TSMC Property

# Optical Scatterometry For In-Die Sub-Nanometer Overlay Metrology

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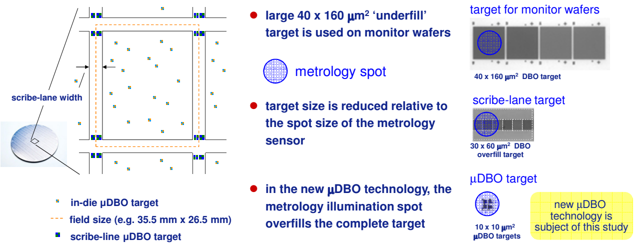
## Introduction

Customer requirements and ITRS specifications for on-product overlay metrology are reducing to sub-nanometer values. This means that many overlay metrology targets per field that are positioned within and distributed over the die, need to be measured, enabling intra-die higher order position corrections. Without loss of real-estate for metrology purposes, this is only possible by significant reduction of the metrology target dimensions. At this point, the best balance between the measurement noise, the speed of measurement and the size of the metrology target is required.

In this view, the recently developed micro-diffraction-based-overlay (µDBO) technology has shown size-reduced production metrology capability at the customer site. Successful tests at pre-production stacks have been performed using µDBO-targets with dimensions of 10 × 10 µm$^2$. Here, the balancing effect between throughput, precision and target size is presented, as well as the impact on accuracy is discussed.



- **large 40 x 160 µm$^2$ 'underfill' target is used on monitor wafers**
- **target size is reduced relative to the spot size of the metrology sensor**
- **in the new µDBO technology, the metrology illumination spot overfills the complete target**

FIG. 1. Overlay target size reduction for scribe lane and in-die application

## Diffraction-based optical scatterometry for overlay

The asymmetry in the +1st and -1st diffraction order intensity of a double-grating stack is a measure for the overlay shift between both layers in the stack. Using two such grating stacks with a programmed overlay-shift of +d and –d, respectively, enables an on-wafer calibration of the detected asymmetry. In the new µDBO technology, both overlay-gratings are small compared to the illumination spot. This requires special optical filtering and signal processing techniques to be applied to select the 1st diffraction orders, and filter out (product) environment and grating-edge effects. The µDBO-target complies well with placement in between device areas on the semiconductor wafer for its dense line-space pattern in both layers, which can be adapted to the environment by sub-segmenting the lines. Furthermore, the signal-to-noise ratio is intrinsically optimized by full usage in both layers of the target area with the dense line-space pattern.(1)

(1) N.P. Smith *et al.*, Proc. of SPIE **8324**, 832418 (2012)

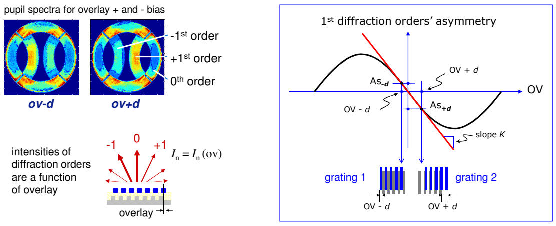


FIG. 2. µDBO: diffraction-based overlay metrology by YieldStar

## Throughput, precision and target-size, and the accuracy of small metrology targets

The performance of µDBO metrology targets on high-end production stacks has been tested at the customer site, presenting good results.(2) Significant R&D effort is dedicated to find an optimum balance between throughput, target-size and precision. Figures 3 shows that the measurement precision can be improved by increasing the number of detected photons, which has as drawback an increased acquisition time. This competitive effect between throughput and precision is presented for a number of production stacks as MAM-time versus TMU in figure 4. The trade-off between TMU and MAM is most difficult for layers presenting reduced sensitivity to overlay, often 'dark' layers, where the variation in the 1st order asymmetry with overlay is small.

(2) H.J.H. Smilde *et al.*, Proceedings of SPIE **8324**, 83241A (2012)

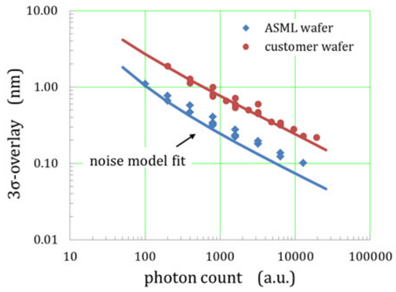


FIG. 3. Photon noise limited measurements

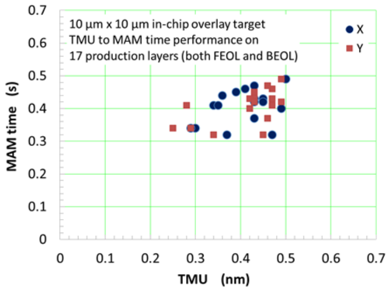
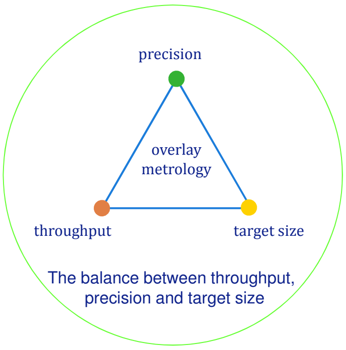


FIG. 4. Throughput *vs.* repro for current node

MAM = move-acquire-measure sequence

TMU = total-measurement uncertainty



The balance between throughput, precision and target size

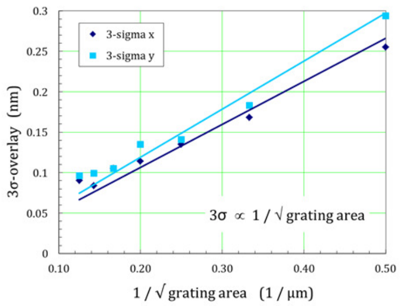


FIG. 5. Precision vs. grating size

The variation of the measurement reproducibility with target-size for constant camera acquisition time is presented in figure 5. An expected linear behavior with the inverse of the square-root of the contributing grating area is observed. The expected behavior is fitted with a linear fit through the origin. Note that, the absolute 3σ-values may further vary amongst others with stack properties and sensor settings.

The small target size not only influences precision, also accuracy aspects needs to be evaluated. Due to the small target size, the sensor optics such as lens aberrations, become important. For physical understanding and risk-assessment of the µDBO-technology, a partial coherent optical simulation tooling is developed. Figure 6 presents first results of the scalar version of the simulation tooling. The distance between a 10 × 10 µm$^2$-size target and a so-called anchor-feature environment is varied, while the 'measured' overlay is compared to the overlay of such a target with a plane stack environment. The overlay deviation is below 0.1 nm, and reduces at a distance of 1.5 µm to below 0.01 nm with proximity-like oscillations, indicating a good accuracy is achievable with these small in-die targets.

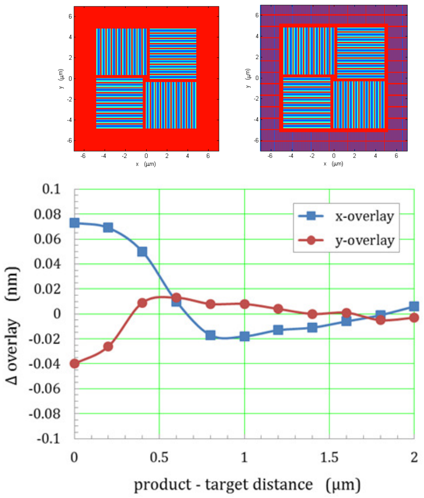


FIG. 6. Accuracy: influence of the distance to environment

## Conclusion

The reduction of overlay metrology target size leads to a trade-off between throughput and precision. In addition, the small target size emphasizes the proximity of the environment as well as aspects of the metrology sensor. The µDBO technology offers here an optimum solution, which retains good accuracy in an in-die environment from first simulations.

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