmitted or reflected image stream is stored in the Optical Data Memory. Several swaths are buffered to allow variable processing rates according to geometry density, thus improving the overall speed. Sophisticated alignment and defect detection algorithms are executed in the Image Compare Defect Detection block to provide both high sensitivity and low false detections. The basic detection method is to overlay a test image with a matching reference image and identify differences above a pre-selected size; since the images should basically match, any differences are the result of a defect. For die-to-die inspection, the test and reference images compared are from adjacent die; for die-to-database inspection, the reference image is reconstructed from the design or write database. For a STARlight inspection, the transmitted light image is compared to the reflected light image – any differences are the result of a contamination type defect.

The TeraScanHR development project included a new image computer with higher speed processors and with configurations containing 2x the number of processors compared with the previous image computer. The change is indicated by the blue dashed box in Figure 3-2. The additional processing power improves scan time for the more processing intensive modes; this can also allow multiple modes to be processed together with minimal inspection slowdown. For example, a transmitted light inspection and a reflected light inspection can be processed together without slowing the inspection station; this allows a much more cost effective T+R inspection than the prior TeraScanTR.
The additional processing blocks for die-to-database inspection are shown in the lower part of Figure 3-2. These processing blocks reconstruct a database image which will match the optical image. The database image is reconstructed in real time from the reticle design or write database. Starting from the left side of Figure 3-2, an off-line data preparation operation is performed to optimally organize and format the input database figures for inspection (rather than for design or writing). This step is done off-line; the resulting inspection-ready file is stored on the lower high speed disc. At runtime, as the optical system is scanning the reticle, the Segment Fetch block selectively accesses the appropriate figure segments of the database for the current swath and stores them in the Database Memory. As each geometry is processed for defect detection, the database figures are rendered (figures placed in the correct locations), and then modeled to match the optical image (coarse rounding and bias added). Sophisticated modeling algorithms are used to ensure that the database image exactly matches the optical image since any error reduces defect detection sensitivity. The image pictures at the bottom of Figure 3-2 represent the rendering and modeling of a database.

The development also included a new die-to-database defect detection algorithm, UHR, to provide much more precise modeling of small OPC structures in both transmitted and reflected light as compared to the previous UCF algorithm. The new UHR algorithm also includes full two-layer modeling for simple tri-tone and alternating PSM reticles – both in transmitted and in reflected light. The algorithm further provides the necessary framework to support other advanced reticle types (e.g. Mask Enhancer, complex tri-tone, CPL, etc). As noted above, the development also included new rendering and modeling hardware to allow faster processing of the more compute intensive UHR algorithm to minimize inspection slowdowns. The new processing hardware also includes faster off-line data preparation and faster run-time segment fetching to provide good throughput for the large databases associated with the advanced nodes.

Finally, referring to the right side of Figure 3-2, the test image is subtracted from the reference image to produce a difference image. Since the test and reference images should exactly match, the difference image should have a uniform gray background except where there is a defect. A defect is then indicated as either black or white, so the defect detectors flag the black or white regions. Any imaging errors, or overlay alignment errors, or database modeling errors will show as residual patterns in the difference image which are “noise”, thus reducing overall defect detection sensitivity. An indicator of a high performance inspection system is very little “noise” in the difference image (e.g. uniform gray background). Similarly, any mask uniformity error also creates “noise” in the difference image.

3.3. Image Acquisition Cut-away

A cut-away illustration of the Image Acquisition System (IAS) is shown in Figure 3-3. In addition (not shown), there is a separate utilities module, one or more image computer electronics racks, and a data preparation electronics rack (remotely located).

Referring to Figure 3-3, the Stage is in the middle, the Transmitted Illuminator is above, while the Optics Bench is below (contains the objective, zoom, sensor, and reflected illuminator). Reticles are loaded and unloaded from the front via either a Manual Load Port for unboxed reticles, or the Reticle SMIF Pod (RSP) Load Port (both can be installed simultaneously). A reticle library is included inside for queued operation. The stand-alone operator console can be located nearby.

The development included changes to the subsystems as indicated by the blue colored dashed boxes.

4. TEST RESULTS

The project recently completed the final phase of development - 4 months of field testing and tuning at three beta sites (December 2006 through March 2007). Selected results from two of the beta sites are reported here: Toppan Printing in Japan (Toppan), and the Advanced Mask Technology Center in Germany (AMTC).
Each beta site verified sensitivity and false detection performance with K-T’s standard programmed defect test reticles, as well as, unique test reticles for each site. The unique test reticles contained geometry patterns typical of the 32nm, 45nm, and 65nm logic nodes, as well as the 5xnm half-pitch memory node. These reticles were tested at both maximum sensitivity settings and production settings. Selected defect detection sensitivity data is shown in the sections below.

Production suitable detector settings with low false detections were determined using a variety of product and product-like reticles from the 45nm, 65nm, and 90nm logic nodes, and the 4xhp, 5xhp, and 7xhp memory nodes. These reticles were for ArF lithography, and included primarily critical layers of 6% EPSM, with some dark field alternating PSM, and EUV reticles.

Overall, the testing showed that the system generally had very good performance. The full area inspection of advanced product reticles with aggressive OPC was excellent, showing high sensitivity and low false detections. The system sensitivity was measured at production settings for many different defect types and showed overall very good performance – some weakness was noted on corner defects. The scan time was very good for the new T+R modes, although the beta sites commented that they would like faster scan time for the 72nm pixel die-to-database T+R mode.

4.1. Improved Imaging with New Image Acquisition
An indicator of the improved optical imaging uniformity of the new system is typically seen on small structures, such as SRAF, where imaging non-uniformity can be very apparent. Figure 4-1 shows a comparison of SRAF difference image noise between the previous 586 system (left side) and the new TeraScanHR 587 (right side). These difference images are from the same 65nm node reticle using the 90nm pixel and the previous UCF die-to-database algorithm. The previous system exhibits noticeable horizontal dark banding in the difference image due to the SRAFs. This banding will cause false detections or require lower detector settings resulting in reduced defect detection sensitivity. The lower noise of the TeraScanHR (right side image) is due to the improved imaging uniformity as compared to the previous system. The improved imaging uniformity is the result of the new autofocus subsystem, lower aberration optics, and lower vibration stage. In this example, there is still some noise in the 587 difference image which is caused by the older UCF algorithm and its limited modeling capability of small structures. The new UHR algorithm includes higher precision modeling which will result in lower noise difference images and lower false detection rates.

4.2. High Resolution and Improved Database Modeling
In addition to improved imaging performance as discussed in the previous section, the new TeraScanHR also includes high NA optics which allows a smaller pixel than the previous platforms. The new 72nm pixel allows the system to resolve small OPC structures, small lines and spaces, and small defects. Figure 4-2 shows the higher resolution by comparing a small dark extension defect imaged with the current 90nm pixel (left images) and the new 72nm pixel (right images). The 72nm pixel has about 40% higher modulation than the previous 90nm pixel (note the larger size and darker signal in the difference image). Additionally, the 72nm pixel includes the new UHR family of die-to-database algorithms which provide higher...
precision modeling resulting in lower noise in the difference image and therefore lower false detection rates.

Figure 4-3 shows the difference image from a 45nm logic gate layer with aggressive OPC being imaged by the new 72nm pixel, and the database modeled by the new UHR algorithm. The difference image shows very low noise on this small geometry which will result in low false detections and high detector settings.

4.3 Die-to-database Transmitted Defect Detection Sensitivity Result for 72nm Pixel and Spica-200-193 Reticle

Figure 4-4 shows typical sensitivity performance in die-to-database mode using the KLA-Tencor Spica-200-193 programmed defect test reticle. This test reticle is standard 6% EPSM for 193 lithography and includes a typical Semi-wire programmed defect test section in multiple linewidths; the smallest being 260nm dark lines (shown). This result uses the 72nm pixel die-to-database with transmitted illumination and the standard high resolution detectors set at maximum sensitivity (HiRes1 and HiRes2). Each gray box indicates 100% detection from 20 contiguous inspections. The upper number in the gray box is the defect size using the KLA-Tencor maximum inscribed circle (MIC) sizing method from SEM images. The lower number is the detection percentage. For the smallest defect detected 100% in each column, the defect size is also shown in a larger font below the printed size for easier reading. Note that small pinholes are difficult to manufacture, so none were present on the reticle for this upper portion (NP=no defect present). Also, pinholes are best detected with reflected light rather than transmitted light due to imaging effects.

4.3. Toppan Printing 45nm Process Level

The test reticles used at Toppan Printing were made with their latest 45nm process. This process showed significant improvements in linearity, corner rounding, and resolution versus the previous processes. Figure 4-5 shows a 57% improvement in linearity versus the previous 65nm process, while Figures 4-6 and 4-7 show the improvements in corner rounding (20%) and resolution, respectively.
4.4. TeraScanHR Defect Detection Performance using Toppan Programmed Defect Test Reticles

Toppan Printing designed two programmed defect test reticles for the purpose of testing advanced reticle inspection system performance ("Carbonate" and "Cyclics"). The Carbonate reticle is a line/space design while the Cyclics is a hole design (360nm and 420nm). The Carbonate test reticle includes several representative patterns for line/space critical layers typical of the 45nm node. These patterns contain aggressive OPC designs with jogs, serifs, and SRAF, and a variety of programmed defects on or near both primary geometry and OPC structures. Figure 4-8 shows the design and SEM images for one of the 45nm sections – the design is ArF 6% EPSM material with 160nm primary geometry and 70nm SRAF.

Figure 4-8: Toppan 45nm line/space programmed defect test reticle (Carbonate) showing design (left) and SEM images with sizes (right) for one section. 45nm design is ArF 6% EPSM material with 160nm primary geometry and 70nm SRAF

Figure 4-9 shows the defect detection performance of the 72nm pixel in the die-to-database and die-to-die transmitted light modes for the 45nm section of the Carbonate test reticle (selected defects shown). This test data shows both the sensitivity when using the maximum detector settings, and also when using production settings. The production settings were determined by inspecting more than 50 different patterns and selecting the tightest setting that provides low false detections. Note that the production settings provide virtually the same sensitivity performance as the maximum settings indicating both a very good inspection system and a very good mask manufacturing process. Note also that the die-to-database performance is very close to the die-to-die performance which indicates both very good database modeling and very good reticle uniformity (die-to-die typically has the highest performance since many system and
mask errors are common mode). Also shown is a red horizontal line which indicates the ITRS defect requirement for the 45nm node – note that the TeraScanHR 72nm pixel meets the requirement for these defect types. Toppan is currently obtaining aerial image measurements of the defects for a typical 45nm wafer process.

![Figure 4-9: TeraScanHR 72nm pixel sensitivity performance on Toppan 45nm line/space programmed defect test reticle (Carbonate) for selected defects. Maximum sensitivity and production sensitivity shown; red line indicates the ITRS requirement.](image)

Figure 4-10 shows the sensitivity relationships between die-to-die and die-to-database along with transmitted and reflected light all for the maximum sensitivity settings. This example uses the Toppan Cyclics test reticle which has various programmed defects using hole geometry patterns including both dense and isolated holes of various sizes. The hole pattern shown here is the 360nm dense pattern representative of the 45nm node. As shown in this example, the general relationships are: (1) die-to-die is more sensitive than die-to-database, (2) transmitted light is generally more sensitive than reflected light for dark defects, and (3) reflected light is generally more sensitive than transmitted light for clear defects. This suggests that the best overall defect detection performance is achieved when both transmitted and reflected light are used together. The green line shows the ITRS requirement.

![Figure 4-10: TeraScanHR 72nm pixel sensitivity performance on Toppan 45nm hole programmed defect test reticle (Cyclics) for selected defects and 360nm dense holes. Die-to-die and die-to-database performance shown for both transmitted and reflected light.](image)

Figure 4-11 shows selected defects from the 32nm node section of the Toppan Carbonate reticle as detected by the TeraScanHR using the 72nm pixel in the die-to-database transmitted (TL) and reflected (RL) mode. The defect images from the TeraScanHR are shown, including the
difference images which show minimal residue indicating good database modeling. The defect SEM images are also shown with the measured sizes using the Toppan size method. To represent the 32nm node, the reticle uses 150nm primary lines and 50nm SRAFs. In the lower right, a 31nm dark extension defect on a 50nm SRAF was readily detected – this performance level is the ITRS target for the 32nm node, suggesting that the system may be extendable to that node.

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<tr>
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<th>Database</th>
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<th>Difference</th>
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<td>Mis-size SRAF (Large)</td>
<td>![Database Image]</td>
<td>![Optical Image]</td>
<td>![Difference Image]</td>
<td>Def. Size: 12nm</td>
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Figure 4-11: Selected defects on Toppan’s 32nm node Carbonate test reticle as detected by the TeraScanHR 72nm pixel die-to-database transmitted (TL) and reflected (RL) mode.

Figure 4-12 shows the defect images and defect map of an over-size SRAF defect in transmitted mode (32nm node section of the Toppan Carbonate test reticle); the enhanced edges function is enabled to more easily discern the geometry. Note again the low residue in the difference image indicating very good database modeling of the small SRAF. The defect map has no nuisance and no false detections suggesting a good mask manufacturing process and a good inspection system.

Figure 4-12: Over-size SRAF in the optical image as detected by TeraScanHR 72nm pixel die-to-database transmitted mode. Toppan’s Carbonate test reticle in the 32nm node section with 150nm primary lines and 50nm SRAF.

4.5. TeraScanHR Performance on Advanced Product Reticles using Die-to-database Transmitted Light Mode

At all three beta sites, a number of product and product-like reticles were used to test the large area false detection performance of the TeraScanHR, and to determine the “production settings” so that defect detection performance under
production conditions could be assessed. Advanced production critical layer reticles from the 45nm node were used to
test the 72nm pixel, while current production reticles from the 65nm node were used to test the 90nm pixel (latter data
not shown) - comparable memory reticles also used. Both die-to-die and die-to-database modes were tested in both
transmitted and reflected illumination; the standard HiRes detectors were used, along with the optional Litho2 detector
for hole layers. The system demonstrated excellent inspectability performance at all three beta sites with low false
detections using high detector settings (most sensitive). Selected defect maps and difference images are shown from
Toppan and AMTC – actual defect images are typically not shown due to confidentiality of the background geometry.

Figure 4-13 shows the large area inspection result from a
Toppan manufactured 45nm logic active layer inspected
with the 72nm pixel in the die-to-database transmitted light
mode. Production detector settings were used which
resulted in 27 total detections. The reticle is standard ArF
6% EPSM material – the design includes small clear SRAF
type OPC. The difference image is for a slight over-size
clear SRAF defect. Note the nearly uniform gray image
which indicates very good modeling using the UHR
algorithm and a very uniform mask manufacturing process.

Figure 4-14 shows the large area inspection result of a
Toppan manufactured 7xnm half-pitch DRAM hole layer
inspected with the 72nm pixel in the die-to-database
transmitted light mode. Production detector settings were
used which resulted in 21 total detections. The reticle is
standard ArF 6% EPSM material. The difference image is
for an under-size hole defect. Note the nearly uniform
gray image which indicates very good modeling using the
UHR algorithm and a very uniform mask manufacturing
process.

Figure 4-15 shows the large area inspection defect map of an AMTC
manufactured 4xnm half-pitch advanced reticle inspected with the 72nm
pixel in the die-to-database simple tri-tone transmitted light mode; chrome
regions were included in the inspection area and were inspected along with
the EPSM regions. Production detector settings were used which resulted
in 23 total detections. The reticle is standard ArF 6% EPSM material. The
low false detection and nuisance detection rates indicate very good optical
imaging and database modeling along with a very good mask
manufacturing process. This same reticle was inspected on the existing 576
using the 90nm pixel in the die-to-database simple tri-tone mode – the
reticle exhibited excessive false detections.

Figure 4-15: 4xnm half-pitch advanced reticle - large area 72nm pixel die-to-
database transmitted light inspection using the simple tri-tone
mode; inspects the clear, shifter, and chrome regions, using
production detector settings - 23 total detections. (reticle image
hidden)
4.6. Transmitted and Reflected Illumination Modes – Highest Quality Inspection

KLA-Tencor previously developed reflected light inspection capability as part of the earlier TeraScanTR project (completed in 2005). This project resulted in STARlight2 capability, as well as die-to-die and die-to-database reflected light capability. Since STARlight2 simply compares transmitted light images to reflected light images, it is the easiest and least expensive method to detect contamination defects, however, it does not reliably find geometry pattern defects such as pinholes, pindots, extensions, breaks, etc. These geometry pattern defects are best detected using either die-to-die or die-to-database mode. Testing of the die-to-die and die-to-database reflected light capability showed that higher sensitivity can be achieved versus transmitted light typically for clear pattern defects (e.g. pinholes, clear extensions, clear bridges, etc.). Similarly, reflected light typically achieves higher sensitivity versus transmitted light to defects on small clear lines and clear SRAF. Finally, reflected light can typically achieve higher sensitivity to defects on top of the opaque areas such as particles, or residual chrome on EPSM material. Therefore, the highest quality inspection can be achieved when using both transmitted and reflected light modes in die-to-die or in die-to-database modes to detect both pattern defects and contamination defects. To facilitate such an inspection, both the previous TeraScanTR platform and the new TeraScanHR include an “integrated mode” capability which allows two or more inspection modes to be integrated into one inspection with one setup, one scan, one review, and one report. When transmitted and reflected light modes are integrated, it is known as “T+R”, and can be used in both die-to-die and die-to-database modes.

As mentioned previously, the new TeraScanHR includes a new image computer with higher speed processing capability. This allows productivity improvements by reducing scan time for several inspection modes as compared to the previous TeraScanTR platform. Specifically, scan times are significantly improved when using transmitted and reflected light inspection modes together in the same inspection (“integrated”). Similarly, scan times are improved when inspecting dense hole layers with the high sensitivity Litho2 detector. Finally, scan times are improved for reticles with many die when using the die-to-die inspection mode for some models.

As shown in Figure 4-16, for the previous TeraScanTR platform, the scan time for a die-to-die or die-to-database T+R inspection requires approximately twice the scan time as transmitted or reflected alone due to the heavy image processing computation requirements. This longer scan time has limited the usefulness of the T+R modes to date. As mentioned earlier, the new TeraScanHR includes much more image processing computational capability which allows full speed operation for most T+R modes. These “Fast T+R” modes include: (1) 72/90/125/150nm pixels in die-to-die mode with COG, EPSM, and tri-tone reticle types, and (2) 90/125/150nm pixels in die-to-database mode for COG and EPSM reticle types (not tri-tone). Fast T+R is not currently available for the 72nm pixel die-to-database mode – Standard T+R is available for COG, EPSM, tri-tone, and altPSM reticle types.

The previous 45nm active layer (see Figure 4-13) was also inspected with the 72nm pixel die-to-database mode in reflected light rather than the previous transmitted light. Figure 4-17 shows a clear extension defect that was detected in reflected light that was not detected in the transmitted light inspection. So, by inspecting with integrated T+R mode this additional defect would have been detected thus providing a higher quality result. Note that the difference image in reflected light mode has a very low residue indicating very good modeling in reflected light by the UHR algorithm, and a very good mask manufacturing process.

Figure 4-17: 45nm active layer - clear extension defect detected in die-to-database reflected light mode and not detected in transmitted light mode.
The previous 7xnm half-pitch DRAM layer (see Figure 4-14) was also inspected with the 72nm pixel die-to-database mode in reflected light rather than the previous transmitted light. Figure 4-18 shows a defect that bridges two holes – this defect was detected in reflected light but was not detected in the transmitted light inspection. So, by inspecting with integrated T+R mode this additional defect would have been detected thus providing a higher quality result. Note the difference image in reflected light mode has a very low residue indicating very good modeling in reflected light by the UHR algorithm, and a very good mask manufacturing process.

Figure 4-18: 7xnm half-pitch DRAM layer - defect bridging two holes detected in die-to-database reflected light mode and not detected in transmitted light mode.

A 4xnm half-pitch DRAM hole layer was inspected in die-to-die integrated T+R mode using both the HiRes detectors and Litho2 detector (Litho2 in T only). The reticle was manufactured by the AMTC and is standard ArF 6% EPSM material. The inspection used production detector settings and resulted in low false detections. Figure 4-19 shows over-size clear SRAF defects detected (upper images) and under-size holes (lower images).

Figure 4-19: 4xnm DRAM hole layer inspected in die-to-die mode using integrated T+R with 72nm pixel.

5. CONCLUSIONS

The new TeraScanHR advanced die-to-database and die-to-die high-resolution reticle defect inspection platform has been developed to meet the reticle qualification requirements of the IC industry for the 45nm logic node and 55nm half-pitch memory node. The system is also designed to be extendable to the 32nm logic and 45nm half-pitch memory nodes. The platform further includes larger pixels suitable for larger nodes. The new platform is based upon the previous field proven TeraScan and TeraScanTR systems.

Three field beta systems have been tested in die-to-database and die-to-die transmitted and reflected illumination modes using numerous programmed defect test reticles and product reticles representative of the 45nm node (and comparable memory nodes), as well as early reticles from the 32nm node. These reticles included COG, EPSM, and altPSM types, with various OPC styles (serif, jog, and SRAF). Data from the testing showed that the platform generally met the targets for high sensitivity, low false detections, and scan speed - selected supporting data from Toppan and the AMTC have been shown in this paper. Testing of the larger pixels was also performed using current generation reticles (65nm and 90nm – data not shown).

The higher NA optics, new autofocus, smaller pixel size, and improved rendering and modeling algorithms of the new platform showed significant improvements in inspection capability of small linewidths, small defects, and aggressive OPC versus the previous TeraScanTR platform. In addition, the new image computer gives the system productivity improvements by reducing scan time for some situations and modes. Finally, reflected light inspection is now a more viable inspection mode since it can now be integrated with transmitted light with no additional scan time for some
modes. Using integrated transmitted and reflected light inspection provides the best defect detection capability and results in the highest quality reticles to the industry.

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- Beta Sites including Toppan Printing, and the Advanced Mask Technology Center
- KLA-Tencor RAPID Applications Team for data collection and analysis

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