Increased Productivity of Repair Verification by Offline Analysis of Aerial Images

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ABSTRACT

Using AIMS™ to qualify repairs of defects on photomasks is the industry standard. AIMS™ provides a reasonable matching of lithographic imaging performances without the need of wafer prints. The need of utilisation of this capability by photomask manufacturers has risen due to the increased complexity of layouts incorporating aggressive RET and phase shift technologies as well as tighter specifications have pushed aerial image metrology to consider CD performance results in addition to the traditional intensity verification.

The content of the paper describes the utilisation of the AIMS™ Repair Verification (RV) software for the verification of aerial images in a mask shop production environment. The software is used to analyze images from various AIMS™ tool generations and the two main routines, Multi Slice Analysis (MSA) and Image Compare (IC), are used to compare defective and non-defective areas of aerial images. It is detailed how the RV software cleans "non real" errors potentially induced by operator misjudgements, thus providing accurate and repeatable analyses all proven against the results achieved manually.

A user friendly GUI drives the user through few simple, fast and safe operations and automatically provides summary tables containing all the relevant results of the analysis that can be easily exported in a proper format and sent out to the customer as a technical documentation. This results in a sensible improvement of the throughput of the printability evaluation process in a mask manufacturing environment, providing reliable analyses at a higher productivity.

Keywords: photomask, repair, AIMS™, CD control, aerial image.

1. INTRODUCTION

The analysis of an aerial image is a comparison between defective and non defective areas acquired according to the litho parameters provided by the customer. Either it is performed with ROI or IMAGE COMPARE methods, the best conditions for the measurement must be defined by the operator through the optimization of several parameters, such as the alignment of the two images, the identification of the maximum peak of their intensity levels and the threshold at which the CD must be performed. Nevertheless all of them could be considered fairly simple operations, they are however operator dependent and some slight potential difference linked to human factors could affect the final result.

The growing complexity of high end mask layouts, together with the increasing demand of improving the CD control tolerance, requires a higher quality of the profiles of the aerial images being evaluated as well as of that of their alignment before performing the analysis. As per the high costs of such products, this leads to the need of removing all the potential errors that could negatively affect the result of the evaluation and raises the need of evaluating tools that can provide results consistently free of potential "non real" errors.

The Repair Verification software, purposely designed to accomplish such tasks, is an off line software package that allows evaluating .MSM images collected with all the generations of AIMS™ tools. It works on images stored on the customer server and can then run concurrently with the main application loaded on the PC that manage the hardware of the tools. This results in a maximization of the use of the AIMS™ tool for the process of acquisition of the images, with no tool time spent to analyse images and produce the needed documentation.

The paper aims to benchmark the performances of the RV software with respect to the manual procedure currently used in a manufacturing environment, with a particular focus to accuracy and throughput aspects.

2. EVALUATION OF THE RV SOFTWARE

2.1 Achievements with the ROI option

As per any tool moved into the manufacturing environment, the RV software performances need to be evaluated and compared with those achieved in production with the procedure in use in order to guarantee continuity and homogeneity of the evaluation results being delivered to the customer. Accuracy, reliability, easiness of use and proper format of the exportable results were then part of the evaluation process with both the comparison options available on the tool, ROI (Region Of Interest) and IC (Image Compare). The expected improvements must be at no or minor expenses for the manufacturing activities.

At operating level the way the software works is much simpler and faster than that used with the manual operations. It is just matter of drawing a slice on the defective-repaired area and a further one on the reference target, set the nominal value of the feature and run the analysis mode. CD and intensity errors will be automatically calculated for all the needed focal planes and the result can be exported as a text file to be attached to the final documentation. The four quadrants of figure 1 display the image to be analyzed, the intensity profiles and the CD measurements at all the defocused planes and the summary of the result. The figure 2 contains the exported .txt file of the summary section, with all the relevant parameters of the analysis result.

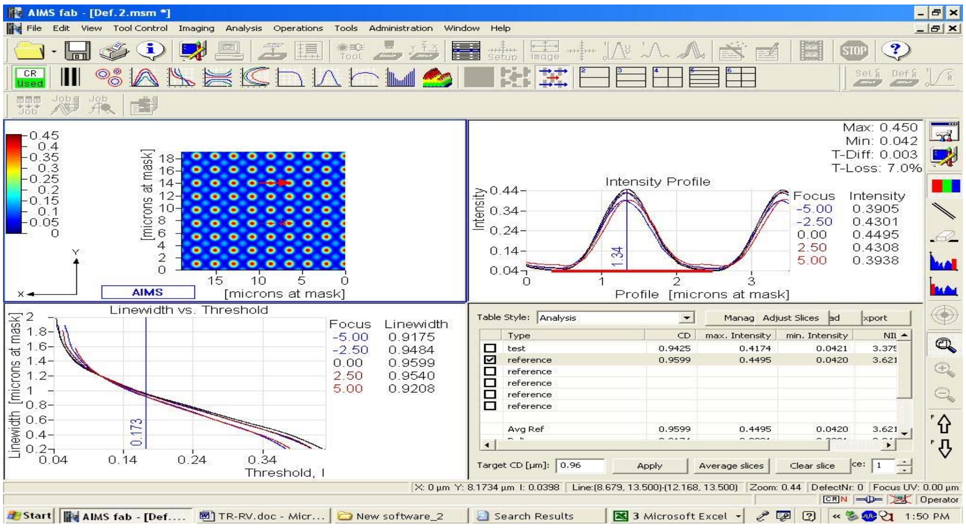

Figure 1. GUI of the ROI option.

Result of ROI analysis					
Type	CD	Max. Intensity	Min. Intensity	NILS	DOF
test	0.9425	0.4174	0.0421	3.3757	9.975
reference	0.9599	0.4495	0.042	3.6219	9.975
reference					
reference					
reference					
reference					
Avg Ref	0.9599	0.4495	0.042	3.6219	9.975
Delta	-0.0174	-0.0321	0.0001	-0.2462	0
Delta [%]	-1.8127	-7.1413	0.2381	-6.7975	0
Common DOF					9.975
Common Intensity Threshold	0.1731				

Figure 2. Exported txt file of the summary section.

To get the same result the manual process would require the definition of a dedicated ROI for each of the areas to be compared, the manual alignment on both axes of the acquired images and the filling of user prepared modules to provide the needed documentation. Being the alignment operator dependent it can potentially lead to non homogeneous results and doubtful decisions that could affect cycle time and delivery date of the involved product, issues that the use of an automatic measurement tool will minimize or eliminate.

As a result of an algorithm calculation the reliability of the analysis performed with the RV software is supposed to be more consistent but its accuracy needs to be compared with the procedures agreed with the customer, whose effectiveness is proven over years of printability evaluation with no failure at the wafer printing. The comparison was carried out on a sample of twenty masks and the results are reported in the following pictures in term of percentage difference between measurements taken with the manual routine and with the RV software. Figure 3 contains the result of CD analyses while those showed in figure 4 comes from the evaluation of intensity peaks.

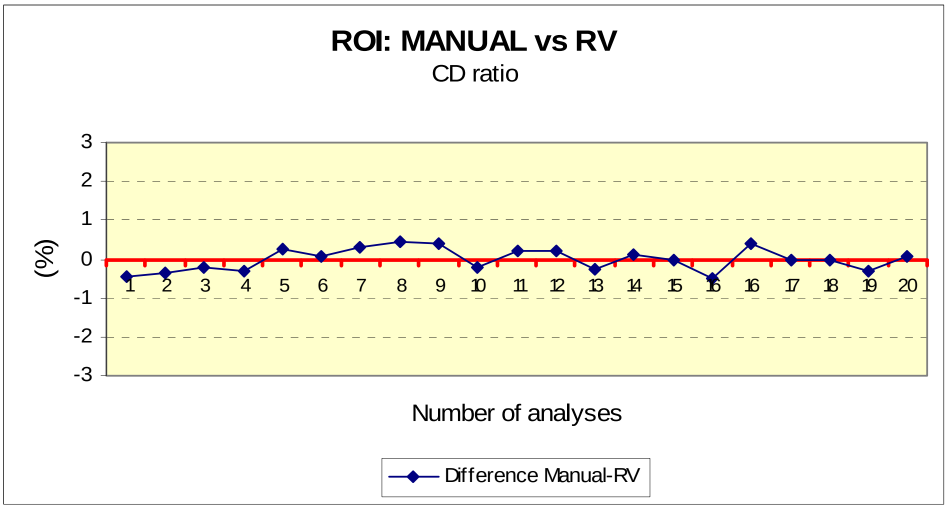

Figure 3. CD analyses (Manual minus RV)

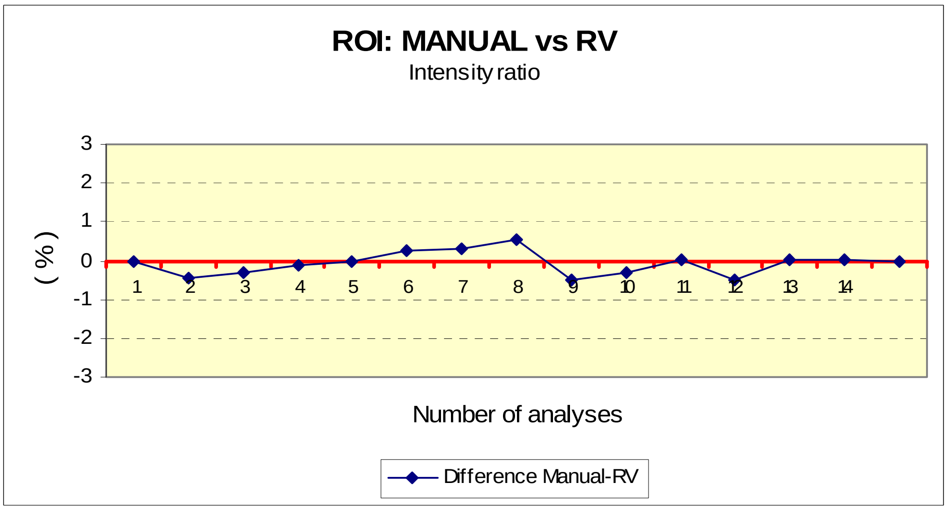

Figure 4. Intensity ratio analyses (Manual minus RV)

The results of both types of analyses confirm either the accuracy or the reliability of the RV measurements as the maximum difference found is lower than 0.5%, which is commonly from ten to twenty times smaller than the requirements of the customers' specification.

2.2 Achievements with the IC option

The use of the IC option is also very simple and fast as it manages with a completely automatic routine the steps the analysis consist of, definition of CD and intensity for the target, alignment of the images, calculation of the errors and visualization of the data to be exported in a customable format as per the customer requirements. Figures 5 to 8 show the GUI windows driving the operator through all the measurement process.

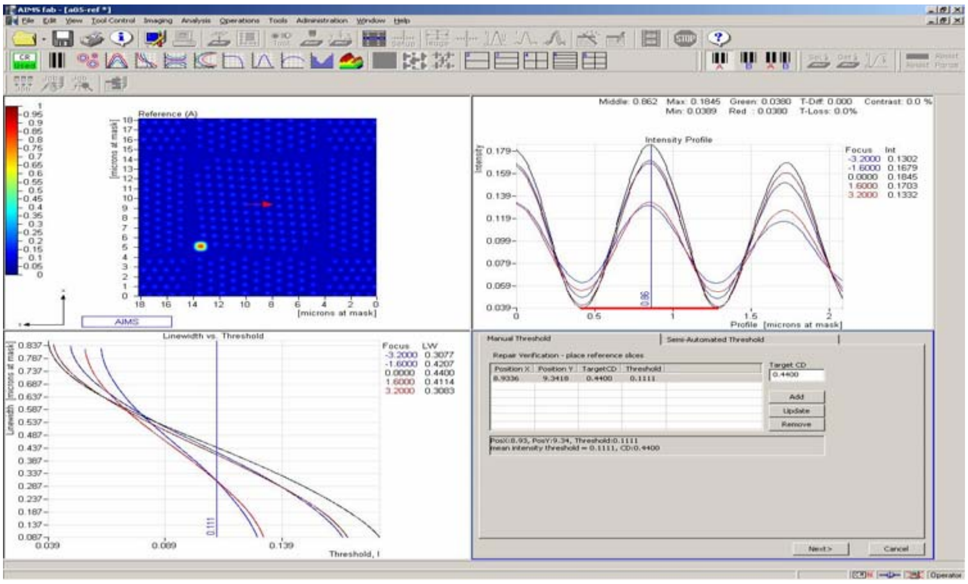

Figure 5. Definition of the targets for the reference.

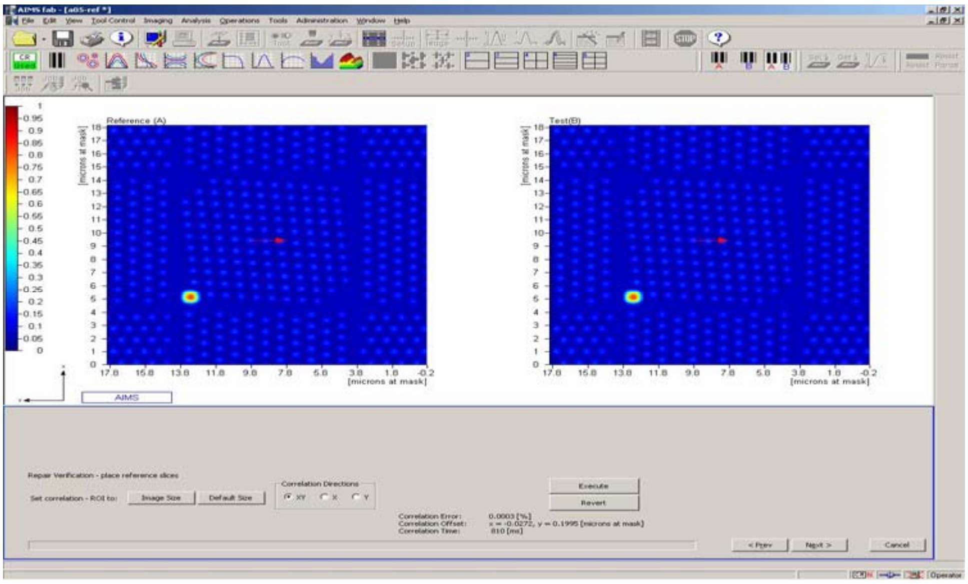

Figure 6. Alignment of test and reference images.

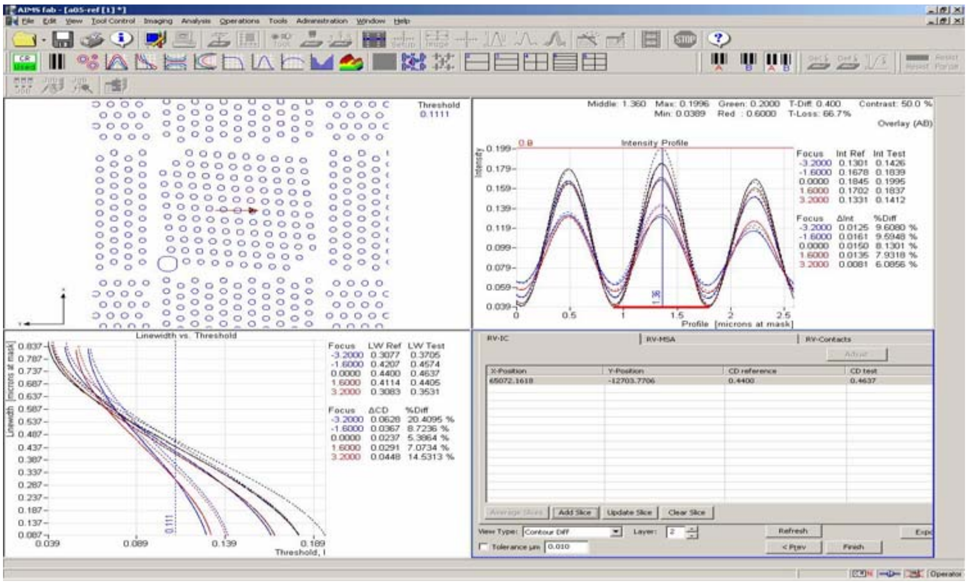

Figure 7. Measurement process.

Slice	X-Position	Y-Position	CD referen	CD test				
1	60241.31	-53876.66	0.562	0.5426				
Slice	Dimension	Start X	Start Y	End X	End Y	Distance	BFP	
1	Mask	13.2417	5.6686	8.4802	5.6686	0	2	
Slice	Plane	Int Ref	Int Test	DeltaInt	PctDiff			
1	All Planes	0.2817	0.2675	-0.0142	-5.0412			
	0	0.2319	0.2227	-0.0092	-3.9672			
	1	0.3043	0.2896	-0.0147	-4.8308			
	2	0.3346	0.3149	-0.0197	-5.8876			
	3	0.3029	0.2915	-0.0114	-3.7636			
	4	0.2347	0.2187	-0.016	-6.8172			
Slice	Dimension	Start X	Start Y	End X	End Y	Distance	BFP	Threshold
1	Mask	13.2417	5.6686	8.4802	5.6686	0	2	0.1372
	Plane	LW Ref	LW Test	DeltaCD	PctDiff			
	0	0.479	0.4647	-0.0143	-2.9854			
	1	0.5436	0.5353	-0.0083	-1.5269			
	2	0.562	0.5426	-0.0194	-3.452			
	3	0.5346	0.5145	-0.0201	-3.7598			
	4	0.4638	0.4321	-0.0317	-6.8348			

Figure 8. Printout of the IC results.

Being based on the comparison of two different images, differently from what happens with the MSA analysis on which the measurements are taken on the same image, the IC analysis is more critical and needs more interaction from the operator. In this case the automatic routine of the RV software provides its highest advantage, either in term of reliability or in those of throughput. As done for the MSA option, accuracy and reliability of the measurements were verified also with the IC measurements and the result is reported in the following pictures.

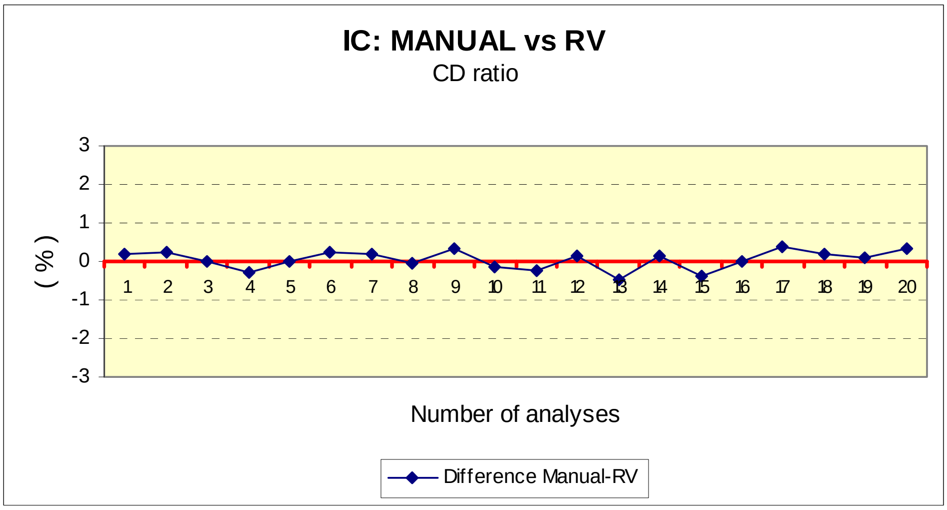

Figure 9. CD analyses (Manual minus RV)

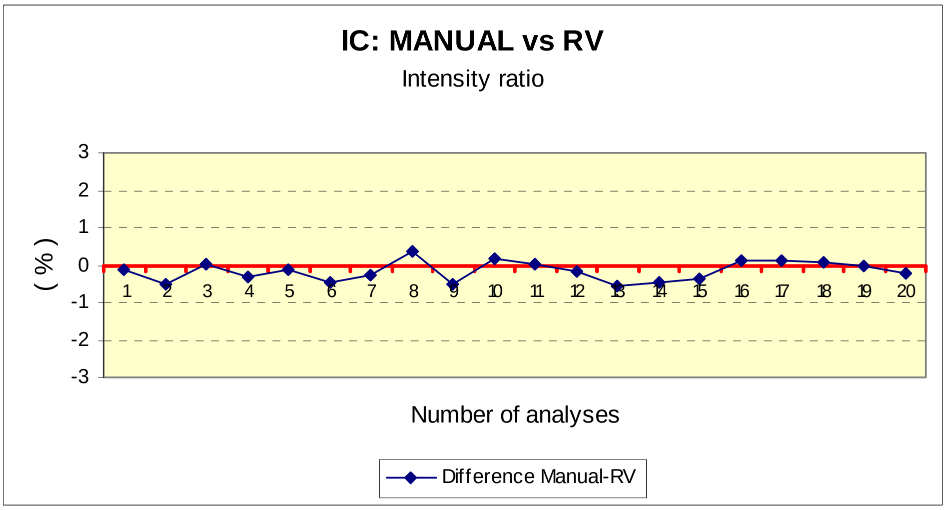

Figure 10. Intensity ratio (Manual minus RV)

In this case too the maximum difference is less than 0.5%, well in line with the limit defined by the customer specification for the printability evaluation processes.

The next figures show examples of some enhancement coming from the RV analysis.

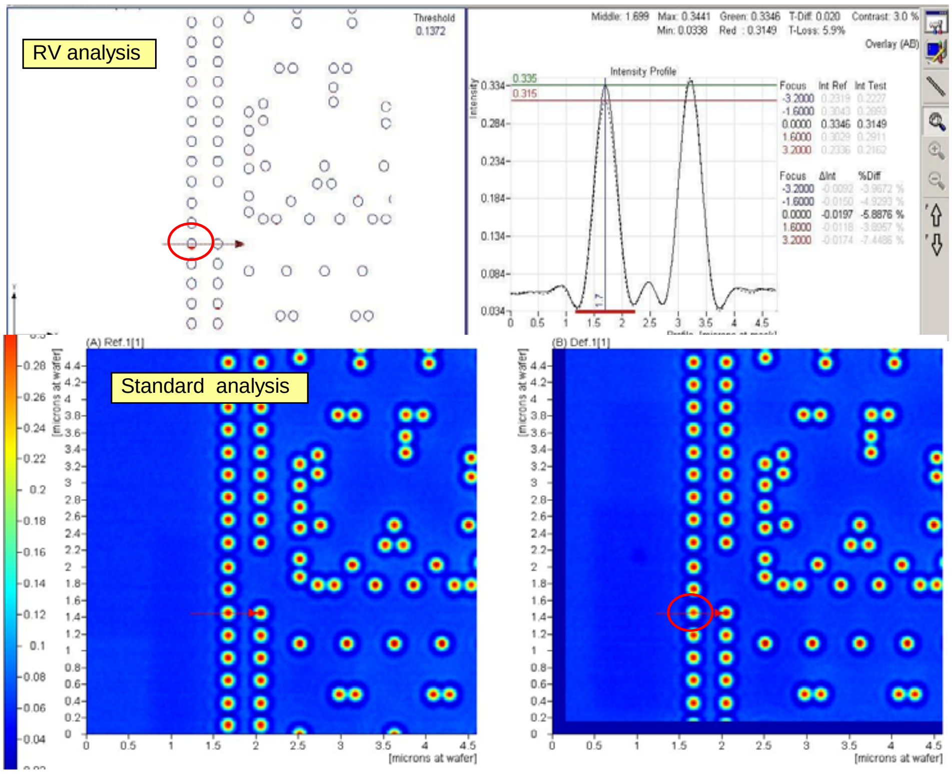

Figure 11. Highlighting of the defective contact.

Figure 11 shows how the use of the "Defect Highlighting" function allows a fast and easy identification of the defective feature as a result of the overlay of the contour plot of the two images. This is not so evident with the standard analysis process, above all in case of small differences, on which the defective feature must be identified with the evaluation of the peak of its intensity profile.

Figure 12 shows an example of the improvement of the alignment of the images with the RV routine with respect to that achieved by the operator with the standard analysis. The curves of the intensity profiles are better superimposed and this reduces "non real differences" of the CD error at the threshold the CD is calculated.

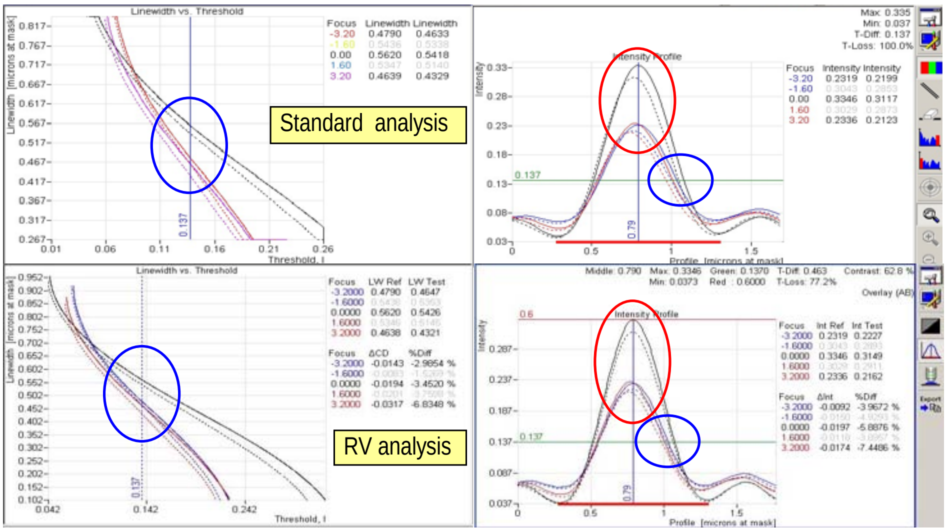

Figure 12. Improved alignment with the RV routine.

Up to now all the activity was focused on the improvement the RV tool provides either in term of reliability or in that of productivity just replicating what the classical path of a standard printability analysis is, which is the minimum requirement to implement its usage in the mask manufacturing process flow.

Together with the two main applications, there is a further option named “RV Contact” that could open an interesting scenario regarding the analysis of contact layers and provide a consistent help toward the need to improve the defect disposition approach directly on the inspection tool at the end of the inspection. The necessity to detect small defects on contacts forced the inspection tools engineers to design algorithms that work on the area of the defects rather than on their linear CD. This results in a more consistent detection, often exceeding the specification requirement, but raises the need to find out the most suitable and reliable way to evaluate such measurement errors with the minimum impact on the cycle time of the products being evaluated. The way the RV Contact works is pretty much similar to that of the inspection tool, on which the defect is detected against a reference calculated on the average of the most representative features on the mask, and in case of arrays of contacts homogeneously sized this makes the AIMS^{TM} evaluation more realistic than that performed on a reference image with a single contact. Also, the possibility to optimize the analysis area with a tailored ROI, and to remove from the analysis non homogeneous features, increases the level of accuracy of the final result.

The next figures show examples of the printout of this type of analysis,

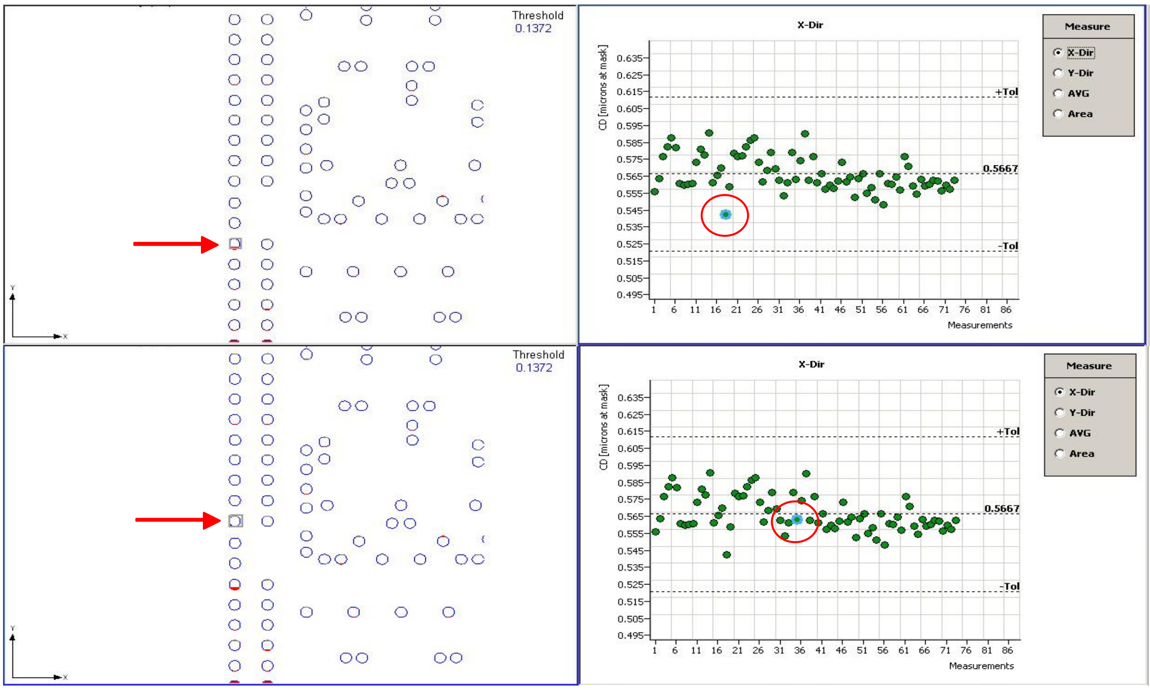

Figure13. Difference between defective and non defective contacts.

The image of figure 13 shows the comparison between the defective contact and a non defective one located in a similar context, and it can be observed a clear difference of the CD measurement calculated on the X axis.

The next picture contains the result of the same comparison calculated with a tailored ROI and with all the available features of the RV contact option.

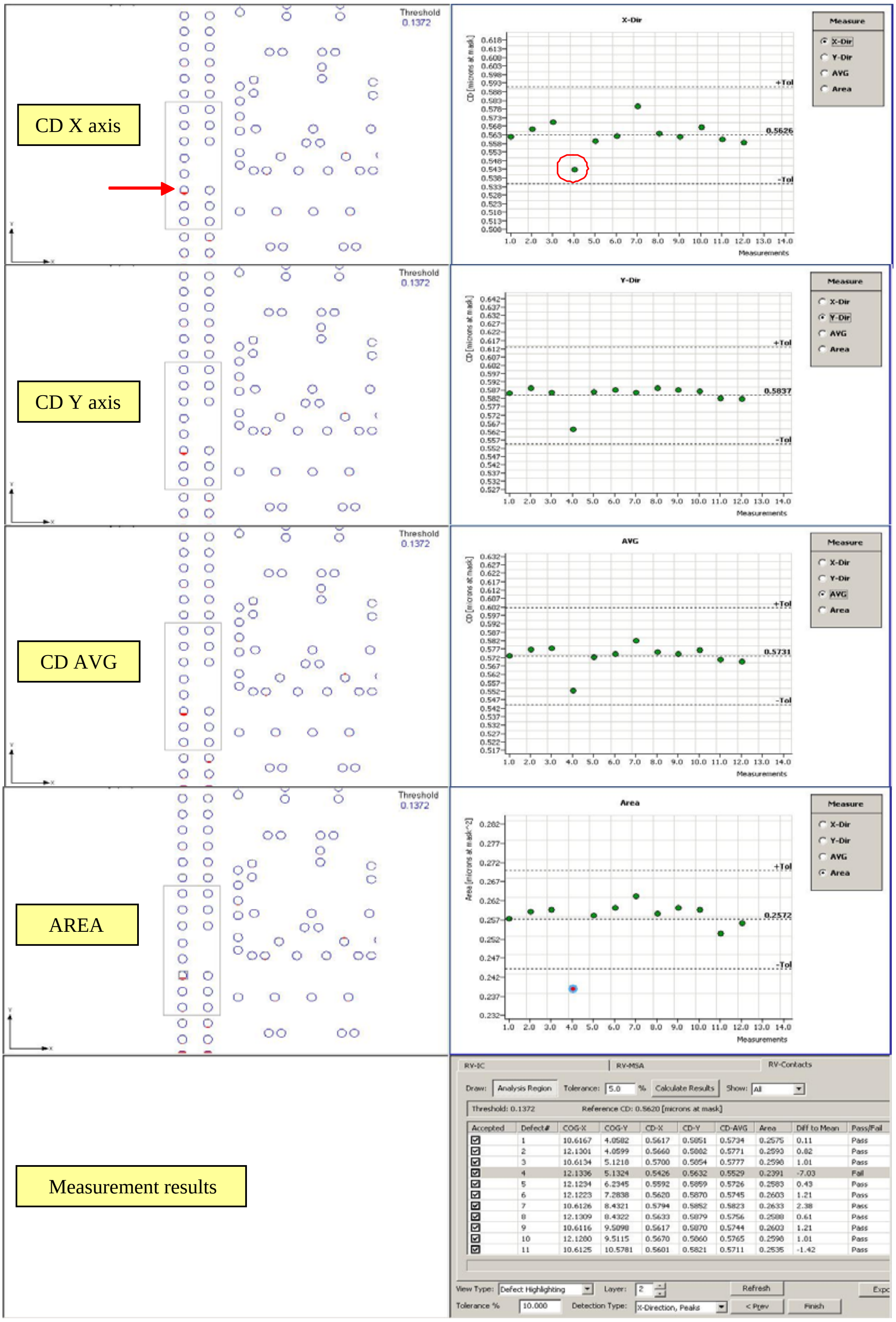

Figure 14. Difference between defective and non defective contacts with all the available options.

The summary of the measurement results calculated inside the ROI area reported in figure 14 highlights very clearly the deviation of those performed on the defective contact from the average of the other ones, with those regarding its area falling outside the control limits set for the analysis. Potential further developments including the possibility to compare test and reference images would extend the field of application of this option, thus covering all different scenarios as the current procedures do, and could definitely open an interesting way to introduce a new accurate and consistent approach toward the printability evaluation of repairs performed on contact layers.

3. CONCLUSION

The RV software was designed to improve reliability and productivity of AIMS^{TM} analyses by means of a complete automation of the measurement routines, whose aim is to eliminate human errors and minimize the time spent to prepare the required documentation. The content of the paper describes the result of the tests performed to validate the capability of the tool, before its implementation into the manufacturing process flow, by means of a comparison with those achieved with the standard procedure. In addition to that, the usage of the RV Contact option can open a new interesting scenario regarding a new approach for the printability evaluations of contact layers as well as for actions of enhancement of their defect disposition.

In term of productivity, the complete automation of the alignment of the images, that of the calculation of the errors and the printout of the most relevant result in an exportable text file, improves the throughput of up to 60-70% depending on the complexity of the analysis being performed.

The increase of the productivity of the manufacturing activities will not be the only advantage of the usage of the RV software. AIMS^{TM} analyses are also part of several engineering activities that on one side will get advantage from the new options and on the other one can be a valuable source for the development of new applications.