Automating Defect Disposition in Fabs and Maskshops

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ABSTRACT

ADAS (Automated Defect Analysis Software) is the first product to fully automate mask defect analysis for mask shops and fabs. ADAS classifies and dispositions photomask defects quickly and accurately. Disposition is based on defect size and printability measurements from simulation.

Full analysis of inspection reports with 100 defects requires 2 seconds. Printability measurements match AIMS within 6 percent at 3 sigma on 45 nm test masks. Repeatability is 5 percent at 3 sigma over multiple inspections. ADAS can reduce the need for production AIMS measurements by 90% and eliminate operator review errors and the re-pelliclizations they cause. ADAS increases overall inspection efficiency for mask shop first-inspection and final inspection. It can automate fab requalification inspections and eliminate the need for incoming inspection.

Keywords: mask inspection, disposition, defect specs, simulation [+]

1. INTRODUCTION

This paper discusses the use of ADAS (Automated Defect Analysis Software) from AVI. ADAS is a Windows software application that reads inspection reports from all advanced mask inspection tools, analyses all the defects in each inspection using the defect images, and then generates a report of classified and dispositioned defects.

ADAS has been developed by AVI with cooperation and ongoing support from DNP, Photronics, Toppan, Hoya, TSMC, Samsung, Hitachi, Qimonda, TI, Freescale, Micron, UMC, NEC, Lasertec, and others.

Photomask defect disposition is the last significant manual step in photomask and wafer processing to be automated. Photomask defects have been analyzed and dispositioned by operators for almost 30 years. This operator analysis has limited the kinds of defect specs and statistics that could be used. Accurate disposition of photomask defects has become more critical because of the increasing cost and risk of repairing defects in small geometry.

Photomasks are typically inspected at four production steps: First inspection (after etching), final inspection (after the pellicle is applied), incoming inspection at the mask customer site (fab), and requalification inspections at the fab to detect contamination, haze and crystals that develop as the mask is used. Advanced processes often use other inspections such as mask blank inspection and ADI (After develop inspect). All of these inspections benefit from automated analysis and disposition, and especially from the ability to quickly analyze thousands of defects track defects from inspection to inspection, even when using different types of inspection tools.

Defect analysis and disposition at each of these steps has two purposes: 1) Find over-spec defects that must be repaired or cleaned and 2) collect defect type and size statistics to be used for process control.

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These two purposes are now accomplished manually, using operator judgment. This paper discusses using ADAS to automate the defect analysis and disposition process. This automation promises significant cost reductions as ADAS is integrated into manufacturing,

2. THE FUTURE OF DISPOSITION

An ideal situation for photomask defect analysis combines all the relevant data from a mask into one software product so that defect images from all inspection tools and review tools are analyzed with the same criteria, as seen in figure 1.

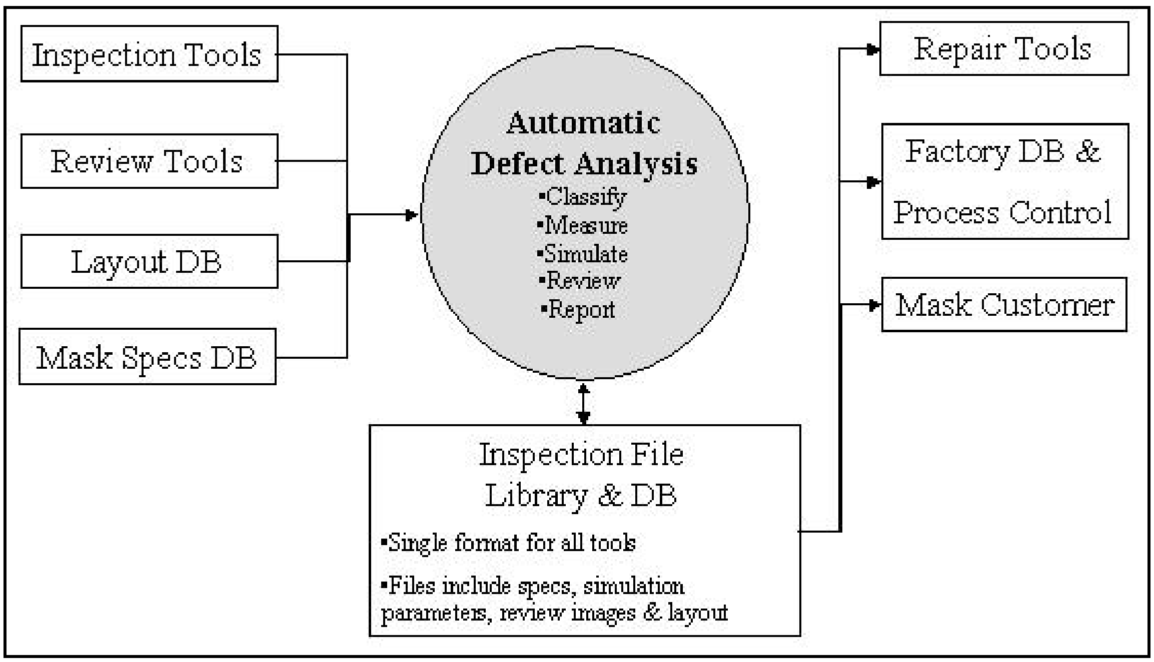

Figure 1: Automatic defect analysis environment

This unified environment has important benefits—providing the same high quality analysis from data from all tools, and allowing improved analysis algorithms to be applied to all tools. Having a standard interface for including the mask disposition specs and layout information reduces the manual effort and potential for error that is present in current processes.

This concept uses one inspection file format for all inspections. This file format includes the inspection data, the mask specs (defect specs and simulation conditions), information from the mask layout, and images from review and repair tools. The result of this is that mask shop engineers and mask customers have all the information they need to understand and correct production problems in one file. For example, the inspection and simulator specs used can always be quickly verified to be correct at review.

Another advantage of such unified interfaces for the photomask industry is that new repair, review, and inspection tools can be integrated into manufacturing more quickly, using fewer maskshop resources.

Figure 2 shows how ADAS has implemented this ideal situation through cooperation with the major mask shops and tool vendors.

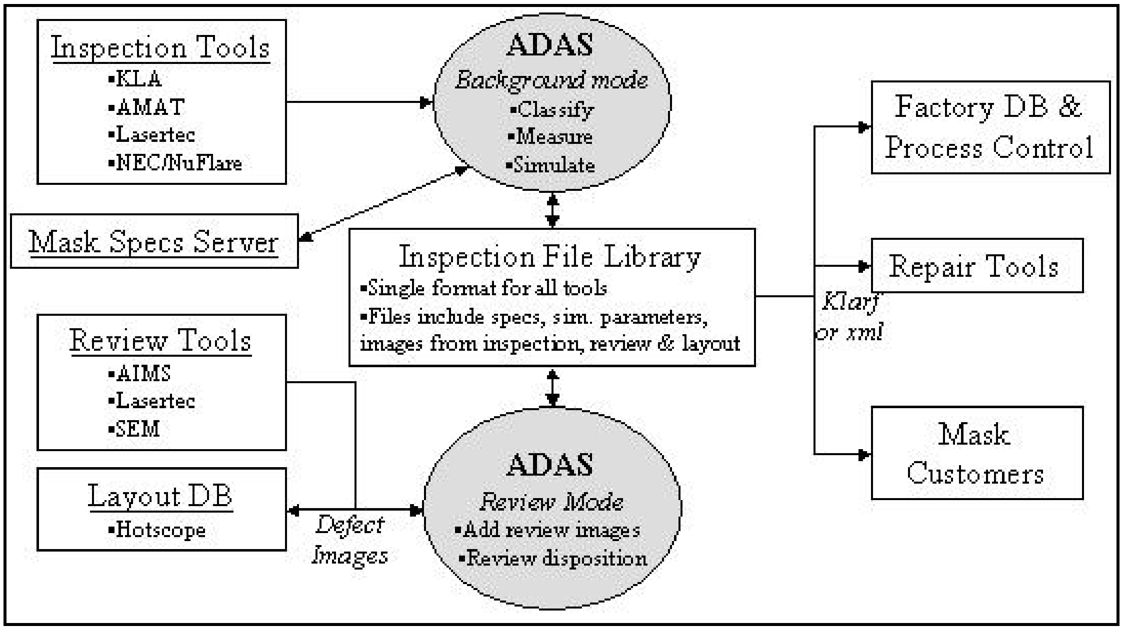

Figure 2: ADAS Inputs and Outputs

The "Background" and "Review" modes use identical software. In smaller mask shops and during testing all operations are performed interactively in the review mode.

Inspection and review tool interfaces are written specifically for each tool, with support from the tool vendor in most cases. Inspection reports can be written to disk in KLARF format, xml, or ADAS's binary format, called IRF, which contains all the mask data and images in one file. ADAS currently reads inspections from six inspection tools from four vendors, plus review data from AIMS, Lasertec MRS-248, and common SEM microscopes.

Mask customers use the IRF file containing all information, which they read at no cost because the ADAS license purchased for the inspection tool applies to all users of data from that tool. Repair tools generally read the KLARF file, although in the future they can make use of the alignment and layout data from the binary or xml file.

The ADAS "Mask Specs Server" interface uses a simple XML file or socket interface. The mask shop or fab provides the inspection and simulation specs for a requested mask in a standard XML format. This data is used and saved with the inspection.

ADAS can read mask layout images into the inspection associated with each defect, in a manner similar to review images. This allows fast, repeatable decisions about the usage of mask features that contain defects. This interface will also allow the mask layout design to include "Design intent" or "Feature Usage" information that is included and used automatically in the ADAS disposition logic and inspection reports.

ADAS Review mode has a complete set of interactive analysis tools that allow visualization of image statistics, from all the inspection and review tools, as well as the simulation images. This allows all inspection and review images to be analyzed with a uniform, repeatable set of tools.

3. BENEFITS OF AUTOMATED DEFECT ANALYSIS

The benefits of automating defect analysis are described here going backwards from the end of the production process.

3.1. Use In fabs

Automation of requalification inspection disposition allows masks to be moved into production faster, reduces the frequency of inspections and cleaning, and reduces the number of repeater defects that are missed or misclassified. Most inspections are analyzed completely with no manual review, or with less than two minutes of review, including inspections with 1000 to 5000 defects. This means that the mask can be put in use as soon as it is removed from the inspection tool. When manual review is needed it is completed quickly because only ambiguous defects need be reviewed, and the defects' printability is estimated by ADAS simulation. The mask engineer only needs to analyze ambiguous defects.

For crystal defects, ADAS uses a sensitive detection algorithm using the raw images from the inspection tool. Crystal defects are transparent, so their unpredictable phase errors cause printability problems 5 times larger than if a similar defect were opaque. Experience at fabs has shown that a mask must be cleaned as soon as any crystal defects are large enough to be detected by a mask inspection tool.

When a mask has no crystal defects the accurate and complete defect size data from ADAS allows process engineers to predict more accurately when a mask should be re-inspected or cleaned. In addition to the "Adders" count of new defects, ADAS computes the growth rate for the fastest growing defects.

Incoming inspections can often be eliminated for two reasons. First, the ADAS analysis (of the final inspection) is objective, so the mask customer does not need to worry about mistakes from the operator. The fab engineer can review the final inspection report from the mask shop to confirm that the correct specs were used and to confirm any operator decisions on ambiguous defects. Second, the mask shop final inspection can be used as the comparison used for detecting adders, even if the final inspection was performed on a different inspection tool type than is being used for the requalification inspections.

Finally, a team of fab engineers and operators do not need to be trained and maintained in the art of analyzing mask defects because the most advanced analysis in the industry is available in ADAS software. Some analysis skills are required to disposition ambiguous defects, but that is reduced to an average of 2 minutes per mask total, including preliminary and final analyses.

3.2. Use In mask shops

In final inspections ADAS provides valuable data for the mask customer as described above. It reduces the frequency of re-pelliclizations because its accurate simulation and access to layout information allows a high level of certainty about whether a detected defect will affect the final silicon. In addition, its automatic analysis almost eliminates the concern about an operator missing a subtle or confusing defect.

First inspections benefit from the speed and accuracy of ADAS. Inspections with a dozen defects or thousands of defects are completely analyzed in less than one minute, including complete statistics of defect sizes and types. This data allows accurate feedback to process engineers so they can correct problems quickly, with all the data collected from all inspections.

As with fab inspections, ADAS frees significant manpower from tiring defect review. This frequently results in higher utilization of the expensive inspection tools.

The false-defect statistics that ADAS provides allows the mask shop or fab to schedule maintenance on inspection tools when the rates of focus-error or white-spot error exceeds a certain level.

ADAS can significantly reduce the need for AIMS analysis of defects before repair by estimating the printability of defects based on simulation. Simulation of defects based on images from an inspection tool cannot be as accurate as actual measurement at the stepper conditions with AIMS, but ADAS printability measurement reduces the range of uncertainty significantly, thereby reducing the number of defects measured with AIMS.

Typically less than 1.4% of real defects cause CD errors between 2% and 15%, as computed from a sample of 15 60-90 nm node production masks. Defects with an ADAS CD error below 2% can be safely assumed to be non-printing,

4. ADAS ANALYSIS STEPS

ADAS processes defects in manner similar to how operators analyze inspections, except, of course, ADAS uses numerical analysis for improved accuracy and repeatability.

The first step is to create a good reference image. In starlight inspections the reference image must be generated from the transmitted and reflected defect images. In die-to-die inspections the defect image must be determined from the two images provided. In all cases sub-pixel alignment and intensity calibration between the defect- and reference images are performed to insure that the reference image gives the best result.

Now that a reference image is available, the feature type is determined, such as iso-clear, iso-dark, contact, line-end, corner, SRAF, etc. Much of the following analysis depends on the feature type.

The next step is to detect a large variety of false defects, such as focus error, white-spots, rendering errors in D-DB inspections, and image-warping that occurs in certain inspection tools. Typically 65% of detected defects are false—caused by problems in the inspection tool.

After eliminating false defects, the defect type is determined. ADAS is limited to the images available, of course, so with defects that do not have reflected images, the decision to call a defect is contamination or hard is based on secondary information such as if the inspection was done in a mask shop or fab.

Next the defect size on the mask images (transmitted and reflected) are measured. Both the area and the transmission error are measured.

Finally the transmission image is simulated, based on the exposure conditions given for this mask. Then the CD error is computed for defects on an edge. For isolated defects the "percent printability" is computed. An isolated defect (or SRAF) that is 100% printable will barely print. A "95% printable" defect may print if the exposure changes by 5%.

There are two main defect specs: 1) The "defect size" spec which judges according to the defect size (square root of area) in the mask image; 2) the simulator CD error spec which uses the CD error measured in the simulator image. The defect is dispositioned "Under-spec" or "Over-spec" according to the given defect specs and the feature type, defect type, defect size, and printability. Finally the defect is assigned a class (1A, 1B,… etc) according to a user defined table similar to the one shown in figure 3.

Defect type	Under-spec Class	Over-spec Class
Unprocessed	2D_Review	2D_Review
NoImage	2D_Review	2D_Review
Undefined	2D_Review	2D_Review
Multi	2D_Review	2D_Review
RepairSite	4B_Repaired_defect	4B_Repaired_defect
Crystal	4D_False /_nuisance	4A_Cont_on_clear
Stain	4D_False /_nuisance	4A_Cont_on_clear
ThinChrome	4D_False /_nuisance	2B_Intrusion
CtmClear	1D_In_spec	4A_Cont_on_clear
CtmEdge	1D_In_spec	4A_Cont_on_clear
CtmDark	4C_Cont_on_dark	4A_Cont_on_clear
CtmHT	4C_Cont_on_dark	4A_Cont_on_clear
Pinhole	1D_In_spec	2A_Pin_hole
Pindot	1D_In_spec	1A_Pin_dot
Intrusion	1D_In_spec	2B_Intrusion
Extension	1D_In_spec	1B_Extension
Contact	1D_In_spec	2B_Intrusion
Placement	1D_In_spec	2B_Intrusion
Linewidth	1D_In_spec	2B_Intrusion
LineEnd	1D_In_spec	2B_Intrusion
SRAF	1D_In_spec	2B_Intrusion
Corner	1D_In_spec	2B_Intrusion
Unprintable	4D_False /_nuisance	2D_Review
Nuisance	4D_False /_nuisance	2D_Review
RenderErr	4D_False /_nuisance	2D_Review
RefEdgeErr	4D_False /_nuisance	2D_Review
FocusErr	4D_False /_nuisance	2D_Review
WhiteSpot	4D_False /_nuisance	2D_Review
SLStripes	1C_Bright	1C_Bright
Bright	3A_Cr_on_atten	3A_Cr_on_atten
CrOnAtten	4D_False /_nuisance	2D_Review

5. ADAS SPEED AND ACCURACY

ADAS analyzes 30-100 defects per second, including simulation and all measurements, as shown in table 1. Manual review usually takes less than one minute because the defects are sorted by severity, and only the over-spec defects are reviewed.

Table 1: ADAS analysis speed for various mask nodes and defect counts (using 2.3 GHz dual core PC)

Defects / Mask node	**90 nm**	**65 nm**
100 defects	1.3 seconds	2.5 seconds
1000 defects	11 seconds	22 seconds
5000 defects	30 seconds	55 seconds

There are several types of accuracy that are optimized in ADAS. First is classification accuracy, especially detection of false defects. False defect detection is vital because measurements of false defects tell nothing about the mask, and waste considerable operator time. Second is simulator accuracy, the relationship between simulator CD errors measured by ADAS, compared to measurements of the same defect measured on a suitable AIMS tool. Third is simulator repeatability. Repeatability is related to the noise in the image coming from the inspection tool, magnified by the simulation algorithm.

ADAS measures defect size and transmission error accurately and repeatably because it uses quantitative algorithms, but the interpretation of those measurements varies significantly between each mask shop and fab. For this reason defect sizing accuracy is not discussed. Earlier AVI papers discuss this issue in detail.

Defect size repeatability

5.1. Classification Accuracy

Classification accuracy is measured and recorded automatically by comparing ADAS defect classification to the operator classification. Classification differences are divided into four categories: 1) Same, 2) Name change, 3) ADAS found, 4) ADAS missed.

In "Name change" defects ADAS and the operator agree that a defect was above-spec or below-spec. In "ADAS Missed" defects the operator classifies a defect over-spec, but ADAS classifies it under-spec; and in "ADAS Found" ADAS classifies a defect over-spec, but the operator calls it under-spec. The "ADAS Missed" and "ADAS Found" defects were examined and a decision was made visually regarding the correct defect classification.

In this study "Name change" defects are considered to be correctly called by ADAS because these defects would not result in any missed over-spec or excess over-spec defects requiring review. A random sample of these defects shows that most were ambiguous differences between "under-spec" and false defects or small contamination vs. extension. In most cases careful review favored the ADAS classification, although the difference would not affect the disposition of the mask.

This test was performed with 24 inspections from a memory fab and 13 inspections from a captive mask shop. Both samples included masks from 45 nm to 130 nm nodes, totaling 13,000 defects.

The critical classification accuracy measures are ADAS' ability to detect all (not miss any) real defects, and its ability to correctly reject false defects. ADAS correctly detected all but 2 real defects in this sample of 13,000 defects giving a real defect detection accuracy of >99.9%. The false defect detection rate was >99%, leading to an average of one defect per inspection where the engineer decided that a defect called over-spec by ADAS was actually a false defect.

5.2. Simulation / Printability Accuracy and Repeatability

Simulation testing was performed by inspecting two defect test masks (LS 65 nm half-pitch, and contact 209 nm half-pitch) ten times each with 72 nm pixels and ten times with 90 nm pixels. The smallest defects detected were measured on AIMS, and the ADAS simulation CD error values were compared to the AIMS measurements. Only two extension defects with AIMS CD error below 12% were detected with 72 nm pixels, and none were detected in the inspection with 90 nm pixels. One intrusion with CD error below 12% was detected, and four contact holes with CD error below 11% were selected from eleven detected. These four contact holes were also detected in the 90 nm pixel inspections.

Figure 4 shows the mean difference between ADAS CD error measurements and AIMS CD error measurements. The mean difference between ADAS and AIMS was 1.2%, and the 3-sigma deviation was 2.7%.

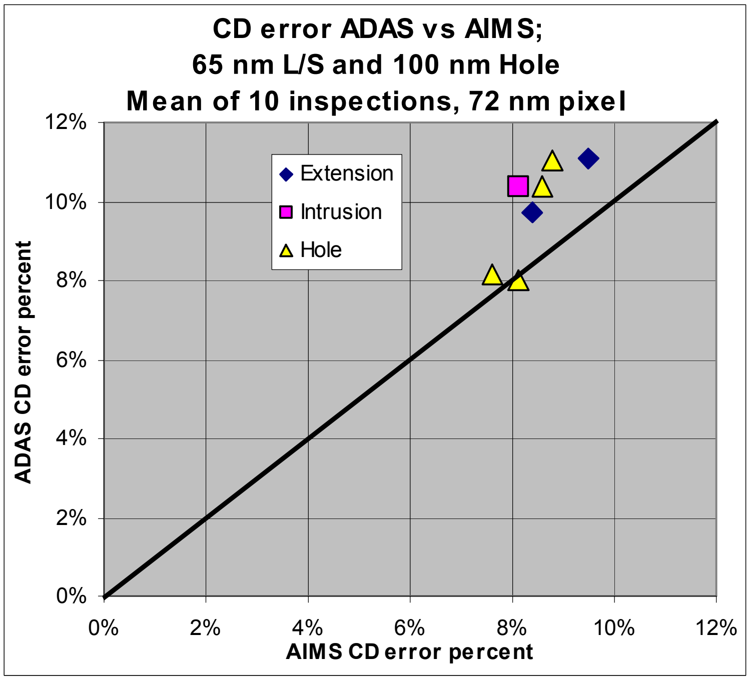

Figure 4: CD error measurement comparison ADAS – AIMS

For inspections with 90nm pixels the results were similar.

The repeatability measurement was performed by measuring the CD variation for each of the seven selected defects over the 10 inspections. The result is shown in table 2.

Table 2: ADAS CD error measurement repeatability for 45 nm node inspected with 72 and 90 nm pixels

	72 nm pixel	**90 nm pixel**
Edge defects 65 nm hp L/S	5.1%	Not detected
Contact defects 100 nm hp	5.3%	3.8%

The notable outcome is that at the 45 nm node the variability due to pixel noise in the source image is four times the average difference between ADAS and AIMS, and double the 3 sigma deviation between ADAS and AIMS. Combining these two error sources (accuracy and repeatability) in quadrature gives total 3 sigma deviation of 5.8%

Preliminary work with contamination defects on 45 nm node masks indicates that the variation in CD error accuracy range compared to AIMS is about double the value for hard defects, giving a total range of 7.5%. This means that the ADAS CD error threshold should be set to 2.5% in order to detect 99.7% of defects causing 10% CD error or more.

Future work will reduce this repeatability range by algorithm improvements, although large improvements are unlikely because these defects are barely detectable to the inspection tool.

6. SUMMARY

ADAS reads inspection reports from all current mask inspection and review tools. It classifies false defects with accuracy above 99%. It classifies real defects with accuracy above 99.9%, compared with operator accuracy of about 97%. ADAS defect size measurement is highly repeatable because it uses accurate sub-pixel reference image alignment algorithms and quantitative measurement methods.

ADAS can reduce the number of defects requiring AIMS analysis by 90%. It uses an accurate simulation engine that has been verified on 45 nm process masks with simple and exotic illumination apertures. CD error measurement accuracy relative to AIMS is 6 percent at 3 sigma for 65 nm L/S patterns. Reproducibility error due to image variability from a KLA 5xx, 72 nm pixel inspection is 5 percent at 3 sigma.

7. CONCLUSION

ADAS fulfills the requirements for a productive automated defect disposition and analysis system. It implements consistent disposition rules for all inspection tools, review tools and operators.

In fabs ADAS can fully automate most inspection analysis while increasing the inspection and cleaning intervals. It does this with accurate printability simulation and by providing complete and accurate defect increase and growth statistics.

In mask shops ADAS will accelerate delivery and reduce costs by reducing repairs and AIMS analysis. It also allows fabs to move to printability specs because each defect is simulated. This will reduce un-needed repairs and waiver requests.

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