



Etch Chamber Matching using Applied E3



Chamber matching is one of the most critical challenges in nanometer-scale processing. As device geometries shrink, processes become increasingly sensitive to small differences in chamber performance. The essence of the chamber matching challenge is in finding and controlling these small sources of variability that can impact on-wafer results. The payoff is higher device yield and improved tool availability.

Good chamber matching is built on a foundation of world-class engineering and manufacturing, but field responsiveness, dynamic control loops and automatic monitoring are becoming more essential as matching tolerances shrink. The matching challenge in the field is compounded in cases where device manufacturers drive requirements for new processes and films that may not have been encountered in factory testing. Engineers are often asked to quickly solve complex chamber performance problems with a combination of experience, instinct and terabytes of sensor data. Consequently, an increasing percentage of a process tool's value lies in its ability to help these engineers turn data into decisions.

The tool-level Applied E3™ application described here is part of a software suite that collects and analyzes tool data to help engineers optimize chamber matching performance on one of the industry's most advanced etch tools, Applied Centris™ AdvantEdge™ Mesa™.

CHAMBER MATCHING ON CENTRIS

Chamber matching software for Centris is built on three pillars:

1. Schedulable, automated software calibrations that use highly reliable and accurate reference sensors to keep process-critical gas delivery systems in control. These calibration services run discretely during tool idle time to check key process parameters like flow and pressure to provide improved control and performance trending for critical chamber hardware.

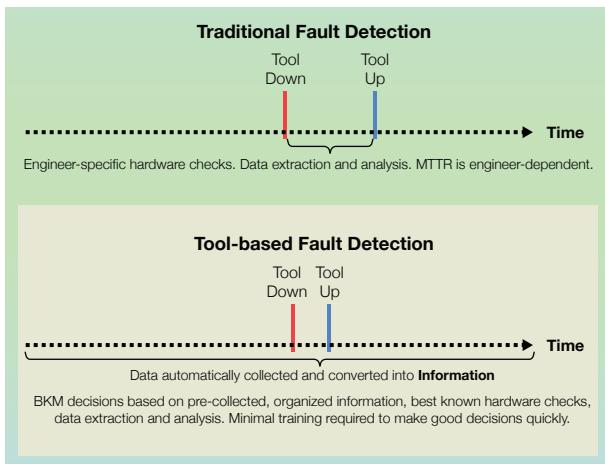
2. Background health checks that can alert the user to trends that can't be automatically calibrated and controlled. For example, mechanical and servo response times can be checked to assess wear or degradation.

3. Software tools that direct users to potential sources of chamber mismatch through engineered contextual reports and other visualization techniques that enable any engineer to approach a problem and view a tool's data through the eyes of its most capable experts.

There are two key chamber matching design goals for Centris: to automatically control and identify on-tool sources of on-wafer variation and to minimize the time required to identify, isolate and correct residual sources of performance variation through tool-level data analysis and visualization (Figure 1).

E3 enables Centris to achieve these goals through:

- Trend analysis and limit checking during calibration and health checks, and trend analysis for production data to alert engineers to critical and emerging sources of variance.
- Configurable, contextual data analysis and reporting to collect, organize and present sensor data in a format engineered to efficiently identify critical performance variations and guide an engineer to root cause.
- Interactive data analysis techniques like data mining to extract potential sources of run-to-run and chamber-to-chamber variance that don't manifest themselves through trend analysis or preconfigured reports.



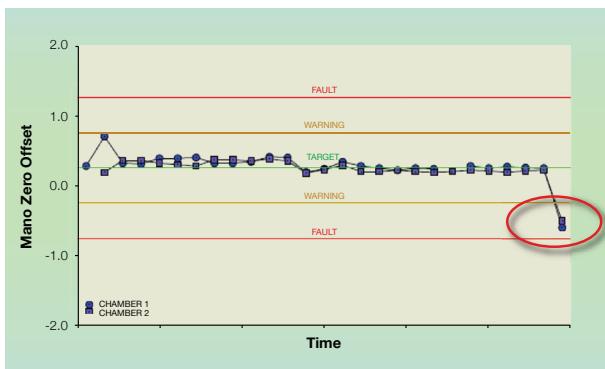
▲ FIGURE 1. Traditional fault detection relies on engineer-specific hardware checks, data extraction and analysis. In tool-based fault detection, the process tool detects and anticipates problems, continuously testing performance and automatically converting raw data in information that can be used to draw conclusions.

TREND ANALYSIS

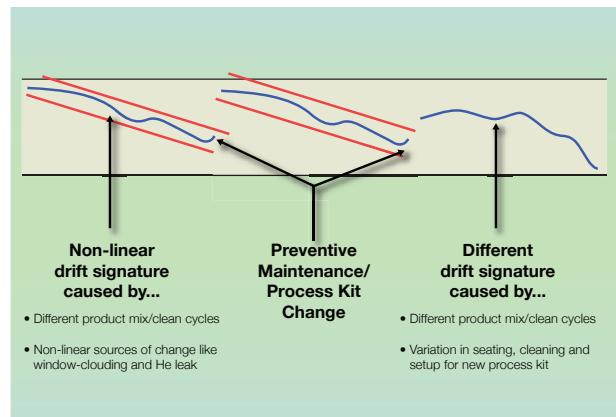
The Applied E3 statistical process control (SPC) module provides historical trending and excursion control limits for automated calibrations and health checks. Limits and alarm responses can be hard-coded in cases where they are well understood or computed statistically from data sets deemed to be good. Figure 2 shows an example where E3 has detected that the calibration adjustments for the offset factor in the pressure control system have drifted out of predefined warning limits.

Trend analysis and excursion control can also be applied to tool data collected during production runs. Tool-level analysis is coupled directly to the tool control software to provide direct access to all tool data at 10Hz speeds vs. the 2-5Hz data rate that is typically available through GEM/SECS.

Statistically computed control limits can be used in cases where limit definitions of *good* and *bad* are based on baseline runs for results deemed as good during tool qualification. Moving limits



▲ FIGURE 2. An E3 SPC chart indicates that a pressure sensor offset has shifted outside its control limits.



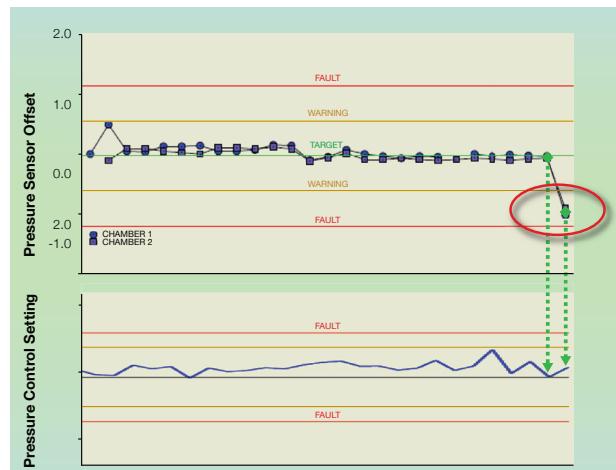
▲ FIGURE 3. Controlled-drift and PM-driven multi-modal behaviors raise unique challenges in etch that can be managed in E3.

can be applied in cases where some drift resulting from factors like process kit wear is expected (Figure 3).

Production trend analysis and excursion control is common at the fab level, but advanced notification at the tool level gives field engineers more time and more information to respond proactively before issues affect the fab level.

VISUALIZATION TO DRAW CONCLUSIONS FROM DATA

Configurable analysis and reporting in E3 enables continuous improvement in the visualization techniques used to convert data into actionable information. In Figure 2, the trend analysis indicated that there could be a problem with the pressure sensor. But does the pressure sensor need to be replaced or is this just a particularly large shift in its offset correction factor? Additional reports generated by E3 can lead the user to the right conclusion.



▲ FIGURE 4. Pressure sensor offset shifts below lower control limit after exposure to atmosphere. Consistent pressure control valve settings before and after sensor offset is applied confirm that pressure sensor offset calibration is valid.

The E3 report in Figure 4 shows no significant change in pressure control settings after the new pressure sensor offset is applied. This helps to confirm that the offset correction is valid. The shift in pressure sensor readings after exposure to atmosphere through a chamber vent history report could also be used to fortify the conclusion that this offset correction is valid. Multiple data traces organized into these types of reports guide the user to a conclusion that would previously have required manual data extraction, analysis and expert-level knowledge of the pressure control system.

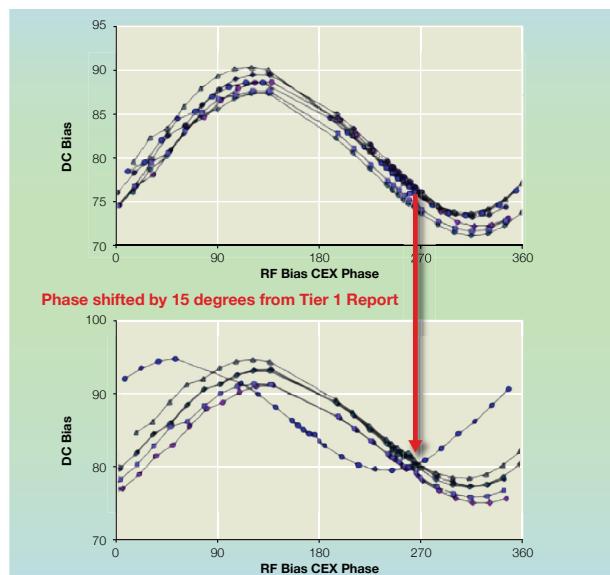
This is a practical example of an expert system; it is a process of guiding the user to conclusions through pre-defined analysis and visualization techniques. The enabling element here is in how the combination of data storage, analysis tools and configurability in E3 facilitates the migration of engineering knowledge onto the etch tool.

AUTOMATION OF EXISTING REPORTS

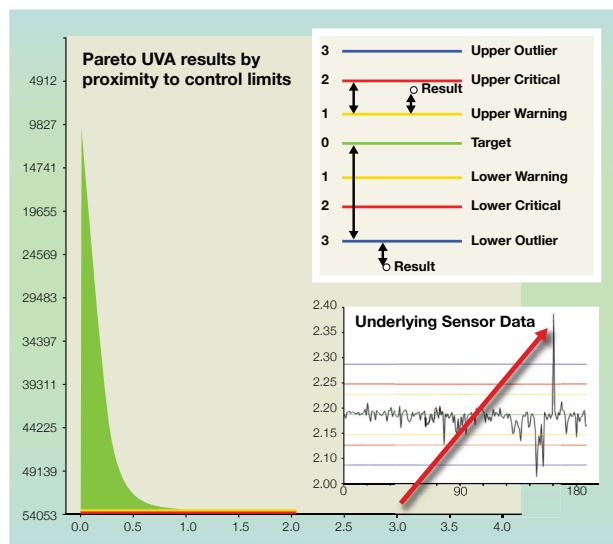
E3 also simplifies the archiving and reporting of benchmark test data that was previously transcribed manually into a spreadsheet. Automation reduces the time required to qualify a new tool and it facilitates subsequent comparisons against the benchmark readings during troubleshooting. Using this tool, field engineers spend less time clicking, copying and pasting and more time thinking. Figure 5 shows an automated acceptance report for an RF subsystem that has shifted after initial setup.

INTERACTIVE DATA ANALYSIS AND MINING

Predefined analysis and visualization strategies frequently show no clear trend or correlation to mismatched on-wafer results. In these cases, newly introduced data mining capabilities in E3 facilitate more efficient navigation of large data sets. Data mining tools can be used to rank degrees of difference in large data sets, avoiding the need to look through hundreds of individual charts to find the most likely sources of variation.



▲ FIGURE 5. RF phase shift from baseline test data detected in Applied E3.



▲ FIGURE 6. Automatic ranking of sensor data by its proximity to control limits facilitates efficient navigation of large quantities of sensor data.

The analysis shown in Figure 6 ranks SPC data by proximity to control limits, enabling an engineer to efficiently review a large data set, starting with the data that is most suspicious as defined by its proximity to its control limits. A less obvious, but equally valuable aspect of data mining is the ability to quickly determine that the answer may not lie in the data. This can point an engineer to a need for additional metrology or sensor feedback to improve the tool's ability to predict on-wafer results with data.

CONCLUSION

Today's engineers commonly conduct chamber matching analyses offline using text files and spreadsheets. Because there isn't enough time or knowledge to assemble the information and expertise required to make the best decision, engineers often resort to hit-or-miss approaches to problem solving. Too often, the best chamber matching knowledge remains in the minds and spreadsheets of a few engineers.

E3 facilitates tool-level generation and retention of chamber matching knowledge through configurable fault detection, data analysis and visualization that can be distributed and matured through ongoing cycles of improvement. In cases where dynamic limit checking and reporting don't reveal the source of a matching issue, interactive E3 analysis and data mining tools can enable experienced engineers to draw additional conclusions from tool data. Conclusions may range from requirements for additional charts or analysis models in E3 to the need for improved process visibility through advanced sensors. Chamber matching maturity is driven by cycles of learning as conclusions from interactive and offline failure analysis drive improvements in automated tool-level diagnostics. The value of Applied E3 grows as more matching issues are detected in less time and unscheduled tool down time decreases. ■

Authors: Todd Egan, Barry Craver, Dermot Cantwell. For additional information, please contact Todd_Egan@amat.com.

