

Techniques for improving overlay accuracy by using device correlated metrology targets as reference

Wei Jhe Tzai
Simon C. C. Hsu
Howard Chen
Charlie Chen
Yuan Chi Pai
Chun-Chi Yu
Chia Ching Lin
Tal Itzkovich
Lipkong Yap
Eran Amit
David Tien
Eros Huang
Kelly T. L. Kuo
Nuriel Amir

Techniques for improving overlay accuracy by using device correlated metrology targets as reference

Wei Jhe Tzai,^a Simon C. C. Hsu,^a Howard Chen,^a Charlie Chen,^a Yuan Chi Pai,^a Chun-Chi Yu,^a Chia Ching Lin,^a Tal Itzkovich,^{b,*} Lipkong Yap,^c Eran Amit,^b David Tien,^c Eros Huang,^d Kelly T. L. Kuo,^d and Nuriel Amir^b

^aUnited Microelectronics Corporation, Fab12 Engineering, No.18, Nan-Ke 2nd. Rd., Science-based Industrial Park, Hsin-Shi Tainan Country 744, Taiwan

^bKLA-Tencor Israel, Optical Metrology Division Application, 1 Halavyan St. Migdal Ha'emek, 23100, Israel

^cKLA-Tencor Corporation United States, Optical Metrology Division Application, One Technology Drive, Milpitas, California 95035, United States

^dKLA-Tencor Taiwan, Optical Metrology Division Application, Tai Yuen Hi-Tech Industrial Park, No. 22 Taiyuan Street, Zhubei City Chupei City, HsinChu Hsien Hsinchu County 302, Taiwan

Abstract. The performance of overlay metrology as total measurement uncertainty, design rule compatibility, device correlation, and measurement accuracy has been challenged at the 2× nm node and below. The process impact on overlay metrology is becoming critical, and techniques to improve measurement accuracy become increasingly important. We present a methodology for improving the overlay accuracy. A propriety quality metric, Qmerit, is used to identify overlay metrology measurement settings with the least process impacts and reliable accuracies. Using the quality metric, a calibration method, Archer self-calibration, is then used to remove the inaccuracies. Accuracy validation can be achieved by correlation to reference overlay data from another independent metrology source such as critical dimension–scanning electron microscopy data collected on a device correlated metrology hybrid target or by electrical testing. Additionally, reference metrology can also be used to verify which measurement conditions are the most accurate. We provide an example of such a case. © The Authors. Published by SPIE under a Creative Commons Attribution 3.0 Unported License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI. [DOI: [10.1117/1.JMM.13.4.041412](https://doi.org/10.1117/1.JMM.13.4.041412)]

Keywords: accuracy; device correlated metrology; overlay; Qmerit.

Paper 14087SSP received Jun. 5, 2014; revised manuscript received Aug. 31, 2014; accepted for publication Sep. 19, 2014; published online Dec. 2, 2014.

1 Introduction

At imaging based overlay (OVL) metrology, a propriety quality metric, called “Qmerit,” can be used to quantify target process imperfections. The metric employed in order to identify the optimal measurement conditions which are less sensitive to process impacts and therefore report the most accurate OVL values. This quality metric can be used in comparative analysis for a range of overlay target designs and metrology settings, thereby identifying good candidate combinations of target designs and metrology settings. The accuracy of the results of each target design and metrology setting is then verified by critical dimension–scanning electron microscopy (CDSEM) data collected on a device correlated metrology (DCM) hybrid target. Furthermore, simulation of the light spectrum behavior per target geometry and film stack information also supports the target designs and metrology settings selection based on the anticipated precision.

Using the quality metric results (Qmerit), an innovative calibration method, the Archer self-calibration (ASC), is used to remove inaccuracies. Using the measurement information from various target or metrology settings, the calibration methodology estimates the inaccuracies and calibrates the overlay data for the most accurate behavior. This in turn results in significant improvement in correlation to reference CDSEM data measured on a DCM target for all available targets and metrology settings combinations.

Both the quality metric and calibration methodology are designed to be on-the-fly applications that do not affect measurement time, making it optimal for the production environment.

In this study, we investigated the inaccuracy factors and their influence on measurement results. By measuring a DCM hybrid OVL target with both Archer and CDSEM tools and comparing the results, we were able to estimate which condition is the most accurate.

2 Overlay Inaccuracy

2.1 Process-Induced Asymmetry and Influence on Identify Overlay Results

A reference layer target pattern, especially for critical layers, is often subject to etch, polish, and further thin film deposition. All the above can contribute to target asymmetry as illustrated in Fig. 1.

An asymmetric slope caused by the etch process is illustrated in Fig. 1(a). Etch-induced asymmetry is caused by nonuniform plasma distribution across the wafer and, therefore, has a radial behavior and appears as an additional expansion term at OVL measurements.

An asymmetric trench caused by the polishing process is illustrated in Fig. 1(b). During a chemical-mechanical polish (CMP) process, wafer is pressed and rotated on a polish pad in a specific direction. In this case, a large area is filled with a softer material than the surrounding material, therefore, the softer material undergoes dishing, and because the wafer is rotated, the dishing profile might be asymmetric. A CMP-induced asymmetry appears as a rotation term on the wafer

*Address all correspondence to: Tal Itzkovich, E-mail: Tal.Itzkovich@kla-tencor.com



Fig. 1 Process-embedded asymmetry. (a) Asymmetric sidewall angle caused by etch. (b) Asymmetric trench caused by chemical-mechanical polish (CMP). (c) Asymmetric layer deposition caused by chemical vapor deposition (CVD) deposition.

at OVL measurements, while the OVL vector follows the CMP rotation direction, as shown in Fig. 2.

Asymmetric layer deposition caused by chemical vapor deposition (CVD), as illustrated in Fig. 1(c), is caused by the nature of the plasma enhanced (PE) CVD at the wafer's edge. Trench fill-induced asymmetry has a radial behavior and appears as a negative expansion term at OVL measurements (opposite to the etch behavior).

These process-induced asymmetries can be addressed by using an optimal target design, which mimics the device geometry and density, for example by segmenting a large feature into few small features and by placing dummy patterns at large un-patterned areas.

Estimation of the asymmetry influence on OVL accuracy was done by simulation. In the simulation, we simulated an advance imaging metrology (AIM) target with a zero-induced OVL, but with induced asymmetry, as described in Fig. 3(a). The value of the right angle was fixed at 90 deg, while the left angle value was modified between 90 deg, 98 deg, and 106 deg (these values are not typical and are usually smaller, however, we used these values to emphasize the influence). The results presented in Fig. 3(b) show that the OVL inaccuracy increases as sidewall angle asymmetry increases. An interesting observation from this simulation is that the OVL inaccuracy strongly depends on the wavelength

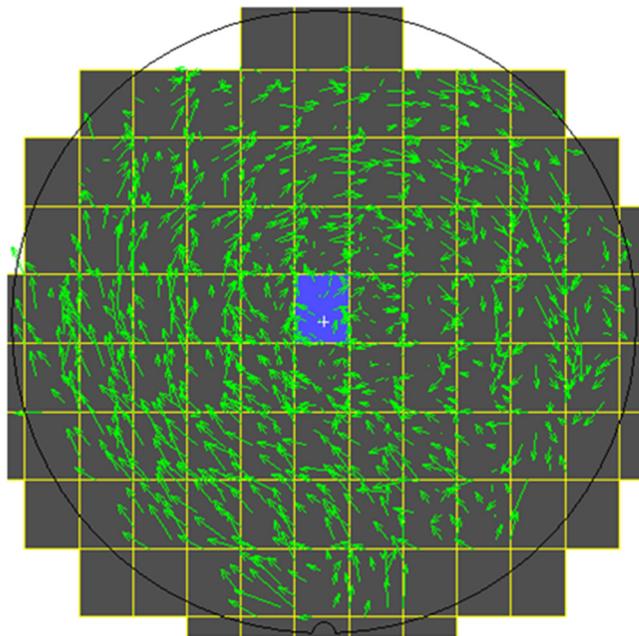


Fig. 2 Identify overlay (OVL) measurement of wafer which undergoes CMP and results in strong translation behavior due to asymmetric dishing.

(WL) used for measurements. This was part of the motivation for having an independent reference metrology (hence CDSEM) to validate which measurement conditions should be used. In this simulation, a WL of 500 nm was not found to be sensitive to target asymmetry.

2.2 Using Qmerit to Estimate the Process Asymmetry

When using an image-based method, OVL can be extracted using several signal processing algorithms. When the target is perfectly symmetrical, all algorithms will report the same OVL value. However, if the signal has a built-in asymmetry, as acquired from the target image, the different algorithms will report different OVL values. Qmerit values represent the distribution of the OVL values through the different algorithms. Using Qmerit values, we were able to identify a target which was damaged by processing and had induced-asymmetry, and additionally identify which measurement conditions (for example, color filter) were less sensitive to the process variation. As can be seen in Fig. 3(b), different WL has different sensitivity to process induced asymmetry, in this case caused by asymmetric side wall angle (SWA).¹

Qmerit can be used for choosing an optimal color filter which has the lowest sensitivity to target asymmetry, and can eventually contribute to measurement robustness.

2.3 Archer Self-Calibration

Using the Qmerit results, an innovative calibration method ASC is used to remove inaccuracies. Using the measurement information from various target/metrology settings, the calibration methodology estimates the inaccuracies and calibrates the overlay data to the most accurate value. For more information, please see Ref. 2.

2.4 Device Correlated Metrology Hybrid Target

The concept and motivation of using CD-SEM as reference for OVL measurements is discussed in Ref. 3. A DCM hybrid target enables OVL measurement using CDSEM on the same pattern which is measured for Archer OVL measurements verification. Figure 4 describe schematically how OVL can be measured using CDSEM, when pattern of one layer is interlaced within pattern of the other layer. The result OVL is calculated according to the formula:

$$\text{OVL} = (A - B)/2.$$

Figure 5(a) shows the schematic drawing of an imaging OVL target of type AIM, where each bar is segmented into several

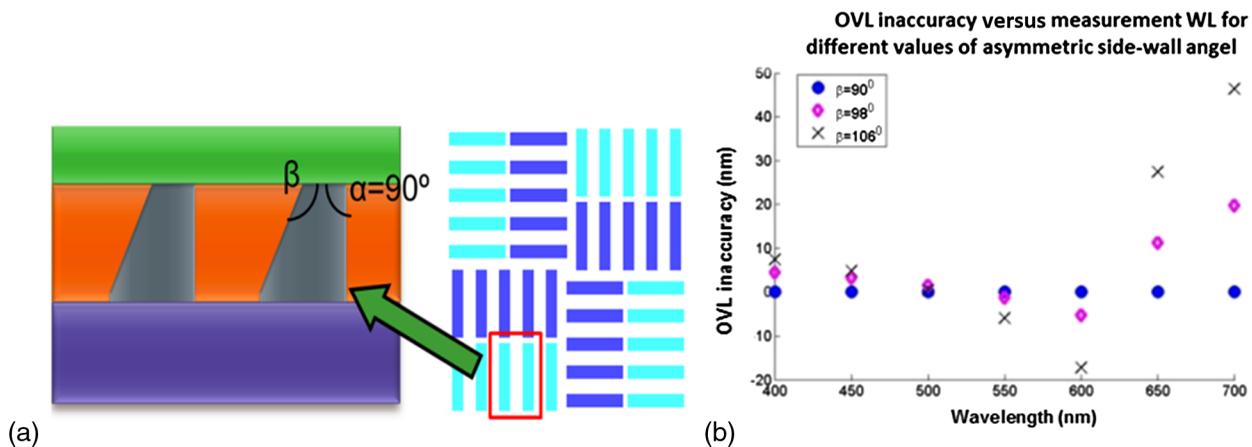


Fig. 3 Simulation of etch-induced asymmetry impact on OVL. (a) Simulated target geometry. (b) Simulation results of OVL inaccuracy versus wavelength (WL) and asymmetric sidewall angle.

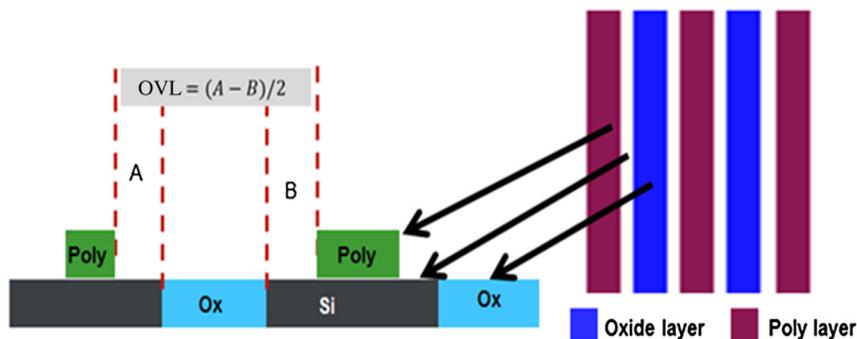


Fig. 4 Schematic description of OVL measurement using CDSEM.

lines with fin CD. The previous layer lines lie between the current layer lines which, after the etch and strip processes are completed, enables us to measure the OVL between them. This measurement is only possible for cases where both previous and current layers are visible at the top view and measurable by CDSEM. In Fig. 5(b), the OVL between the poly and isolation layers was measured.

Since both metrology methods are measuring at the same location, the comparison is done on a pattern which has

undergone the same process conditions and has the same applied OVL shift.

3 Results and Discussion

3.1 Qmerit Results

As discussed in the process-induced asymmetry part, we have found that different WLs show different sensitivities to asymmetry in the measured pattern. Therefore, it is necessary to

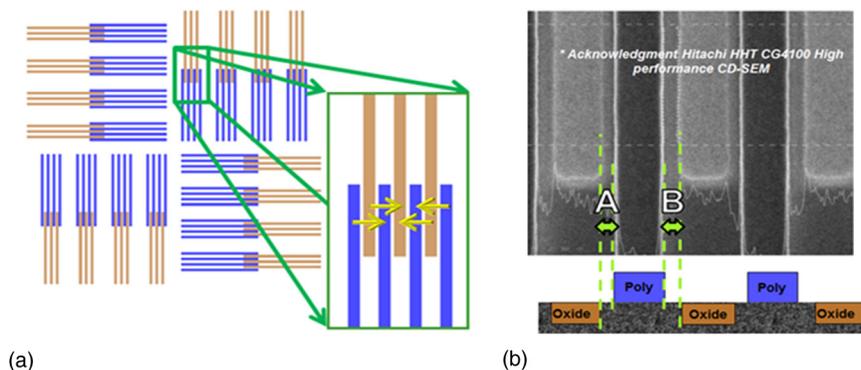


Fig. 5 (a) Example for CDM hybrid target. (b) Hitachi CDSEM measurement of an OVL using CDSEM on device correlated metrology (DCM) hybrid target. The measurement was performed after etch and resist strip at a process step, where both previous and current layers are visible and measurable by CDSEM. In this picture, OVL between poly and SN (isolation) layers is measured.

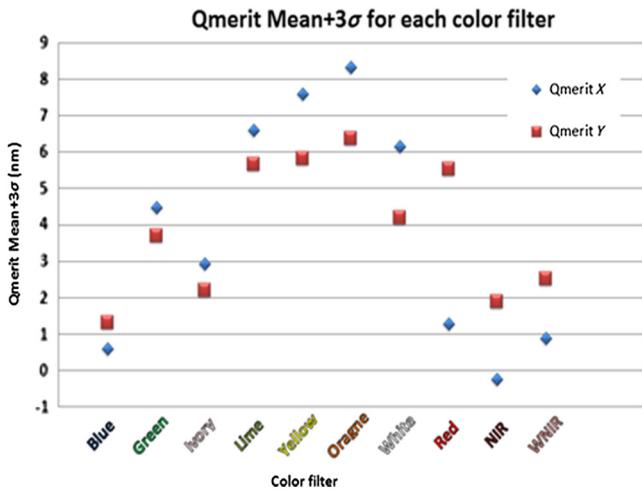


Fig. 6 Qmerit data for X and Y directions for each WL filter.

have a method which enables us to select the WL for measurement that will have the lowest sensitivity to asymmetry. As shown in Fig. 6, different color filters show different Qmerit values; blue is the one with the lowest deviation, which makes it the best candidate for the OVL measurement setup.

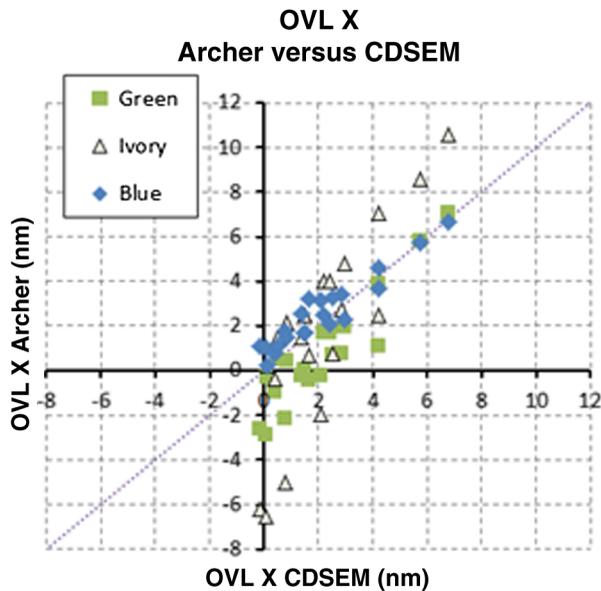
Two interesting observations can be seen from the Qmerit results. First, the best two color filters within the spectrum are blue and NIR, which are positioned on the edges of the spectrum. Second, when looking at the results through the spectrum, a structural trend can be observed, although it

has distortions at the wide band color filters (ivory, white, and wide-near-infra-red). A possible reason for this is that within wide spectrum color filters, several WLs respond differently to the geometry and may compensate, or average, the geometric influence.

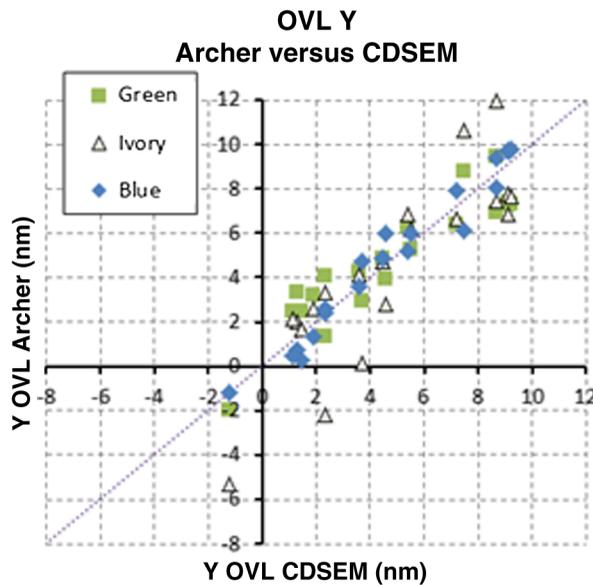
3.2 Device Correlated Metrology Hybrid Target: Results of Identify Overlay Correlation to CDSEM

OVL measurements by CD-SEM where done on AIM target that was specially design to have previous layer line interlaced with current layers lines, forming a structure like the one describe in Fig. 4. This design is an AIM target in which both current and previous layer bars' features were segmented and extended toward each other until they interlaced. Once the previous and current layers lines are interlaced, OVL measurement can be done using CDSEM. Measurements were done after the etch process using Hitachi HHT, CDSEM CG4100 high performance CDSEM tool. The measurement setup was as described in Sec. 2.3, and the results are shown in Fig. 7 for three color filters which had the best correlation: blue, green, and ivory, where the blue color filter shows the best results.

Currently, OVL measurements using CDSEM are only possible when both measured layers are apparent on the wafer surface, which has limited this method for specific layers; however, using de-cup, which etches the layer that cover the required layer, we are able to measure these layers as well.



(a)



(b)

Color filter	Correlation R^2	Slop	Intersect
Blue	0.9	0.83	0.83
Green	0.83	1.21	1.78
Ivory	0.67	1.91	2.23

(c)

Color filter	Correlation R^2	Slop	Intersect
Blue	0.95	1.04	0.14
Green	0.85	0.8	1.02
Ivory	0.76	1.14	0.94

(d)

Fig. 7 (a) and (b) Correlation between Archer OVL and CDSEM OVL for X and Y, respectively. (c) and (d) Correlation parameters (linear fit).

3.3 Archer Self-Calibration Calibrated Data

ASC algorithm was applied on the Archer OVL data. It used the OVL and Qmerit values as measured in blue, green, and ivory color filters to determine accurate OVL values. It also determined the Qmerit-based calibration function per color which is used to eliminate measurement inaccuracy (and to get an accurate ASC OVL). The correlation between the ASC OVL and CDSEM OVL values was significantly improved with respect to the raw OVL for all color filters, as can be seen in Fig. 8.

3.4 Imaging Simulation Results

Imaging simulations are done using the rigorous coupled-wave analysis algorithm. The resultant Jones matrices are then used in special software describing the Archer illumination and collection optical system. In the investigated case, imaging simulation results show that the blue color filter is the best measurement setup since the kernel profile at short WLs had the highest contrast for the target pattern (yellow lines are trenches of oxide within the Si substrate); this provided additional confirmation for blue as the preferred candidate. Figure 9 shows the stack kernel profile of both the previous and current layers.

4 Summary

In this paper, we have demonstrated how OVL measurement accuracy can be improved by using Qmerit and the ASC algorithm and verified accuracy by reference metrology using a DCM hybrid target. Results have shown that all methods, Qmerit, CDSEM, and imaging simulation, converged into one conclusion: the blue WL filter is the most accurate candidate for measurement setup of this layer.

Using ASC, we are able to use a variety of color filters which are imbedded in the Archer tool, and by calibration of the data, Archer demonstrated the accuracy required to enable sub-20-nm nodes.

References

1. E. Amit et al., "Overlay accuracy calibration," *Proc. SPIE* **8681**, 86811G (2013).
2. S. C. C. Hsu et al., "Innovative fast technique for checking overlay accuracy with ASC (Archer self calibration)," *Proc. SPIE* **9050**, 90501R (2014).
3. C. Chen et al., "DCM: device correlated metrology for overlay measurements," *Proc. SPIE* **8681**, 86812R (2013).

Biographies of the authors are not available.