# Automatic Classification and Defect Verification Based on Inspection Technology with Lithography Simulation

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## ABSTRACT

Even small defects on the main patterns can create killer defects on the wafer, whereas the same defect on or near the decorative patterns may be completely benign to the wafer functionality. This ambiguity often causes operators and engineers to put a mask “on hold” to be analyzed by an AIMS™ tool which slows the manufacturing time and increases mask cost. In order to streamline the process, mask shops need a reliable way to quickly identify the wafer impact of defects during mask inspection review reducing the number of defects requiring AIMS™ analysis.

Source Mask Optimization (SMO) techniques are now common on sub 20nm node critical reticle patterns These techniques create complex reticle patterns which often makes it difficult for inspection tool operators to identify the desired wafer pattern from the surrounding nonprinting patterns in advanced masks such as SMO, Inverse Lithography Technology(ILT), Negative Tone Development (NTD).

In this study, we have tested a system that generates aerial simulation images directly from the inspection tool images. The resulting defect dispositions from a program defect test mask along with numerous production mask defects have been compared to the dispositions attained from AIMS™ analysis. The results of our comparisons are presented, as well as the impact to mask shop productivity.

**Keywords:** simulation, inspection, photomask, reticle, defect, disposition, requalification

## 1. INTRODUCTION

At 20nm and below (especially 7nm and 10nm), new lithography technologies have been adopted such as ILT, SMO, and NTD. The mask has small assist and/or complex high MEEF patterns so operator judgment of defects is difficult. Figure 1 is an example where it is very difficult for an operator to determine which features are main and which are assist.

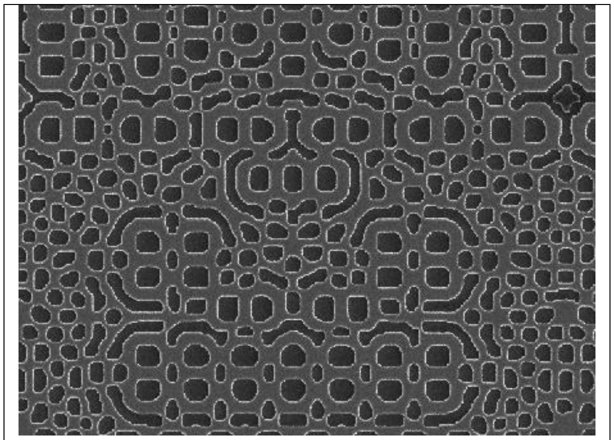

Figure 1 – Complex OPC Mask

There is the strongest correlation between AIMS™ and wafer results, however it is difficult and time consuming to perform AIMS™ measurements for many (>100) defects.

We need a new defect classification method in order to reduce AIMS™ load for 7nm and 10nm optical mask.

### 1.1 Current versus new mask flow

Figure 2 shows the current back-end mask inspection flow. Defects detected by an inspection tool are judged by the operator. Large defects are repaired, and all repaired defects are measured by AIMS™. Suspicious defects from the inspection tool are sent to AIMS™ in order to determine if they need repair. A large percentage of these are very small suspect defects on complex high-MEEF patterns. The current flow is inefficient causing sometimes more than 100 defects needing AIMS™ verification wasting time of operators, AIMS™ throughput and mask cycle time

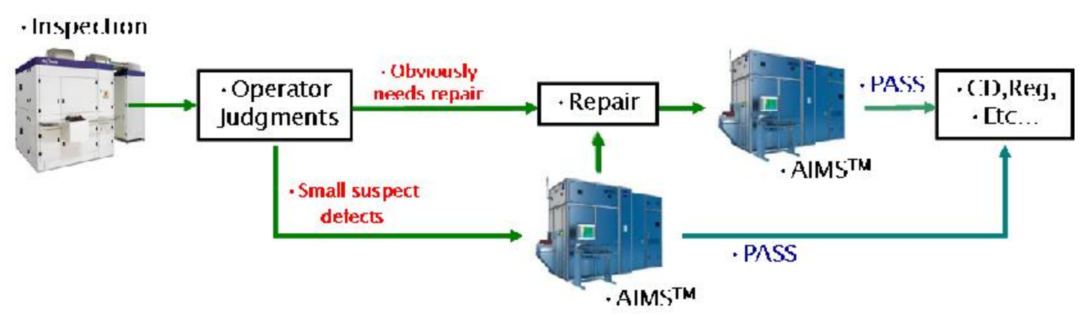

Figure 2 – Current mask inspection flow

Figure 3 shows the newly proposed mask flow where ADAS™ is used to filter out the majority of defects that previously required AIMS™ analysis.

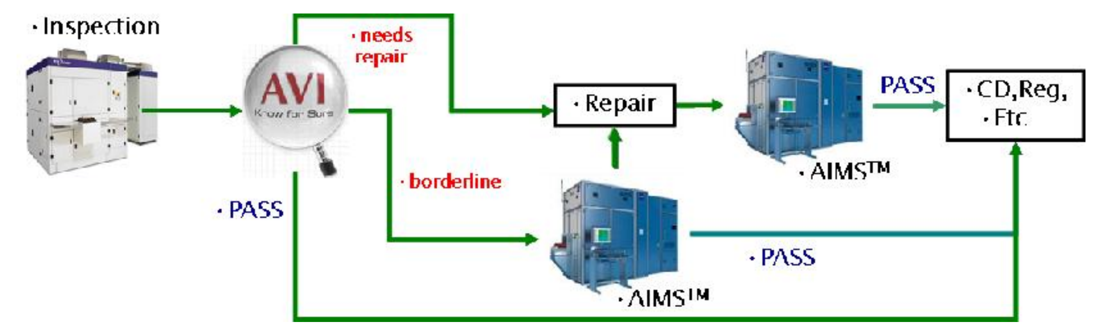

Figure 3 – New mask inspection flow

### 1.2 Lithography Simulation using ADAS™

Automated Defect Analysis System (ADAS™) classifies all defects in a given reticle inspection. It automatically reads the inspection reports from any reticle inspection tool – KLA-Tencor, Lasertec, and NuFlare. ADAS™ has been in continuous development for the last 12 years and it is currently being used in production in multiple sites around the world. [1]

ADAS™ generates lithography simulation images from reticle inspection tool images. To confirm the performance of review with ADAS™, we have compared simulation results between ADAS™ and AIMS™ as seen in Fig.4. The precision of ADAS™ has been compared to that of AIMS™ by correlational analysis.

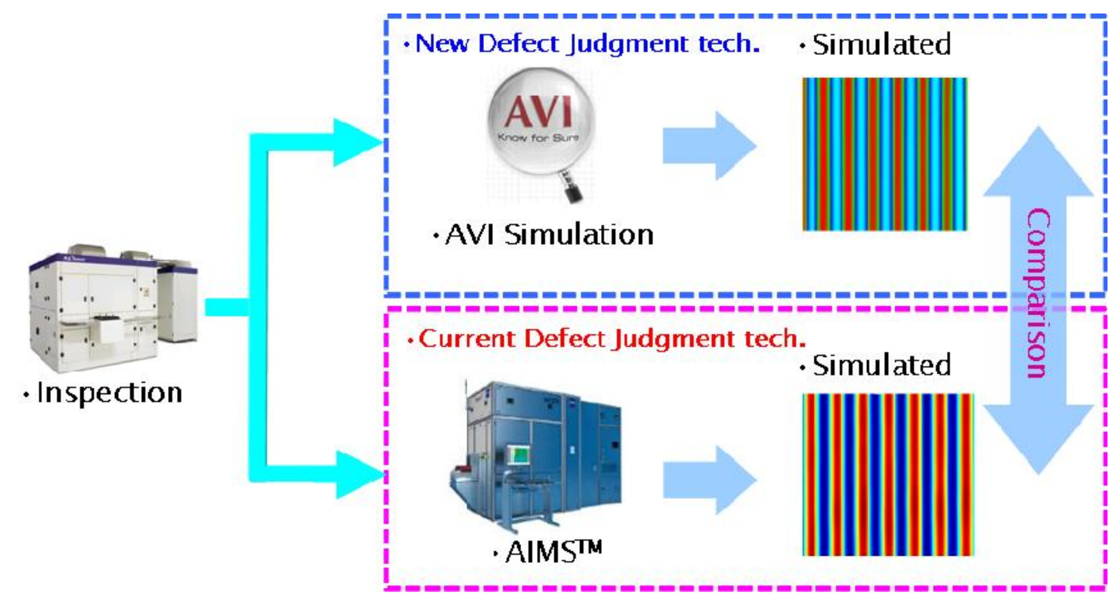

Figure 4 – New Defect Judgment technique vs. Current Defect Judgment technique

## 2. OBJECTIVES

The objectives of our work:

1. Confirm the performance between AIMS™ and ADAS™ systems using production and programmed defect masks.
2. Evaluate ADC capability and defect disposition to confirm accuracy, time and usability.
3. Evaluate NGL lithography simulation results on complex OPC masks like ILT and NTD.

# 3. EXPERIMENTAL

## 3.1 Evaluated patterns and simulation settings

Two programmed defect masks were used in order to compare the simulation results of AIMS™ versus ADAS™. The evaluation pattern and simulations of this work are as follows:

1. Line and space 140nm@mask, DENSE (1:1.5), ArF-HT (6%)
    - Inspection tool: KLA-Tencor Teron™ 617, Wave length: 193nm, Pixel size : 55nm and 72nm
    - Inspection mode: Die to Die, Die to Database
    - Printability simulation: ADAS™ and AIMS™ 32-193i
    - Exposure condition : 1.30NA, ArF Immersion lithography
    - Source Shape: Diser (Open angle 60 deg., sigma=0.9,/0.594, Polarization=Y-Polarizer)
    - Defect categories: Opaque extension, Clear extension, Under CD, Over CD, Bridge

2. Contact Hole 290nm@mask, DENSE (1:1.5), ArF-HT (6%)
    - Inspection tool: KLA-Tencor Teron™ 617, Wave length : 193nm, Pixel size : 55nm and 72nm
    - Inspection mode: Die to Die, Die to Database
    - Printability simulation: ADAS™ and AIMS™ 32-193i
    - Exposure condition : 1.30NA, ArF Immersion lithography
    - Source Shape: Quasar (sigma=0.98,/0.735)
    - Defect categories: Opaque extension, Clear extension, Under CD, Over CD

## 3.2 Printability simulation results

1. Line and space 140nm@mask, ArF-HT (6%)

The accuracy of ADAS™-predicted %CD error was validated by comparison with AIMS™ % CD error. The result of the correlational analysis is shown in Figures 5-8.

The correlation is strong, however, these data have been corrected with a 2X scale for clear defects. The reason for the 2X scale factor appears to be 3D effects in which less light gets through the hole or “mouse bite” when illuminated at high NA (wide cone of light) from the inspection tool, compared to the low NA (pencil beam) in the AIMS™. AVI will continue to investigate this issue.

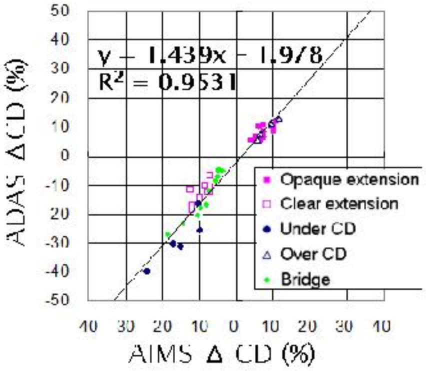

Figure 5 – L/S140nm P72 DD ADAS-AIMS correlation

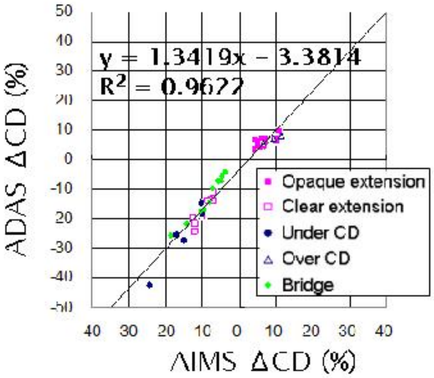

Figure 6 – L/S140nm P72 DB ADAS-AIMS correlation

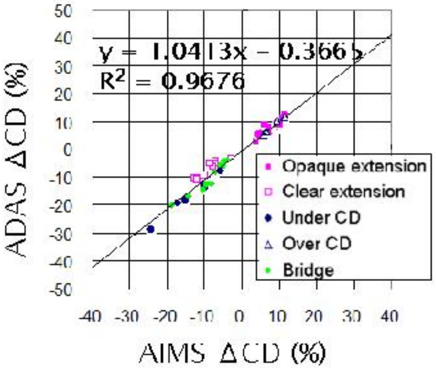

Figure 7 – L/S140nm P55 DD ADAS-AIMS correlation

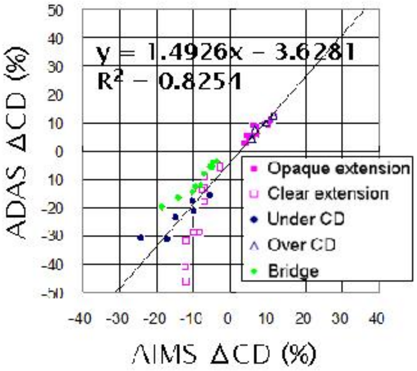

Figure 8– L/S140nm P55 DB ADAS-AIMS correlation

2. Hole 290nm@mask, ArF-HT(6%)

The accuracy of ADAS™-predicted %CD error was validated by correlation with AIMS™ % CD error. Figures 9-12 shows correlational analysis results. The correlation is excellent. Regression is y = x on most defect types.

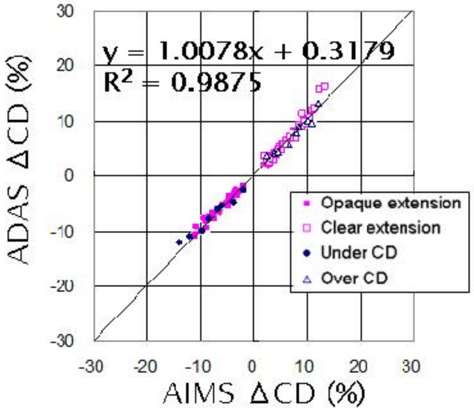

Figure 9 – Hole 290nm P72 DD ADAS-AIMS correlation

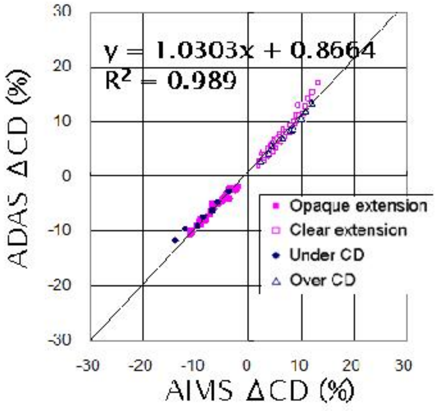

Figure 10– Hole 290nm P72 DB ADAS-AIMS correlation

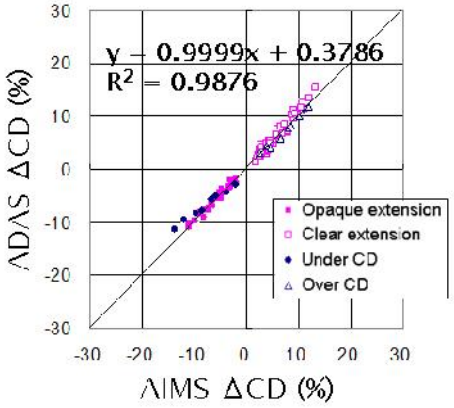

Figure 11 – Hole 290nm P55 DD ADAS-AIMS correlation

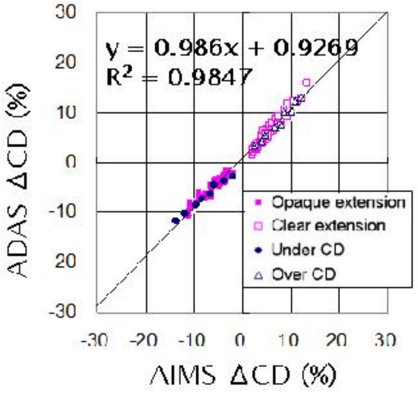

Figure 12 – Hole 290nm P55 DB ADAS-AIMS correlation

### 3.3 Product mask evaluation

The following mask types were selected in order to test ADAS™ ADC capabilities:

- 40nm Logic FEOL: 100 masks
- 28nm Logic FEOL and 3Xnm Memory FEOL: 100 masks
- 14nm Logic FEOL: 30 masks

DNP has tested over 230 production masks with ADAS™. ADAS™ ADC speed is excellent. Speed is >1000 defects /minute. The correlation on production is strong. Regression is y = x on most defect types.

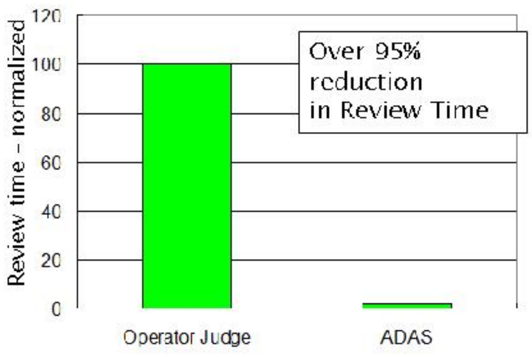

Figure 13 – ADAS Automatic Defect Classification

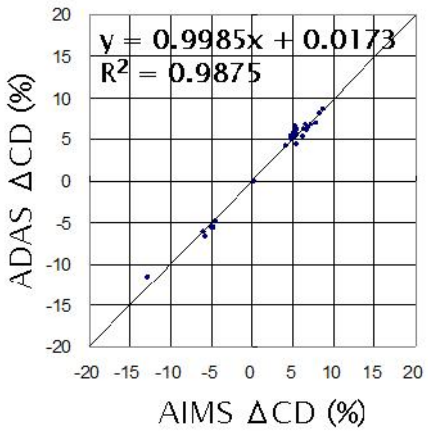

Figure 14 – ADAS and AIMS Simulations on 14nm to 40nm node Production Defects

## 4. ADVANCED STUDY RESULT

### 4.1 Advanced mask evaluated patterns and simulation settings

In order to test ADAS™ capability on advanced masks, the following two masks were evaluated:

1. Complex ILT OPC contact layer, MoSi-Binary
    - Inspection tool: KLA-Tencor Teron™ 617, Wave length: 193nm, Pixel size: 55nm
    - Inspection mode: Die to Database
    - Printability simulation: ADAS™ and AIMS™ 32-193i
    - Exposure condition: 1.35NA, ArF Immersion lithography
    - Source Shape: SMO (sigma=0.98, Polarization=XY-Polarizer)
    - Defect categories: Under CD, Over CD

DNP has developed new high-transmittance att. PSM. The new PSM shows high lithographic performance on NTD process on wafer. [2]

2. Line and space 140nm@mask, DENSE (1:1.5), High-transmittance (over 18%) new PSM NGL mask
    - Inspection tool: KLA-Tencor Teron™ 617, Wave length: 193nm, Pixel size: 55nm
    - Inspection mode: Die to Die
    - Printability simulation: ADAS™ and AIMS™ 32-193i
    - Exposure condition: 1.30NA, ArF Immersion lithography
    - Source Shape: Diser (Open angle 35 deg., sigma=0.98,/0.784, Polarization=Y-Polarizer)
    - Defect categories: Opaque extension, Under CD, Bridge

### 4.2 Advanced mask printability simulation result

1. Complex OPC Mask like ILT, MoSi-Binary

The accuracy of ADAS™-predicted CD error (CDE) was validated by correlation with AIMS™ CDE. The experimental result has been shown in the Figure 15. The charts show strong correlation results between AIMS™ and ADAS™ simulation for programmed defect patterns, but in general, defects are under predicted compared to AIMS™. ADAS™ has been designed to be most accurate on defects producing % CD errors between 5-15% since most fabs consider anything over 10% CD error to be defective. Even still, further study is needed to understand and correct the variations of slope between defect types.

2. Line and space 140nm@mask, DENSE (1:1.5), High-transmittance new PSM (over 18%, NGL mask)

The accuracy of ADAS™-predicted CDE was validated by correlation with AIMS™ CDE. The strong correlation results between AIMS™ and ADAS™ simulation for programmed defect pattern were shown as in Figure 16. However the tendency depends on the defect type. Future software changes are expected to accommodate the new material properties correctly and restore accuracy to that shown with other conventional HT masks.

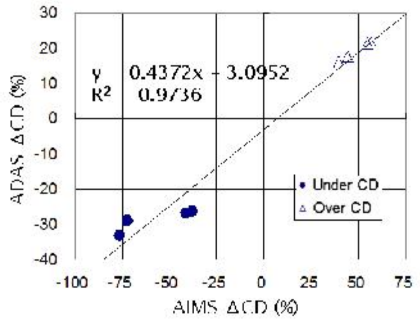

Figure 15 – Complex OPC mask like ILT P55 DB ADAS-AIMS correlation

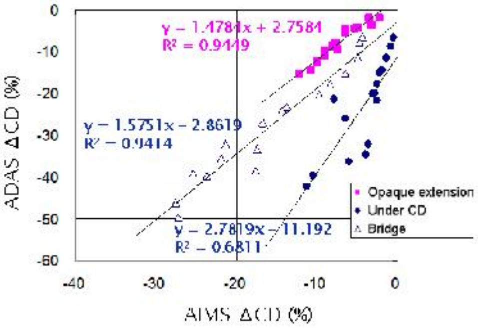

Figure 16– High-transmittance att. PSM P55 DD ADAS-AIMS correlation

## 5. SUMMARY AND FUTURE WORK

We have studied the defect verification capability of AVI ADAS™ ADC and simulation. We have come to the following conclusions:

1) ADAS™ shows excellent correlation with AIMS™ on Contact patterns. Line/Space correlation is strong, but currently requires a 2X scale factor on all clear defects.
2) ADAS™ ADC speed is excellent. Correlation on production is strong. ADAS™ is the best solution tested to date for defect verification after inspection.
3) Complex OPC PDM masks like ILT show strong correlation to ADAS™. However, defects are systematically under-predicted.
4) High transmittance-NTD PDM masks show overall strong correlation to ADAS™, however the current performance changes with defect type.
5) DNP believes that ADAS™ is required in order to meet the needs of 10nm node and below although improvement is needed on simulation of clear defects and narrow spaces of complex OPC masks.
6) AVI plans to further study the optical effects of the new high transmission NTD material in order to improve simulation results.

# REFERENCES

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[2] Takashi Adachi, " Development of new high transmission eaPSM for Negative Tone Development process on wafer” SPIE Proc. 9658, Photomask Japan 2015: Photomask and Next-Generation Lithography Mask Technology XXII, 96580P (July 9, 2015); doi:10.1117/12.2197611