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TM200/TM300 METROLOGY MODULES ENABLE COMPREHENSIVE MANAGEMENT OF COATING PROCESSES

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Process engineers regularly achieve precise process performance with the ACS200 and ACS300 coating systems, but maintaining this process with the real-world situation of a HVM fab is another task completely. Atmospheric, material and mechanical variations contribute to the drifts in resist coating processes, and vary from location to location.

With ever tightening process windows maintaining high yield is already a challenge, especially if sample rates are low and/or there are several process steps after the coat. Precise inspection and CD measurements can be made after development or after etch, but deciding whether drifts or signatures are due to coat, exposure, development or etch equipment can be a challenge. In addition to this challenge, the current metrology portfolio can only alert you to an issue but not the source, let alone suggest how to resolve it.

The current standard tool qualification test of coating an unstructured wafer and measuring thickness is adequate for low frequency inter-wafer thickness drifts, but is blind to intra-wafer excursions. What is needed, is an enhanced method of tool qualification metrology that captures excursions caused by all sources of coating variation. With exposure and development variations removed from the equation, the process engineer has an ideal sample to analyse all variables in the coating process.

The new TM200 and TM300 metrology modules from SUSS MicroTec are the tools that finally reveal a clear picture of the coating process, and fully automate the tool qualification process.

INTRODUCTION

Our process and SUSS application engineers are expected to deliver excellent results on a daily basis, but maintaining this high performance over time is not so straight forward. Variation from equipment, materials and the cleanroom environment cause low frequency drifts and intermittent excursions. Monitoring and controlling such processes to maintain yield is an important task in any production environment, and becomes critical in the back end of line when the substrate value is high, metrology is less frequent and materials are difficult to rework.

Working closely with customers to extend high performance of our ACS coating systems beyond existing capabilities is a gap in metrology that was repeatedly encountered.

- Periodic thickness checks with bare wafers is good for compensating for inter wafer drifts over time, but is blind to intra wafer excursions.
- Post lithography CD and defect inspection tell you there is an issue, but cannot tell you where it is coming from, let alone how to resolve it.

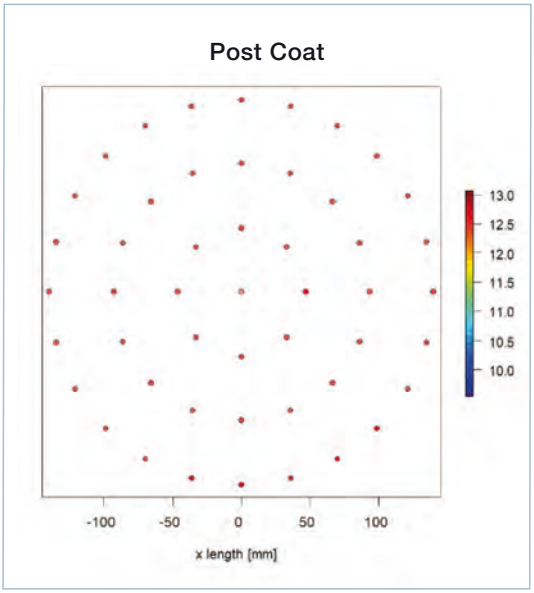

Figure 1 49-point thickness measurement using ellipsometer

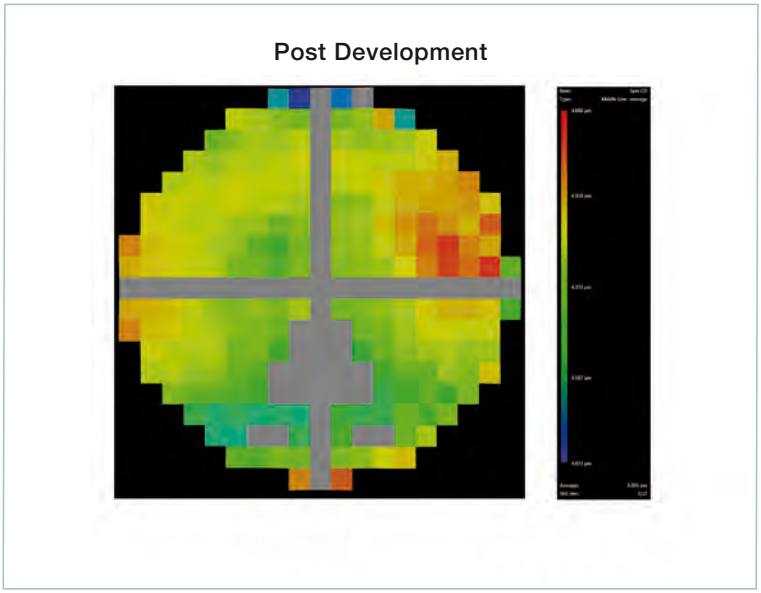

Figure 2 CD measurement

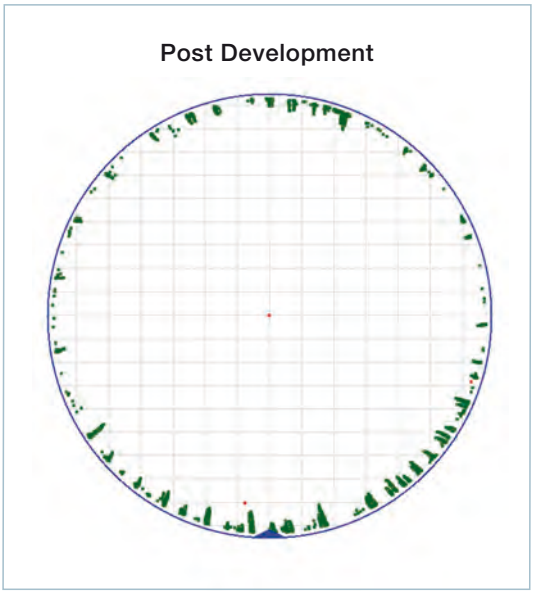

Figure 3 Defect inspection

What we need is to monitor coating process variation, not just react to defects detected later in the process flow. The best method to monitor the coating process would be immediately after a wafer is coated with a high density of measurement points; Ideally with the ability to correlate coating signatures to other sensors throughout the tool. Speeding up this measurement process with automation would enable higher frequency of such measurements to keep a tighter control of the tool.

THE TARGET

SUSS MicroTec set out to develop a comprehensive metrology platform that could quantify all variations that contribute to the coating process. The goal was to go beyond measuring thickness during periodic tool qualification tests and catch everything; once we could measure it, we could then manage it. The additional targets of integrating the module into the coater, automation of the measurement and feedback loop capability would deliver an industry 4.0 ready coating platform.

The key criteria for such a metrology module are:

- Non-destructive measurement method
- High density of measurement locations for thorough analysis of the wafer coat
- Precision to match existing metrology platforms
- Accuracy to give stable results in HVM environment
- Small package and low maintenance for integration inside the coater system
- High measurement speed maintain coating process throughput
- Feedback loop capability to automatically optimize coating parameters
- Fully integrated within tool controller software, sharing the same easy-to-use GUI and allowing offline analysis of collected data

THE RESULT

The principle of the TM200/300 is a high-speed interferometric thickness measurement of a full wafer surface with nanometer accuracy and stability. Using a novel positioning stage, the module is able to measure thousands of points, with a small footprint in less than a minute. This small package allows integration inside a coater, and the high throughput mitigates any throughput impact on processes running in parallel.

To ensure high MTBF (mean time between failure) and measurement stability, an LED-based illumination system was selected. This means maintenance-free operation, and exceptionally stable results are achieved.

A feedback loop was introduced to the ACS coater software to allow recipe modification based on the thickness measurement result. This feedback loop enables:

- Full automation of the current tool qualification procedure
- Flexibility to modify all coating parameters
- Compatibility with signature analysis algorithms

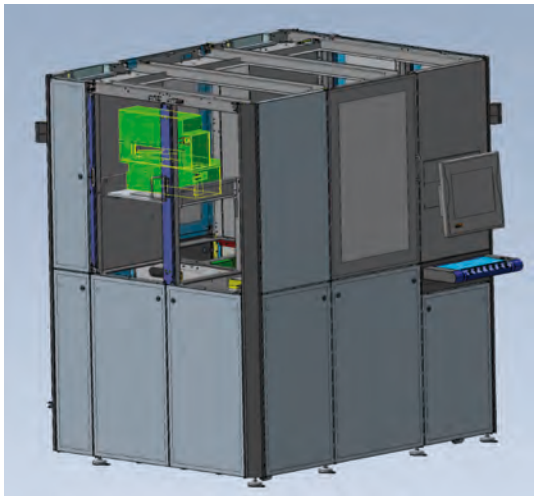

Figure 4 *TM200 module in an ACS200*

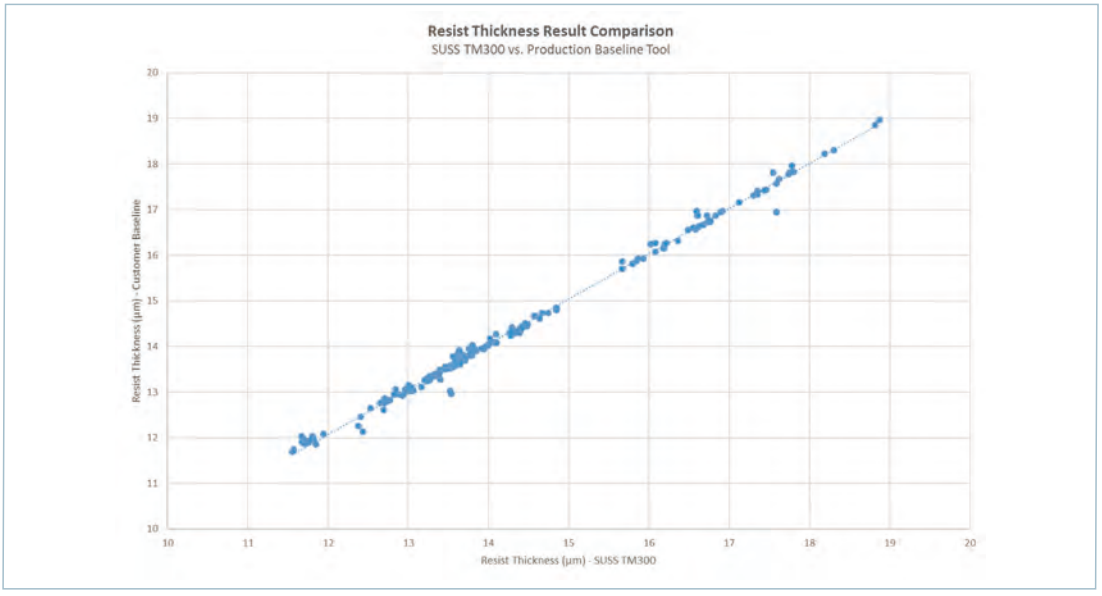

Figure 5 *Validation of TM300 accuracy and stability in production line*

BASELINE VALIDATION

Before exploring the new capabilities of the high density of measurement points, the accuracy and stability of this new metrology unit must be validated. In close collaboration with customers, SUSS MicroTec performed this validation, in a 300 mm HVM environment.

The customer tool qualification process was as follows:

1. Coating of a bare 300 mm Si wafer using the production coating recipe.
2. Manual transportation of the wafers from the ACS300 to their automated ellipsometer, and measurement of the resist thickness at 49 points.
   a. If thickness was out of spec the recipe was adjusted; increase spin speed if thickness is too high, reduce spin speed if it is too thin.
3. The coating and measurement process is repeated until the measured thickness is within SPC limits.
4. This procedure is repeated for each product, meaning multiple recipes with different target thickness.
5. A similar process is performed for polyimide material, but spin time is adjusted to reach the target thickness instead of spin speed.

Once installed, the TM300 measured the tool qualification wafers in parallel to the baseline ellipsometer over a period of 6 months. A comparison of the mean thickness result from the 7500 point measurement of the TM300 vs the 49-point baseline tool is plotted in the graph below. The results are 99.7 % correlation (multiple R) between the TM300 and baseline tool over a range of different thicknesses, and over the course of 6 months.

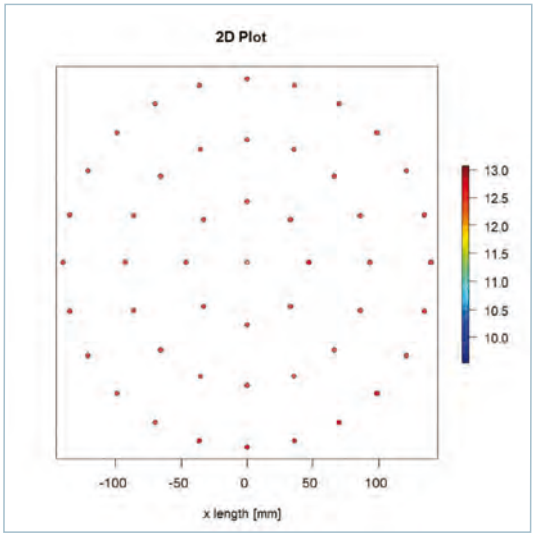

Figure 6 *49-point thickness measurement using ellipsometer*

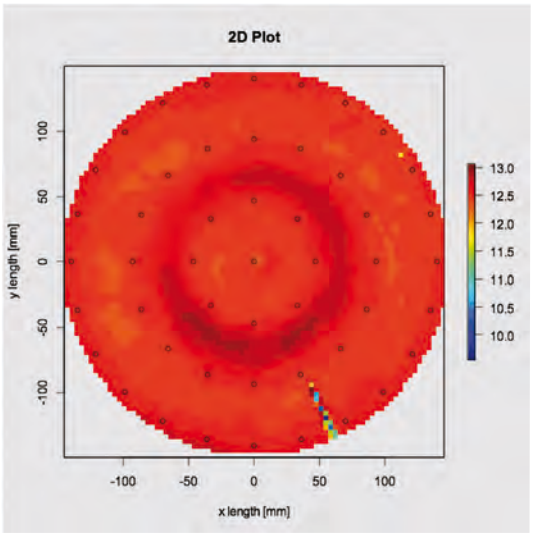

Figure 7 *DI300 comprehensive measurement (with overlay of 49-point locations)*

ENHANCED CAPABILITY OF THE TM300

Now that the TM300 mean thickness results are validated in terms of accuracy and stability we can investigate the benefits of the unique high-density measurement capabilities. The TM300 is capable of measuring thousands of points across the full wafer surface, including the wafer edge, in the same amount of time as the standard 49-point measurement of existing tools. Figure 6 and 7 shows a comparison result of the same wafer with the standard 49-point thickness measurement and a 7500-point measurement with the TM300, both with similar inspection times.

This wafer was in the first batch of tool qualification wafers measured after installation. Not only could we quantify the comet in the lower right corner that was missed by the baseline tool, but a long suspected ring of thicker resist was revealed. This signature was not quantifiable prior to the deployment of the TM300.

Over the course of the evaluation more intra-wafer thickness variation signatures were observed periodically, examples of which are shown in figures 9 - 14. The high quantity of measurement points generated by the TM300 delivers statistical power to identify these intra-wafer excursions. Providing the quantified measure of variation from each wafer in addition to mean thickness via SECS-GEM allows Statistical Process Control (SPC) at the host. Figure 8 shows the variation data collected during the evaluation period with the customer. An upper control limit of 1.25 % was created to identify intra-wafer excursions. Typically the baseline ellipsometer tool did not report these signatures so they were visually inspected to verify that they were true coating defects. Once verified, the data was reviewed by SUSS MicroTec application engineers to identify the root cause and appropriate corrective actions.

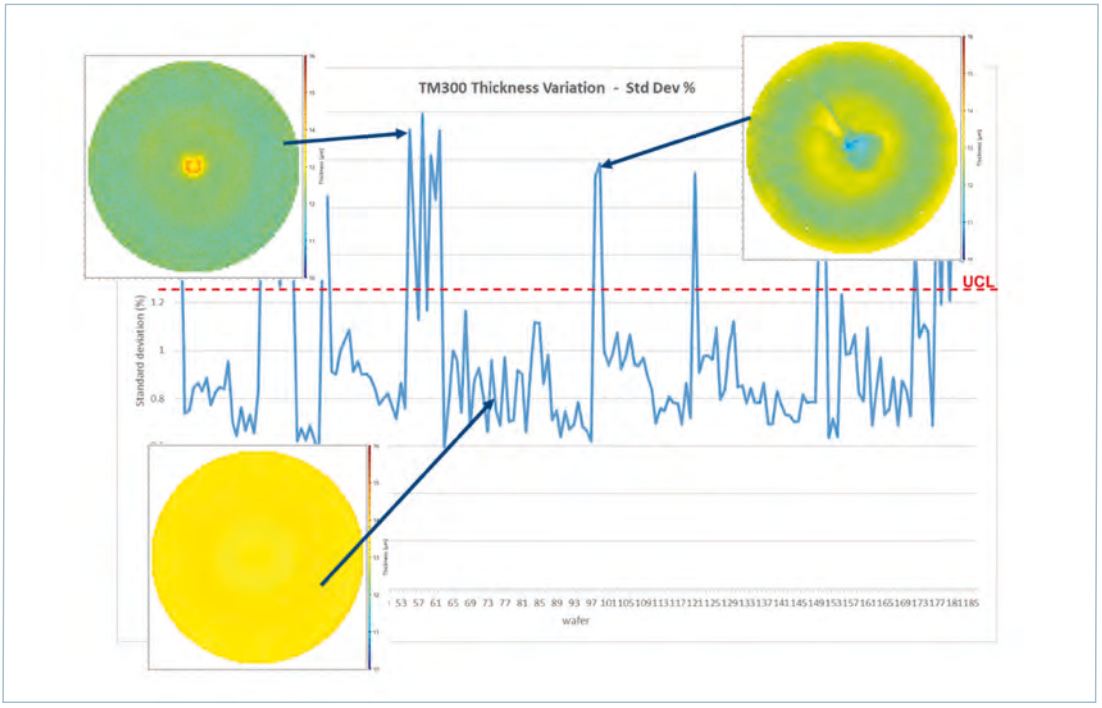

Figure 8 *Thickness variation data per wafer with new UCL to catch excursions*

IMMEDIATE IMPLEMENTATION

1. Manpower required for tool qualification tests is reduced significantly; from what used to take 30 – 40 minutes now takes less than 5. This manpower requirement drops to zero for fabs with automated transport since the ACS can alert the host of a successful result and automatically return to production.
2. Statistical variation data is sent to the host in addition to mean thickness. A control limit of 1.25 % is set for this new data, and an alert is created if this control limit is reached. Such an excursion is a reliable predictor of issues beyond low frequency thickness variations and must be addressed before returning the coating system to production.
3. A troubleshooting guide was created with the customer to enable technicians to quickly identify known excursion signatures and how to resolve the root cause.
   - High-resolution result images are available for process engineers to troubleshoot new excursions, and continually improve the troubleshooting guide.
   - The reduction of coating defects detected post development on production wafers and the resulting yield improvement is currently being calculated.

On the next page are some examples from the TM200/300 troubleshooting guide based on measurements at the HVM site.

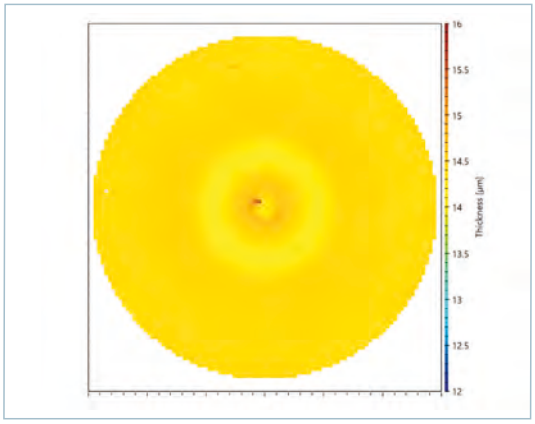

Figure 9 *Clogged nozzle during static dispense*

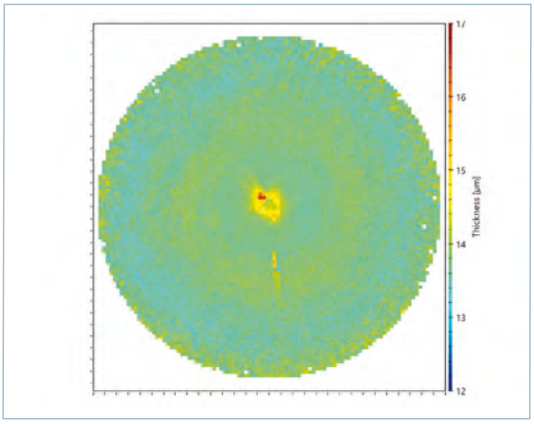

Figure 10 *Incorrect nozzle suck back*

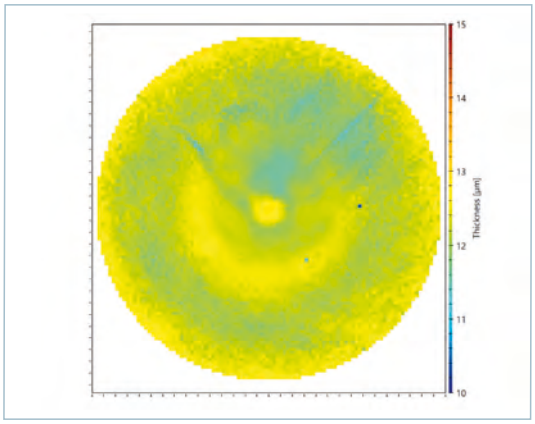

Figure 11 *Static dispense acceleration too high*

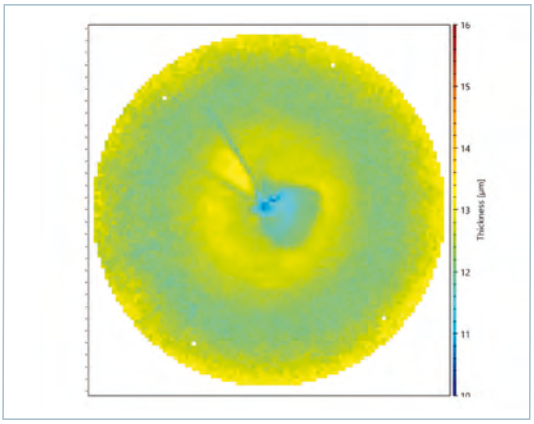

Figure 12 *Dynamic dispense rotation speed too high*

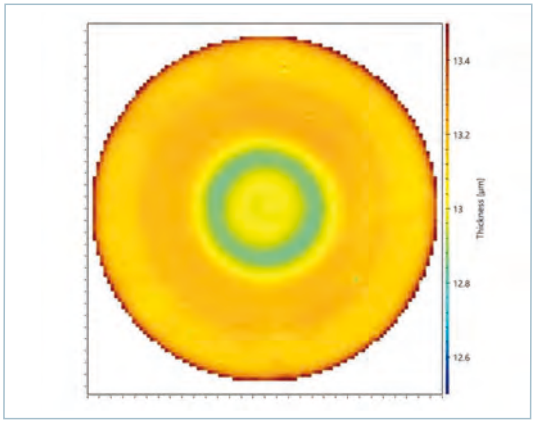

Figure 13 *Spin start too late after static dispense*

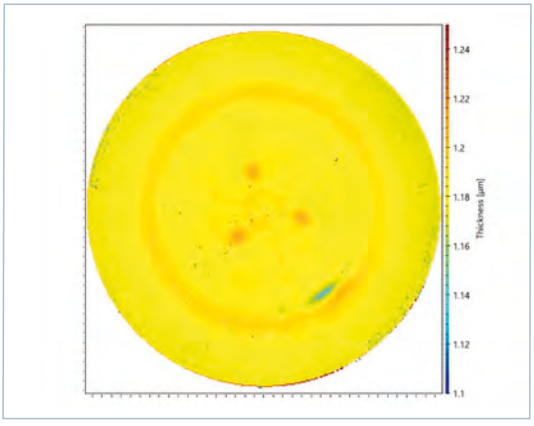

Figure 14 *Temperature variation at vacuum channels*

NEXT STEPS

Learning algorithms are being developed to correlate thickness signatures to coating parameters. Such tool intelligence can then alert the process engineer of specific issues and/or automate corrective measures within the ACS300 coater tool and resume production. A patent is pending for this functionality.

CONCLUSION

The new SUSS TM200/300 module is a game changer that finally enables precise process control of the lithographic coating processes. The key points of the module are:

- Excellent measurement accuracy allows the TM200/300 results to be compatible with existing thickness SPC baselines.
- The high density of the data enables real statistical analysis of each wafer, catch yield limiting excursions before the tool is returned to production.
- Automation and feedback loop capability reduces time required for tool qualification tests. The frequency of qualification tests can therefore be increased if needed for unstable production environments.
- Compact size and high throughput allows integration inside the ACS200/300 coating systems without impact on throughput of processes running in parallel.
- Automatic signature classification is already under development to deliver intelligent industry 4.0 capability.

This unique metrology module is an option for new ACS200 and ACS300 systems, and is available for field upgrades. Both new and upgraded systems have already been installed at HVM sites. The thickness measurement modules are available at SUSS MicroTec in Sternenfels and Garching for demonstration with a broad range of substrates and materials.

Acknowledgements
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Greg Savage joined SUSS MicroTec in 2014 as the Director of Application Engineering, and since 2018, he is Product Manager for Metrology. Prior to SUSS MicroTec he has accumulated 20 years of experience with micro defect inspection, macro defect inspection and metrology for lithography and 3D integration processes.
He received his B.S. in Electrical Engineering from Northeastern University in Boston.