Improving reticle defect disposition via fully automated lithography simulation

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ABSTRACT

Most advanced wafer fabs have embraced complex pattern decoration, which creates numerous challenges during in-fab reticle qualification. These optical proximity correction (OPC) techniques create assist features that tend to be very close in size and shape to the main patterns as seen in Figure 1. A small defect on an assist feature will most likely have little or no impact on the fidelity of the wafer image, whereas the same defect on a main feature could significantly decrease device functionality. In order to properly disposition these defects, reticle inspection technicians need an efficient method that automatically separates main from assist features and predicts the resulting defect impact on the wafer image.

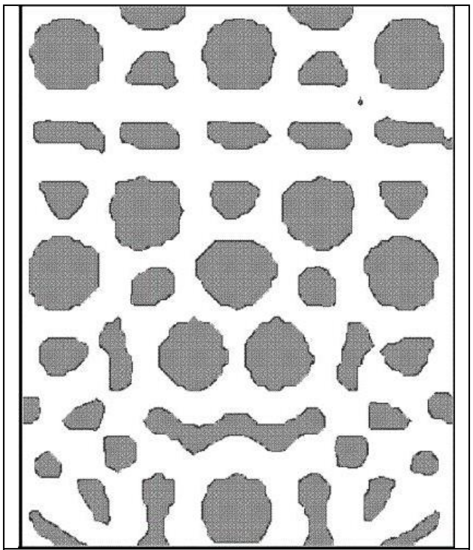

Figure 1 Complex decoration

Prior work has shown that reliable predictions of defect impact to the wafer can be produced using the Automatic Defect Analysis System (ADAS) defect simulation system[1]. Up until now, using ADAS simulation was limited to engineers due to the complexity of the settings that need to be manually entered in order to create an accurate result. A single error in entering one of these values can cause erroneous results, therefore full automation is necessary.

In this study, we propose a new method where all needed simulation parameters are automatically loaded into ADAS. This is accomplished in two parts. First we have created a scanner parameter database that is automatically identified from mask product and level names. Second, we automatically determine the appropriate simulation printability threshold by using a new reference image (provided by the inspection tool) that contains a known measured value of the reticle critical dimension (CD). This new method automatically loads the correct scanner conditions, sets the appropriate simulation threshold, and automatically measures the percentage of CD change caused by the defect. This streamlines qualification and reduces the number of reticles being put on hold, waiting for engineer review. We also present data showing the consistency and reliability of the new method, along with the impact on the efficiency of in-fab reticle qualification.

Keywords: simulation, inspection, photomask, reticle, defect, disposition, qualification

1. INTRODUCTION

Cutting-edge semiconductor manufacturing has challenges of increased complexity in mask pattern design and reticle enhancement techniques such as advanced OPC and complex ILT designs. In order to keep up with the increasing number of inspections that are required in a foundry business, there is a need for a faster and more reliable reticle defect simulation solution for mask inspection review and defect disposition. AVI's ADAS has made improvements in the past year in order to meet such requirements. This paper focuses on the results from the implementation of a new feature of the ADAS software that automatically loads all simulations parameters and determines aerial image printability threshold at SAS reticle department for the 14nm technology node. Traditionally, a defect classification is carried out by manually entering simulation parameters and measuring CD variation at the defect site. The new approach of automatically loading simulation parameters and classifying defects helps eliminate human error, reducing the chance of any reticle repeating defects impacting wafer yield.

2. MOTIVATION

ADAS is a PC-based software system that automatically loads high resolution inspection images, identifies defect locations, performs simulation, and determines whether defects will print on the wafer or not. It quickly analyzes all defects within a few seconds and separates false from real defects. This makes it easier for the operators to focus on real defects, ignoring the false. ADAS performance at identifying false defects has been measured to be accurate 95% of the time (see Fig.2a). The 5% of the defects not identified correctly as false are all marked by ADAS as non-impactful to the wafer. ADAS is constantly being improved, and now enables inspection technicians to completely ignore false defects automatically classified by ADAS. See Fig.1a for data that was collected before and after the most recent ADAS improvements. Operators can rely completely on ADAS for false defect classification. This progress has made a great impact on the turn-around time for reticle requalification and re-pelliclization.

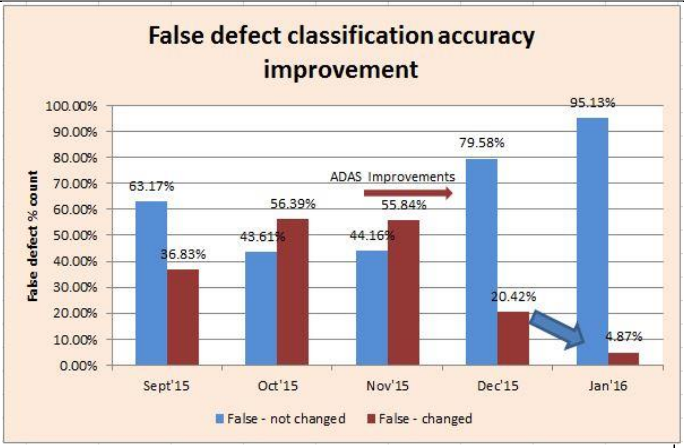

Fig. 2a: False defect classification accuracy improved to 95%

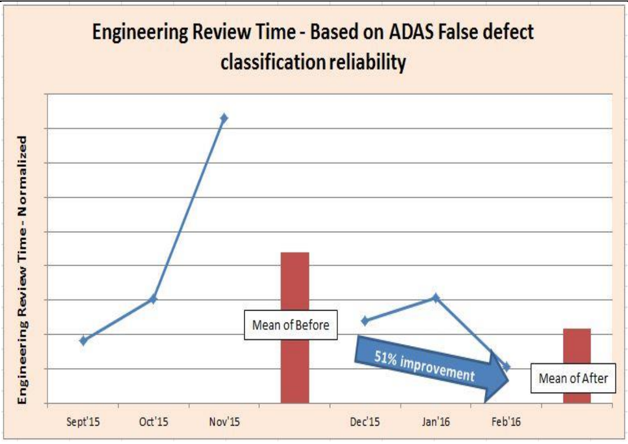

Fig. 2b: Engineering time spent reviewing reticle inspections was decreased by 51%

Average daily inspection review time also improved by 51% (see Fig. 2b) just by relying on ADAS false defect classification capability. In the previous software versions of ADAS, there were still many manual steps to get to the final analysis and classification of a defect. These manual inputs are sometimes erroneous, relying on an engineer to gather and input the correct information for simulation. The manual entries include: inputting scanner conditions (such as NA and sigma values, aperture shape, and blank material type) and finding the correct target CD for threshold calculation. To further improve this system and move away from human data entry and manual classification of real defects, there is a strong need for automation. Scanner conditions and other required parameters, such as printability threshold based on target CD size, must be loaded automatically. Also, considering a typical fab's inspection rate of greater than 50 inspections per day, manual review of defects can lead to misclassifications and yield loss. Fig.3 is an example of a defect that was simulated manually using the incorrect aerial threshold which resulted in a repeating defect on the wafer.

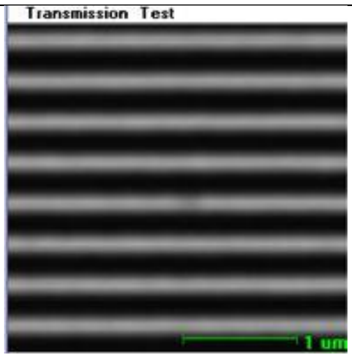

Fig. 3a: Reticle defect

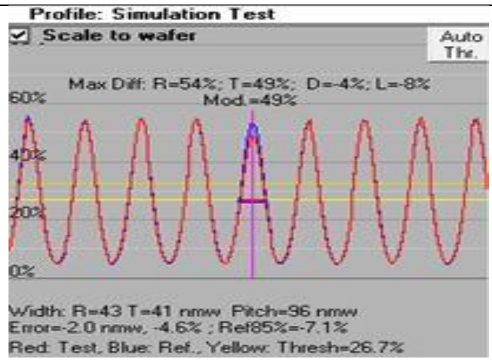

Fig. 3b: Simualted aerial image profile showing defect in spec

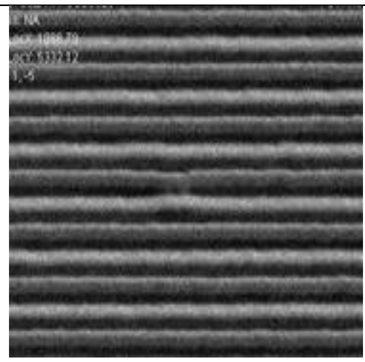

Fig. 3c: Wafer image

Once simulated with the correct threshold, the defect was correctly simulated to be out of spec (see Figure 4). This shows how important it is to have a proper threshold for simulation. Human errors can cost a lot time and money and this is the main motivation going forward to have more automated procedures in place.

Fig. 4a: Reticle defect, transmitted image

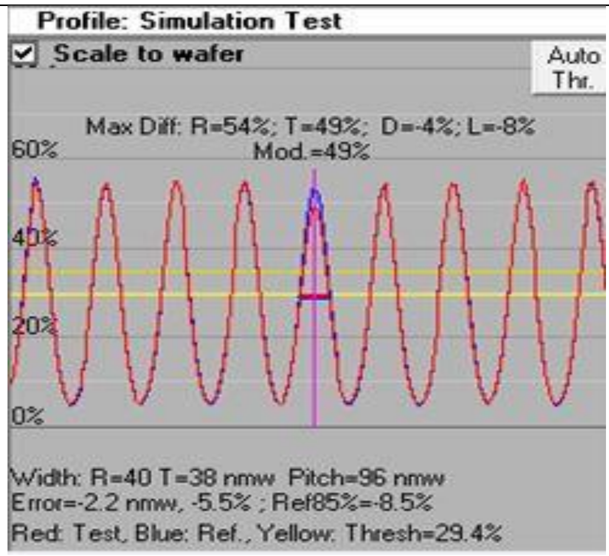

Fig. 4b: Simulated aerial profile showing defect is out of spec after calculating CD error using the correct threshold

3. PROPOSED SOLUTION

Our goal was to automate the only two areas remaining where human data entry could cause erroneous results: scanner illumination parameters and aerial image printability threshold setting. Most fabs have a single database that contains all scanner settings for a given wafer node, product, and wafer level. We have created a CSV file containing all of this information and made it accessible to the ADAS server. Once a new inspection is detected by ADAS, the inspection file is copied to the server which extracts the wafer node, product name, and wafer level from the file. ADAS then finds the appropriate scanner illumination parameters from the CSV file and automatically loads them into the ADAS simulator. These parameters include: NA, wavelength, pupil type (annular, dipole, free-form, etc.), inner and outer sigma, mask substrate, and polarization. In the case of free-form illumination, the illuminator file is located and also automatically loaded.

The more challenging parameter to automate is the aerial image printability threshold. The standard method of setting this threshold is to simulate a feature on the reticle where the measured critical dimension (CD) is known, and adjust it until the aerial image profile measures the same CD at wafer scale. This is very challenging in fabs because it is difficult to know what the true CD is on the various feature sizes that exist on any given reticle. Our solution involved software changes to both the inspection tool and ADAS. Mask shops always provide coordinates and CD SEM measured values for numerous critical dimension features in the data file that ships with each reticle. This data file is now automatically being transferred to the inspection tools and to the ADAS server. When the inspection tool recognizes a new reticle, the tool identifies the mask coordinates of the CDs measured at the mask shop and scans these locations at the end of the inspection. These images are then saved in a separate CD image folder. When the inspection is complete, the ADAS server copies the inspection data and identifies that the CD target images have been captured. ADAS then retrieves the coordinates, measured value, feature tone, and measurement direction from the mask shop data file. Figure 5 shows the data flow.

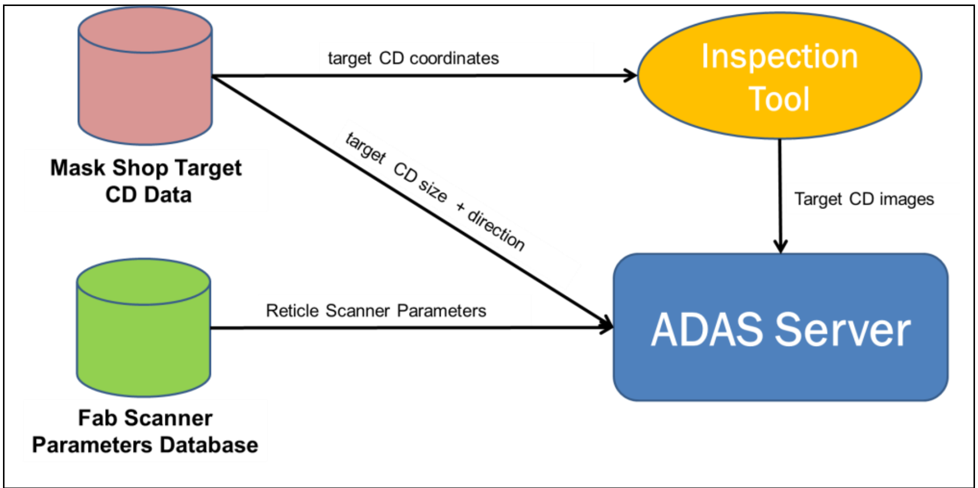

Figure 5 Data transfer flow

Once the inspection is loaded into the ADAS server, the operator views the target CD image, selects the measurement area, and then selects the “Auto Threshold” button. ADAS then displays the CD target value and orientation, and automatically adjusts the threshold to match the target CD value as seen in Figure 6 below.

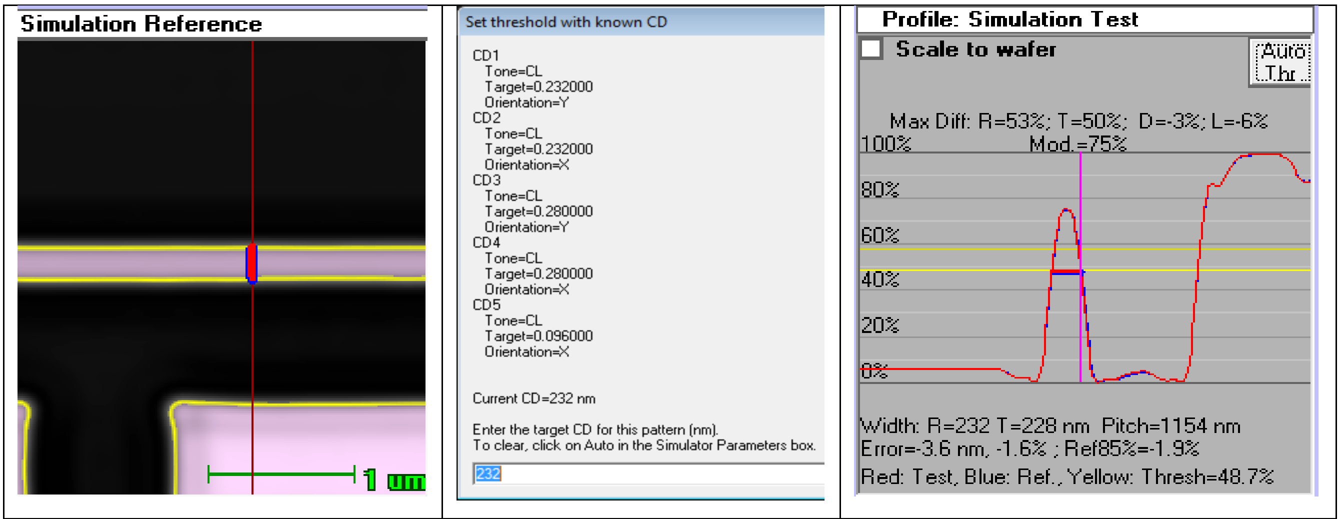

Figure 6a Target CD simulated aerial image displayed	Figure 6b Target CD Tone, orientation, and measurement	Figure 6c ADAS automatically adjusts the threshold to the wafer level target CD

4. PROGRAMMED DEFECT TEST MASK (PDM)

The new ADAS automation flow was tested using a programmed defect mask. This mask was specifically designed and fabricated with programmed defects for ADAS software testing and evaluation of the auto-threshold technique. The test mask is a 6% PSM mask with 7 different types of defects for each 14nm L/S and contact patterns. The different types of defects include pinholes, pindots, extensions, and intrusions. Each type of programmed defect has 29 sizes ranging from 4nm to 60nm, in increments of 2nm. This covers a wide range of printing to non-printing defects on wafer. Figures 7a and 7b show examples of programmed defect designs with corresponding inspection and ADAS simulation aerial images for both L/S and contact patterns.

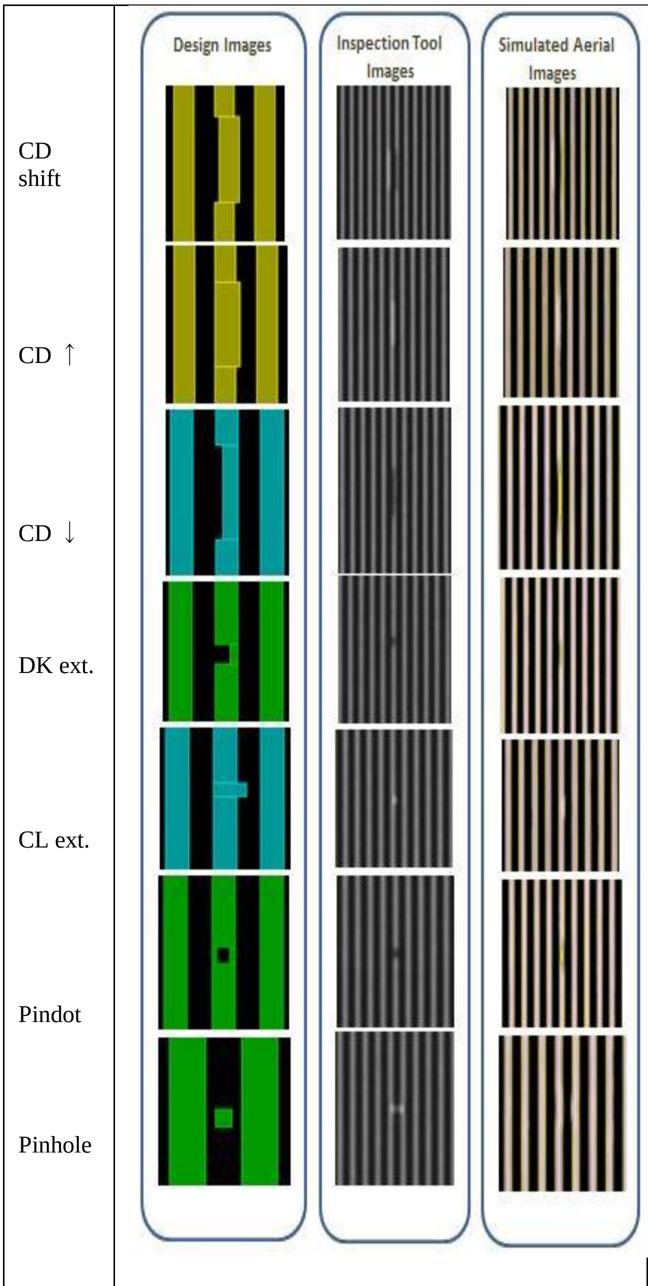

Fig. 7a: Design, inspection and simulation images of programmed defects on L/S pattern

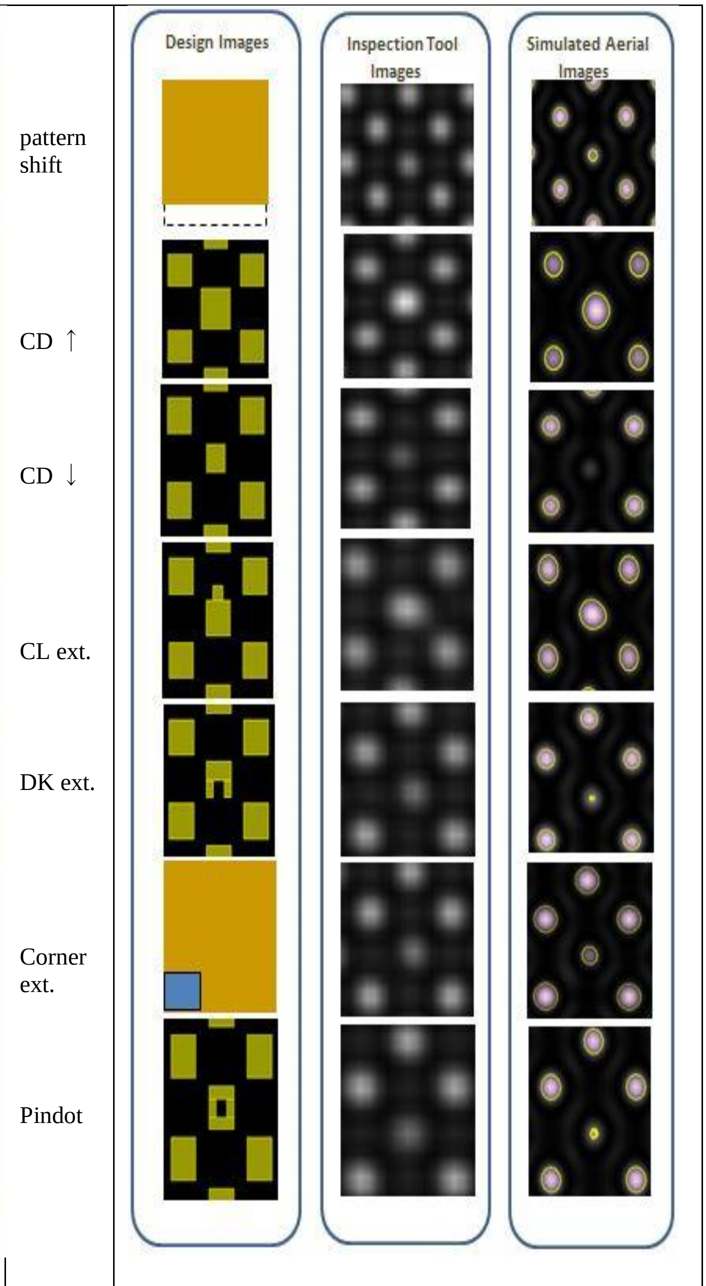

Fig. 7b: Design, inspection and simulation images of programmed defects on contact pattern

5. PROGRAMMED DEFECT TEST MASK RESULTS

ADAS simulation results on the PDM mask were verified using AIMS simulation, the industry standard for printability analysis. All defect types at the borderline of spec were measured and the results showed good correlation between the two measurement systems. It was observed that ADAS tends to over predict printability in some cases and under predict it in others. This is expected because there are some physical limitations to using inspection images for wafer simulation, such as defects that may induce 3D effects like phase shifts or diffraction. In order to provide a guard band, AVI has incorporated another methodology to overcome these limitations. There are now two thresholds calculated to analyze each defect: one is the threshold based on target CD, and the other is at 85% of the target CD threshold. Defects are now analyzed using both thresholds, which has proven to provide a good guard band against defects where phase may impact printing.

5.1 Line / Space Pattern

Figure 8 shows the percentage CD error calculated for each defect site for L/S pattern calculated by ADAS and compared to the AIMS data. These data show good correlation between the two measurement systems. What is under spec on AIMS is under spec in ADAS, and the same applies for over spec defects. In cases where ADAS is measuring defects at the very limit of the spec, an additional guard band was created to avoid allowing a suspicious defect to pass. Fab engineers tested past data and came up with a new threshold strategy, as mentioned above, to measure defect CD error based on 85% of the threshold calculated originally. This strategy is now a standard procedure for measuring defects on critical patterns. PDM data also shows that defects measured at borderline spec have a good guard band when measured using the 85% threshold.

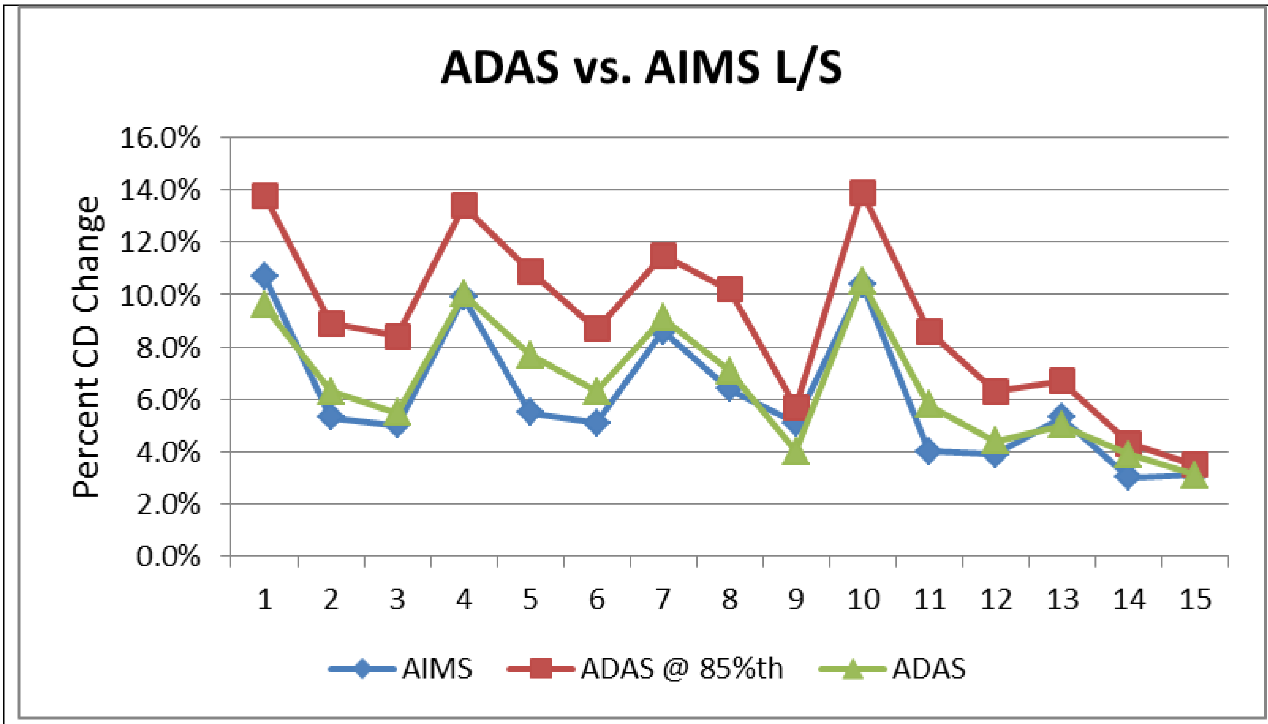

Fig. 8: ADAS vs. AIMS simulation on PDM L/S defects

Figure 9 shows a good correlation of percentage CD error between ADAS and AIMS. It’s also seen in the graph that ADAS tends to overestimate CD errors, especially on defects measured to be over spec on the AIMS tool.

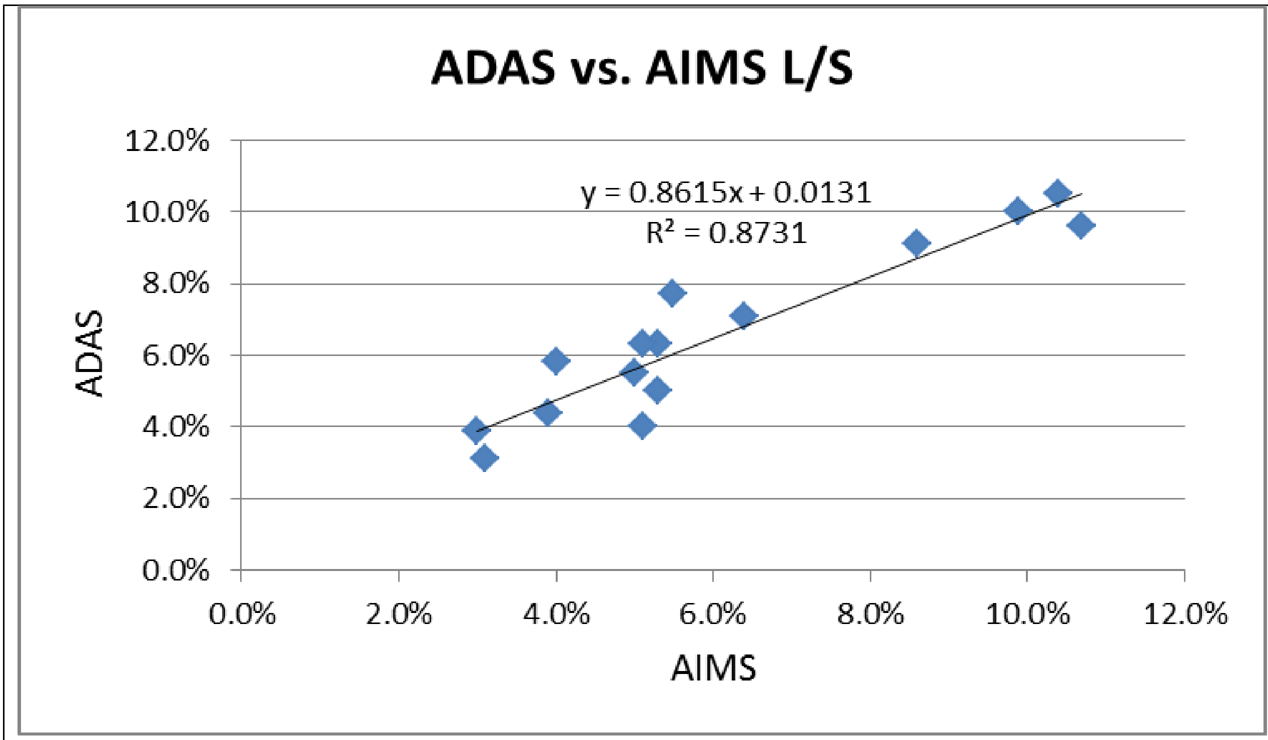

Fig. 9 ADAS vs. AIMS CD percentage error results comparison

5.2 Contact Pattern

Similar results were measured on the contact pattern programmed defects. The measurements showed a slightly better correlation than the L/S pattern. Any over-spec defect calculated by AIMS is also failing as reported by the ADAS simulation. Figure 10 shows AIMS vs. ADAS simulation comparison on the contact pattern programmed defects.

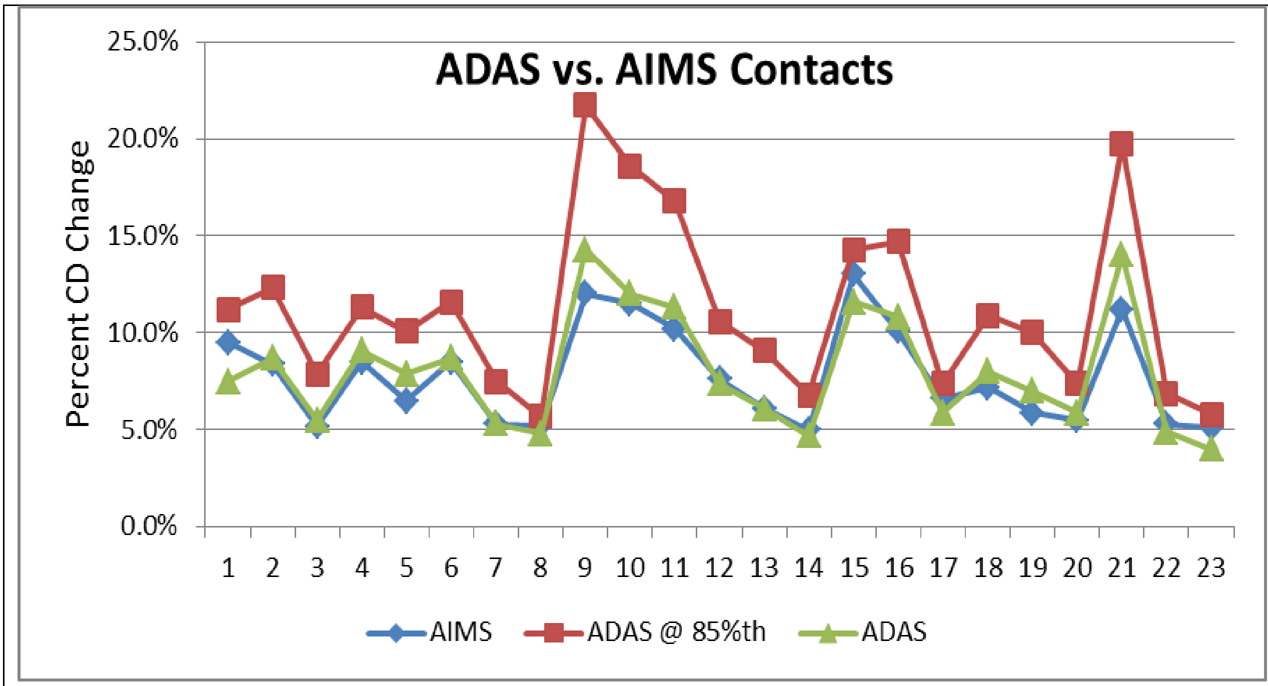

Figure 10: ADAS vs. AIMS simulation on PDM contact pattern defects

Figure 11 shows a good correlation of %CD error between ADAS and AIMS tool on the contact pattern program defects.

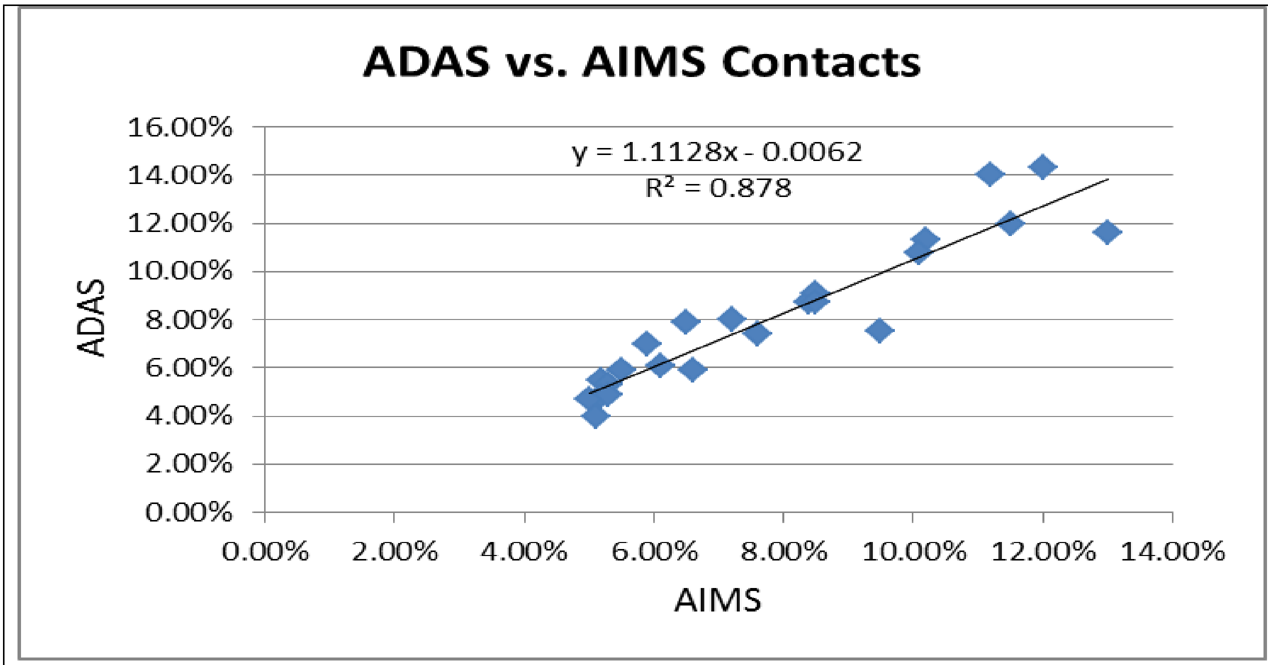

Fig. 11: ADAS vs. AIMS CD percentage error results comparison

6. INCOMING RETICLE RESULTS

Each reticle shipped to the fab comes with AIMS simulation results of all repaired defects. Figure 12 shows the comparison on 30 random repairs on numerous masks between ADAS and AIMS. In all but one case, defects that passed AIMS also passed ADAS simulation at the 5% CD spec.

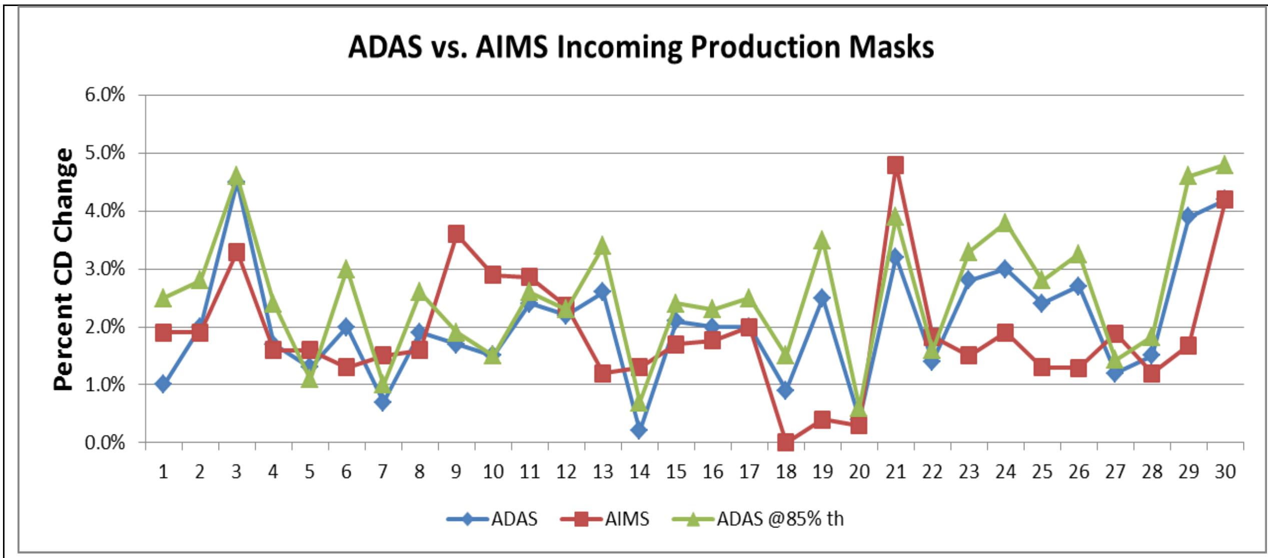

Figure 12 AIMS versus ADAS simulation results on incoming reticle repairs.

7. CONCLUSIONS AND FUTURE WORK

7.1 Conclusions

In this study, we have confirmed that subtle errors in manual operator data entry can result in erroneous simulation results that can lead to wafer repeating defects. Automating the loading of scanner parameters and the setting of simulated aerial image printability thresholds has resulted in the following:

- Automated loading of scanner parameters eliminates simulation errors caused by manual entry.
- Automated scanning of target CD locations with displayed target size and orientation ensures proper aerial image printability threshold determination.
- With accurate scanner parameters and proper threshold settings, ADAS simulation provides reliable defect impact prediction, which increases wafer yields and minimizes fab disruptions.

7.2 Future Work

- Adapt ADAS for the next node (10nm)