Application of advanced hybrid metrology method to Nanoimprint Lithography

Ilya Osherov [a], Limor Issacharoff [a], Oram Gedalia [a], Koichi Wakamoto [b], Matthew Sendelbach [c], Masafumi Asano [d]

[a] Nova Measuring Instruments, LTD, P.O. Box 266, Weizmann Science Park, Rehovot 76100, Israel

[b] Nova Measuring Instruments KK,1-7-11-403 Higashigotanda, Shinagawa, Tokyo 141-00222, Japan

[c] Nova Measuring Instruments, Inc., 2055 Gateway Place, Ste. 470, San Jose, CA 95110, USA

[d] Toshiba Corporation, 8 Shinsugita-cho, Isogo-ku, Yokohama, Kanagawa, 235-8522, Japan

ABSTRACT

Nanoimprint lithography (NIL) is one alternative lithography solution that is being pursued by the industry. A metrology-related problem specific to NIL is the measurement of the residual layer thickness (RLT), as knowledge of this is key to the monitoring and control of the NIL process and subsequent patterning. Scatterometry is used to measure the RLT due to its ability to measure profile features non-destructively with high throughput. But because scatterometry is sensitive to features unrelated to the parameter of interest, complex geometries throughout the film stack can make the measurement challenging. New methods to reduce the impact of such complex geometries on the measurement parameters of interest are therefore needed. Because of the use of NIL for 3DNAND development, the measurement of the RLT with complex structures underneath becomes necessary. This paper describes the results from a new hybrid metrology method that can combine key information from these complex geometries with scatterometry measurements to reduce the impact on the RLT measurement due to the layers beneath the resist. By reducing this impact, scatterometry measurement noise and cross-correlation of parameters are reduced, resulting in better precision and accuracy in the RLT measurement.

Keywords: NIL, nanoimprint lithography, RLT, residual layer thickness, OCD, scatterometry, hybrid metrology, proxy

1. INTRODUCTION

Alternative lithography solutions have made significant advances in recent years, still offering a variety of choices within the semiconductor lithography community. In order for these advancements to be fully utilized, lithography methods also need innovative metrology solutions to address their unique challenges. Once such metrology solutions are in place, the lithography is much closer to being fully adopted. NIL is a method that enables lithography patterning

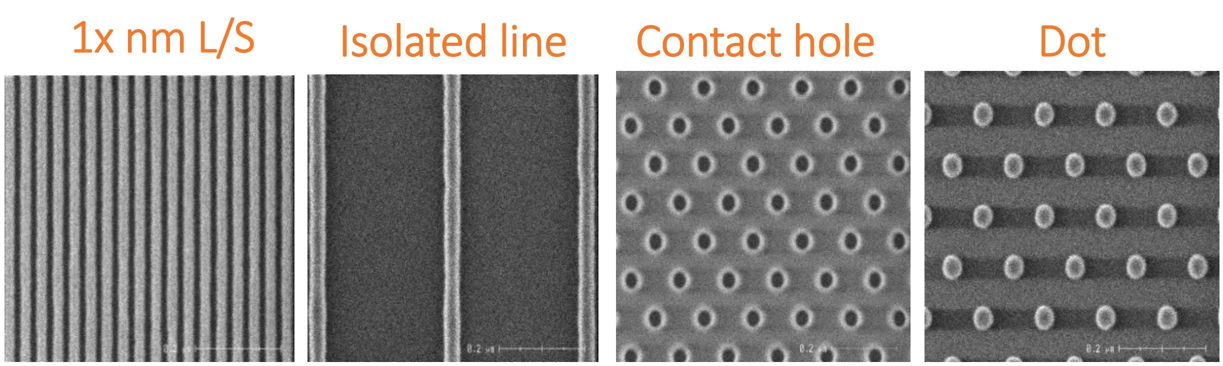

Figure 1: NIL applications. 1x nm L/S, isolated line, contact holes, and dot pattern.

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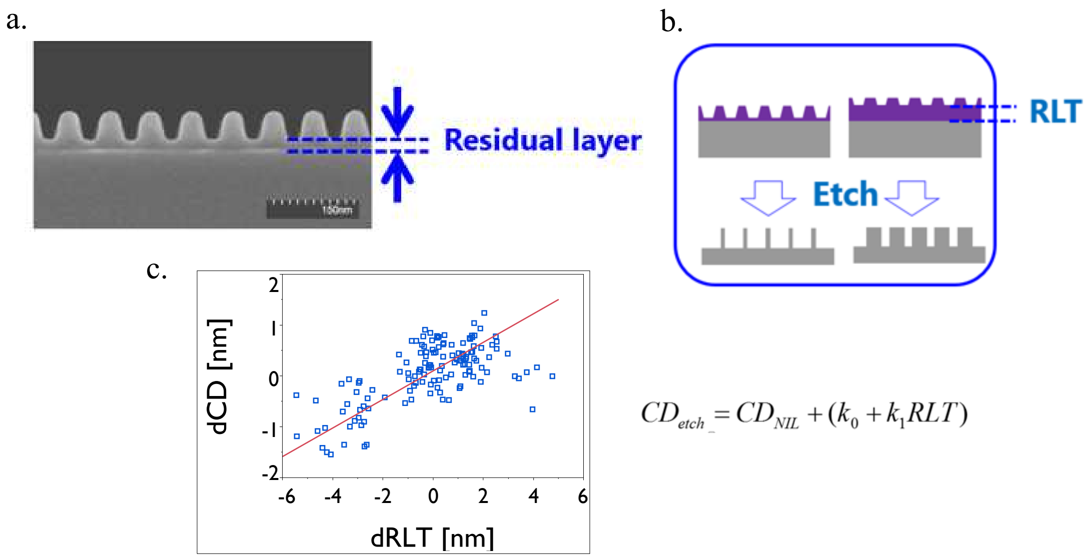
by means of mechanical deformation of an imprint resist and subsequent hardening by a UV light treatment. The NIL provides both economic and technological advantages. For example, the method is capable of fabricating sub-1x nm scale patterns without the need to implement multi-patterning techniques. NIL has various applications such as 1x nm line/space (L/S), isolated lines, contact holes, and dot patterns (Fig. 1).

2. RLT METROLOGY NEEDS

Residual layer thickness (RLT) metrology is critical for NIL patterning[1,2] because it has a direct impact on critical dimension uniformity (CDU). Figure 2a presents a cross-sectional scanning electron microscope (SEM) image L/S NIL pattern. A resist layer underneath the L/S is observed. This resist layer is made from residual material that is unable to enter the trench of the template during imprinting. RLT can be intentionally controlled by changing the amount of resist applied. The residual layer is essentially unavoidable in NIL, but undesirable for the etch process immediately after NIL. Figure 2b shows a schematic of the effect of RLT on the etched pattern. If the RLT is thinner than the target, the amount of side-wall etching is expected to become larger. As a result, the etched CD may become smaller. Figure 2c shows a correlation plot between the etched CD change and the post-NIL RLT variation, including inter- and intra- shot RLT variation. There is a positive correlation with an R^2 of 0.66. This result agrees with the prediction shown in Fig. 2b.



$$CD_{etch\_} = CD_{NIL} + (k_0 + k_1 RLT)$$

Figure 2: a. Cross-sectional SEM image for NIL resist pattern printed on Si wafer. b. Schematic of the effect of RLT on etched pattern. c. Correlation plot between etched pattern change in CD (dCD) and change in RLT (dRLT).

3. SCATTEROMETRY CHALLENGES AND HYBRID METHOD

A scatterometry measurement becomes very difficult when many materials and geometrical structures are needed for the model description, parameters have low spectral sensitivity, and strong crosstalk is exhibited between the parameters. Scatterometry (also called OCD, or Optical Critical Dimension metrology) model complexity becomes very high for NIL patterning on top of 3D NAND structures. The hybrid method used in this work helps to reduce the model complexity by combining key information from the complex geometries with scatterometry measurements. With hybrid[3,4,5] metrology, data from multiple sources are shared in a complementary way to enhance metrology performance and enable the measurement of complex structures that are not feasible using an individual technique. The hybrid method used here enables the elimination of the impact of model complexity on the RLT measurement by lowering the model complexity, effectively reducing the number of floated parameters and eliminating cross correlations. With this hybrid method, the solution is sensitive to the NIL pattern alone. This helps to overcome the OCD model complexity challenge by replacing a complex model with a simple one (Fig. 3).

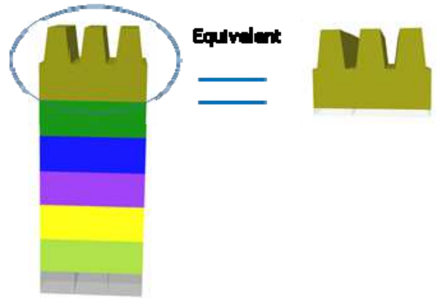


Figure 3: Schematic of how the hybrid method enables the reduction of model complexity of complex structures.

Figure 4 describes the general implementation scheme of the hybrid method. It requires the combination of two or more measurements in a unified hybrid model. The measurements are combined through the Nova fleet management system. Results from the Hybrid model are transferred to fab automation.

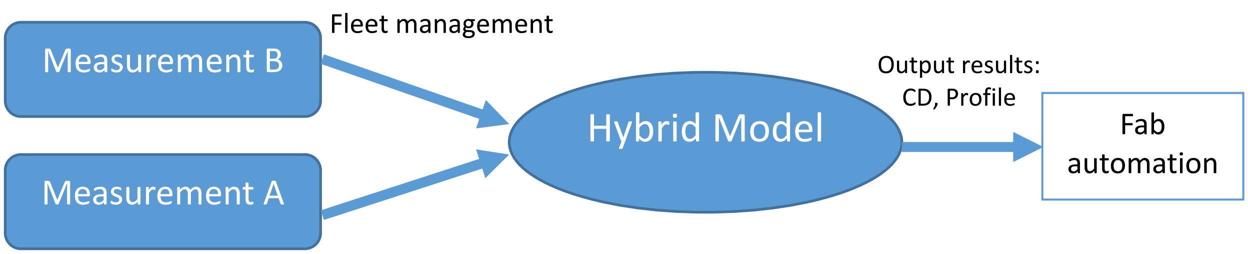


Figure 4: Schematic of a hybrid metrology implementation.

4. HYBRID METHOD VALIDATION TECHNIQUES

In this paper we present results verifying the measurement quality of the RLT on complex 3DNAND structures using this new hybrid method. Three methods were used to validate the hybrid method performance.

4.1 Method 1: Correlation between proxy and target wafers

The first method is illustrated in Fig. 5. The "proxy" wafer only contains the NIL patterned resist plus a couple of other layers identical to the target wafer, but not the complex under-layer pattern, thus making standard OCD a straightforward method to measure the RLT. Because of the insensitivity of the NIL process to the underlayers, target structures and proxy structures processed using the same NIL conditions should have nominally the same RLT. We call the locations where the complex structures are measured the target structure or "target" film stack (Fig. 5), which are on the target wafers. This structure, or film stack, consists of the NIL pattern over several film layers and a complex under-layer 3DNAND pattern. Comparison is performed between results obtained on target wafers using the hybrid metrology solution and proxy wafers measured with a standard scatterometry solution. This concept is similar to the commonly used idea of "sister" wafers, which are wafers that are nominally identical in an experiment. The term "proxy" is instead used in this case to indicate that the wafers are not even nominally identical (one contains the complex under-layer pattern, the other does not), but the relevant aspects of the wafers (the NIL resist on top) are still nominally identical.

4.2 Method 2: Robustness to complex geometry variations

In the second comparative approach, we take advantage of the fact that the NIL process is insensitive to the underlayers, whether simple or complex, as long as planarity is achieved before the NIL. By using the hybrid method to measure wafers with intentionally different underlayer parameter values but identical NIL process conditions, and confirming good correlation of the RLT between these different wafers, robustness to complex geometry variations can be verified.

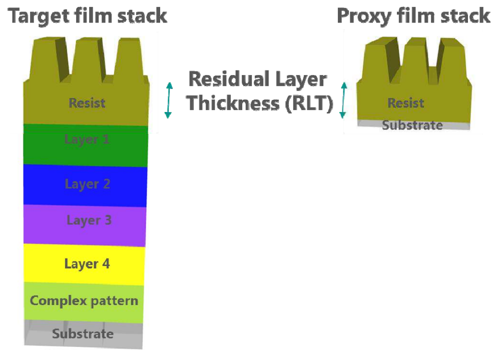


Figure 5: Schematic of the target film stack (left) and the proxy film stack (right). The critical parameter to measure after the nanoimprint lithography (NIL) is the residual layer thickness (RLT). Because the target film stack contains a complex under-layer pattern that makes standard scatterometry difficult for measuring the RLT, proxy wafers are produced that contain a much simpler film stack to enable standard scatterometry, but identical NIL process conditions (and therefore nominally the same resist parameters) as their corresponding target wafers.

4.3 Method 3: Matching to reference (XSEM & CDSEM)

Comparison to reference measurements collected from the same target wafers is the third validation method. The reference metrology used includes both XSEM (cross-sectional scanning electron microscopy) measurements of the RLT and the CD (critical dimension) of the resist, as well as CDSEM measurements of the resist CD. Although the resist CD is not as important to measure for NIL as the RLT, verifying it as well as the RLT increases confidence in the hybrid method.

5. RESULTS

Validation method 1: Because the NIL processing for each wafer (including intentional variation across die and across wafer) is nominally identical and insensitive to under-layer structure (assuming planarity before the NIL), the good correlation achieved between identical locations on the different wafers is an indication that the hybrid metrology measurement quality is good. Each data point is from the same location of each wafer. The different cells indicate different regions across the die (with intentionally induced across-die variation). Figure 6 presents comparison of the RLT and the middle CD (MCD) of the resist on a proxy wafer measured with standard OCD to the resist on a target wafer measured with the new hybrid method. The NIL for both wafers was processed identically, and included intentional RLT and CD variation across die and across wafer. The good correlations indicate that the hybrid method is measuring the target wafer well.

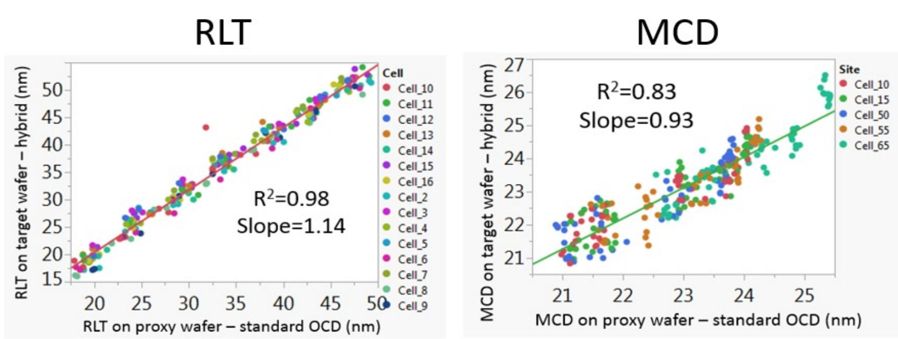


Figure 6: Residual layer thickness (RLT, on the left) and middle CD (MCD, on right) measurement comparisons between a proxy wafer measured with standard OCD and a target wafer measured using the new hybrid method.

Note that three different sources collectively contribute to the total error in each of these correlations: the hybrid measurement error of the target wafer, the OCD error of the proxy wafer, and the slight differences in RLT and MCD between the identical locations of each wafer (although the NIL processing is nominally the same between the two locations, the resulting resist parameters of each wafer at the same location are not identical).

Validation method 2: In order to test the robustness of the hybrid measurement method of the RLT on the target structure, other parameters of the target film stack were varied to see if they affected the RLT measurement. Because the NIL processing for each of these wafers (including intentional variation across die and across wafer) is nominally identical and insensitive to under-layer structure (assuming planarity before the NIL), the good correlation achieved between identical locations on the different wafers is an indication that the hybrid metrology measurement of RLT is robust to layer 2 thickness changes. Figure 7 presents one such case. Here, the thickness of layer 2 of the target structure was varied significantly across three different target wafers. Thickness "C" for layer 2 was nearly twice as thick as thickness "A", while thickness "B" was an intermediate thickness. All three wafers received the same NIL processing, including intentional variation across die and wafer. Even though the thickness of layer 2 varied significantly among the wafers, comparisons of the RLT at identical locations on each wafer show that the wafers correlate well to each other. In other words, the RLT measurement using the hybrid approach was not affected by even significant changes to the layer 2 thickness, indicating robustness to such changes. Not only are the slopes and R-squared values close to unity, but the average offsets (not shown) in each case are about 1 nm or less.

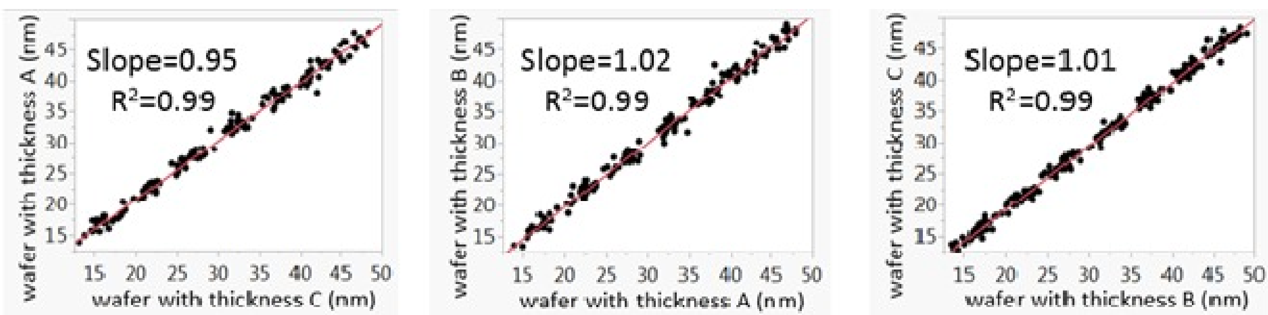


Figure 7: Residual layer thickness (RLT) measurement comparisons between 3 different target wafers measured using the new hybrid method. Each data point is from the same location of each wafer. Each of these wafers had a different thickness for layer 2 (see figure 5): thickness "C" was almost twice as large as thickness "A", with thickness "B" somewhere in between.

Validation method 3 results are presented in Fig. 8 and 9. They show metrology performances when compared to external reference metrology methods XSEM and CDSEM. Figure 8 presents the comparison of the RLT hybrid results versus XSEM, where an R^2 of 0.97 is obtained.

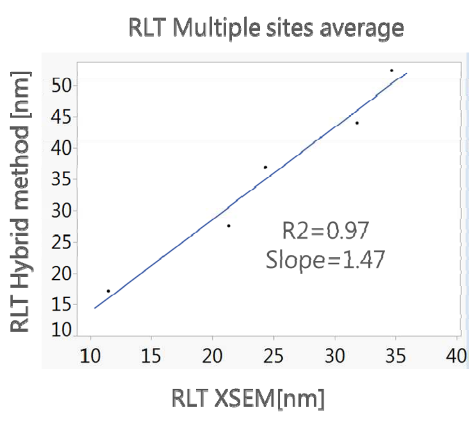


Figure 8: Hybrid RLT vs XSEM.

Matching of standard OCD and the hybrid method to CDSEM are presented in Fig. 9. The hybrid method shows a better R^2 (0.8 vs 0.75).

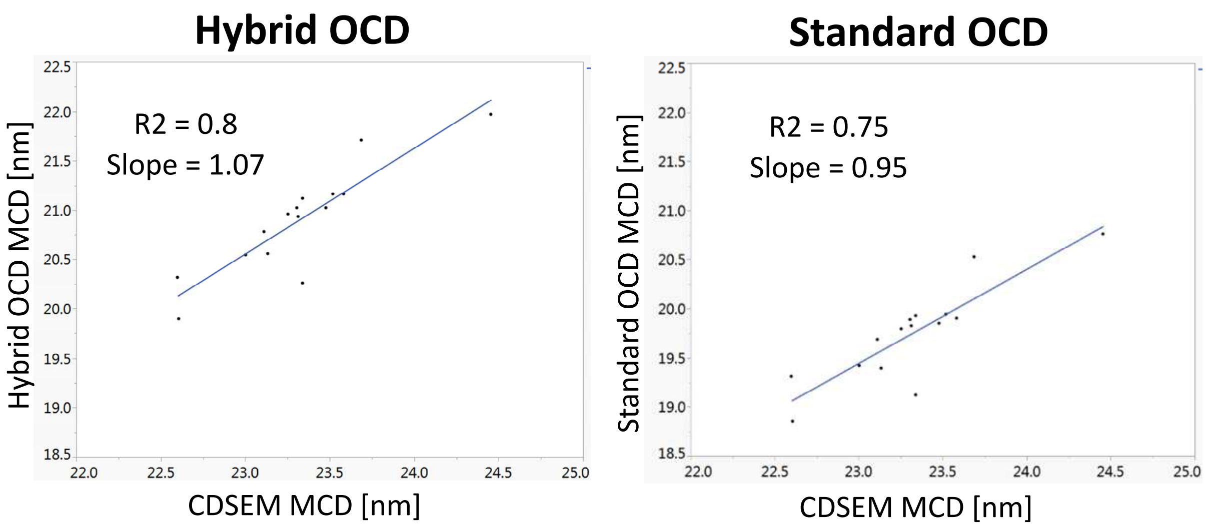


Figure 9: MCD obtained on a "target" wafer with hybrid and standard OCD approaches vs CDSEM.

6. CONCLUSIONS

Scatterometry can be used to measure the residual layer thickness (RLT) of nanoimprint lithography (NIL) due to its ability to measure profile features non-destructively with high throughput. But because scatterometry is sensitive to features unrelated to the parameter of interest, complex geometries throughout the film stack can make the measurement challenging. A new hybrid method was proposed to reduce the impact of complex geometries on the measurement parameters of interest. In this paper we presented a hybrid method as a tool that can help the metrology of the RLT on NIL patterns for 3DNAND. This method helps reduce the effective model complexity and makes it possible to overcome the metrology challenges. Results based on three different validation methods demonstrated the ability of the new hybrid method to successfully measure the RLT as well as the CD of the NIL pattern.

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REFERENCES

[1] Asano, M., Abe, H., Matsuki, K., Yoshikawa, R., Komori, M., Hirano, T., Mikami, S., Kim, Y., Choi, E., and Jung, W., "Required metrology and inspection for nanoimprint lithography," Proc. SPIE **10145** (2017).

[2] Asano, M., Kawamoto, A., Matsuki, K., Godny, S., Lin, T., and Wakamoto, K., "Application of optical CD metrology for alternative lithography," Proc. SPIE **8681**, 86812C (2013).

[3] Vaid, A., Yan, B. B., Jiang, Y. T., Kelling, M., Hartig, C., Allgair, J., Ebersbach, P., Sendelbach, M., Rana, N., Katnani, A., Mclellan, E., Archie, C., Bozdog, C., Kim, H., Sendler, M., Ng, S., Sherman, B., Brill, B., Turovets, I., and Urensky, R., "A holistic metrology approach: hybrid metrology utilizing scatterometry, CD-AFM, and CD-SEM," Proc. SPIE **7971**, 797103 (2011).

[4] Vaid, A., Elia, A., Kelling, M., Allgair, J., Hartig, C., Ebersbach, P., Mclellan, E., Sendelbach, M., Saleh, N., Rana, N., Kawada, H., Ikegami, T., Ikeno, M., Kawasaki, T., Bozdog, C., Kim, H., Arnon, E., Koret, R., and Turovets, I., "Hybrid metrology solution for 1X node technology," Proc. SPIE **8324**, 832404 (2012).

[5] Godny, S., Asano, M., Kawamoto, A., Wakamoto, K., Matsuki, K., Bozdog, C., Sendelbach, M., Turovets, I., Urensky, R., and Milo, R., "Hybrid approach to optical CD metrology of directed self-assembly lithography," Proc. SPIE **8681**, 86812D (2013).