IN-SITU FAULT DETECTION AND EXCURSION PREVENTION FOR WAFER PROCESSING EQUIPMENT

Or

We already know our machine is guilty… Now how do we fix it and restore the Fab Manager's confidence?

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Introduction (I)

- The data collection and analysis needs of Fab Management are different from those of wafer processing equipment suppliers and module engineers
  - Fab Managers need to look at the fab globally and need accurate functional-area-level performance metrics to determine where the problem areas are in the overall manufacturing flow
  - Once the “Trouble spots” in the Fab have been defined, Process Integration and Functional Area Managers need accurate station-level and lot-level metrics to identify problem modules and tool sets
  - **Hardware and process engineers associated with under-performing tool sets need *machine-level* data to rectify the problem(s)**

Introduction (II)

- The equipment-level problems module engineers face today are bad and only getting worse:
  - Subtle hardware/process interactions that used to be “in the noise” are now often fatal…. Caused by eroded process margin from relentless device shrinkage
  - Process margins will almost certainly continue to shrink along with device size

Introduction (III)

- **…And will probably continue to get worse.** As it gets more difficult to improve device performance by additional shrinkage, the industry will most likely focus on other means of maintaining/improving profitability:
  - More emphasis will be placed on manufacturing prowess
  - Die/line yield excursions will be tolerated less
  - Higher capital utilization will be demanded
  - Modules will be driven to minimize the quantity of non-product monitor wafers they use while guaranteeing a higher level of safety for the product they process
  - MTBF, MTTR and repair cost metrics will receive greater scrutiny

Introduction (IV)

- **Bottom Line:**
  1. **The process and reliability performance demands on wafer processing equipment are relentlessly increasing.**
  2. **To meet customer expectations, hardware and process engineers need meaningful tool performance/ diagnostic data.... More detailed than what is available at the Factory MES level.**

"PROCESS" FAULT DETECTION AND EXCURSION PREVENTION METHODOLOGY (I)

1. Start with the tool's own control system…. The I/O signals required to control each subsystem (Vacuum, gas flow, ESC, RF delivery, etc.) most often act as valid performance "sensors" as well. Use automated collection to record them as a function of time, *all on the same time-base.*
2. Analyze the resulting time trace data with respect to the specific process recipe structure to generate wafer-by-wafer statistical metrics for each major subsystem on the tool.
3. Leverage process sensitivity pareto information to define the most critical subsystems to scrutinize.
4. Monitor the subsystem metrics trend charts with respect to process performance at the wafer/lot level to establish tool performance stability and determine ***acceptable natural tolerance.***
5. Once statistical baselines for the various subsystem metrics have been established, set control limits to stop the tool when it is clearly off baseline (Different is bad until proven otherwise!).

- Each I/O point here has value for process control, trouble shooting or cross-check

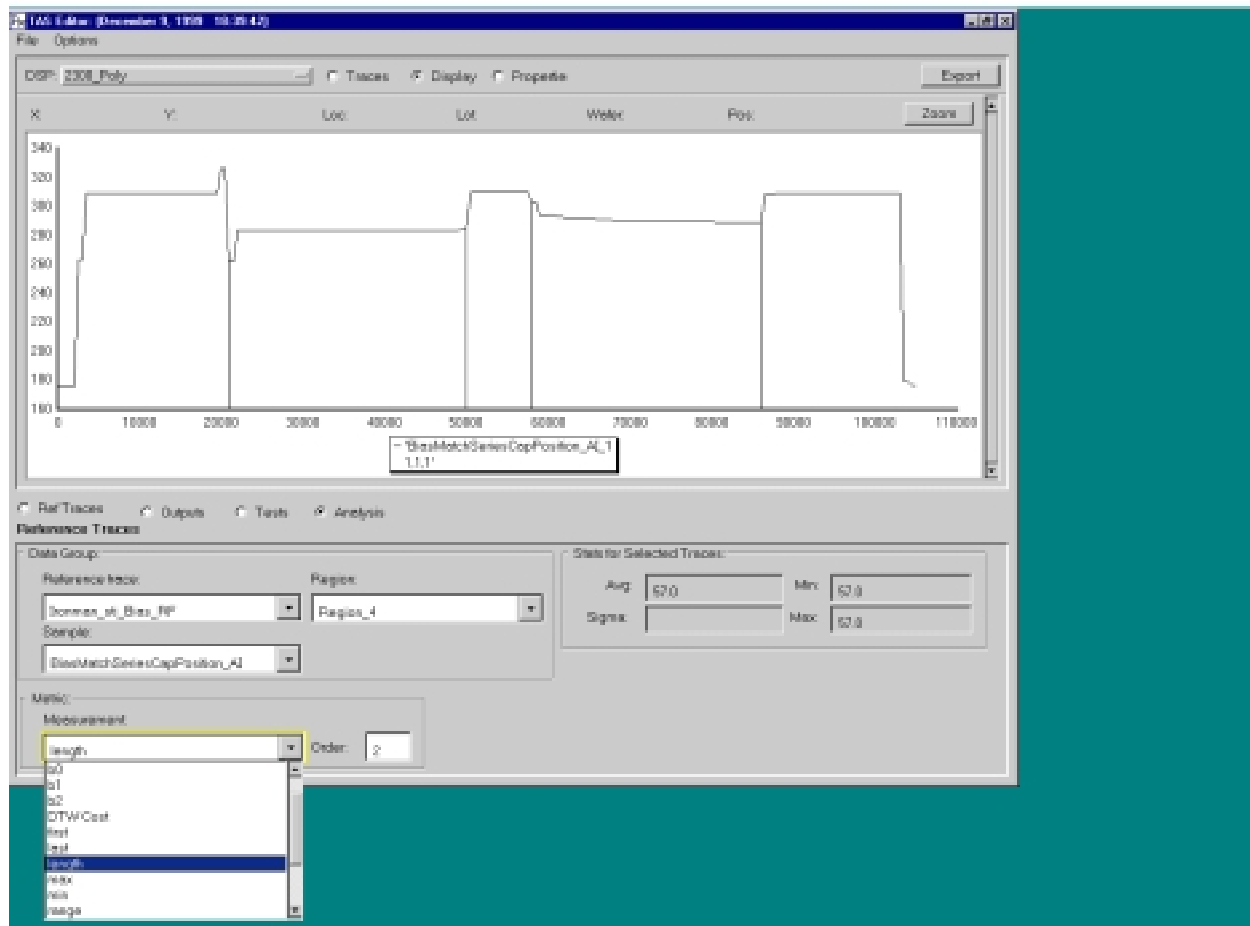
	2300 Conductor PM I/O Points Recommended for Collection			
	I/O point Name	**Suggested Sampling Frequency (Hz)**	**Collection Value**	**Description/Comments**
1	**BiasMatchCurrentSense_AI**	2	High	Potentially excellent for correlating to subtle process performance shifts in volume production
2	**BiasMatchImpedanceMagnitude**	2	High	" "
3	**BiasMatchImpedancePhase**	2	High	" "
4	**BiasMatchSeriesCapPosition_AI**	2	Highest	Excellent integrated indicator of tool stability and essential for tracking/diagnosing RF system transient behavior
5	**BiasMatchShuntCapPosition_AI**	2	Highest	" "
6	**BiasMatchVoltageSense_AI**	2	Highest	Proven in the past to mirror very subtle changes in process performance; also an excellent indicator of bias current return path characteristics and stability
7	**BiasRFGenForwardPower_AI**	1	Highest	A very basic check of fundamental RF generator performance
8	**BiasRFGenReflectedPower_AI**	2	Highest	A very basic check of fundamental RF match performance
9	**BiasRFVoltageProbe_AI**	2	Highest	Proven in the past to mirror very subtle changes in process performance; also an excellent indicator of bias current return path characteristics and stability. If accurate, serves as an indirect indicator of the wafer sheath potential
10	**ChamberFrontLeftTemperatureMonitor_AI**	1	Moderate	Good as a archival reference when the unavoidable chamber-to-chamber matching issues arise in volume production…… Can eliminate a lot of busy-work in the future

11	**ChamberFrontRightTemperatureMonitor_AI**	1	Moderate	Good as an archival reference when the unavoidable chamber-to-chamber matching issues arise in volume production…… Can eliminate a lot of busy-work in the future
12	**ChamberPressureManometer_AI**	2	High	An excellent cross-check signal when gas flow performance questions arise…. e.g. If the steady-state throttle valve position is drifting with time, this signal can be used to help answer if the actual process pressure is remaining constant
13	**ChamberRearLeftTemperatureMonitor_AI**	1	Moderate	Good as a archival reference when the unavoidable chamber-to-chamber matching issues arise in volume production…… Can eliminate a lot of busy-work in the future
14	**ChamberRearRightTemperatureMonitor_AI**	1	Moderate	Good as a archival reference when the unavoidable chamber-to-chamber matching issues arise in volume production…… Can eliminate a lot of busy-work in the future
15	**GasRingTemperatureAI**	1	Moderate	Good as a archival reference when the unavoidable chamber-to-chamber matching issues arise in volume production…… Can eliminate a lot of busy-work in the future
16	**CurrentStepNumber**	1	Highest	This is the highest leverage piece of information available for parsing data streams into physically meaningful regimes…. Truly a must!
17	ElapsedWaferCountToClean	1	Moderate	" "
18	**ESCClampVoltageMonitor**	2	Highest	For the monopolar chuck circuit, tracking this over time is an excellent idea until we establish complete confidence in the accuracy of the measured DC bias
19	**ESCCoolantFlow_AI**	1	Highest	Good as a archival reference when the unavoidable chamber-to-chamber matching issues arise in volume production…… Can eliminate a lot of busy-work in the future

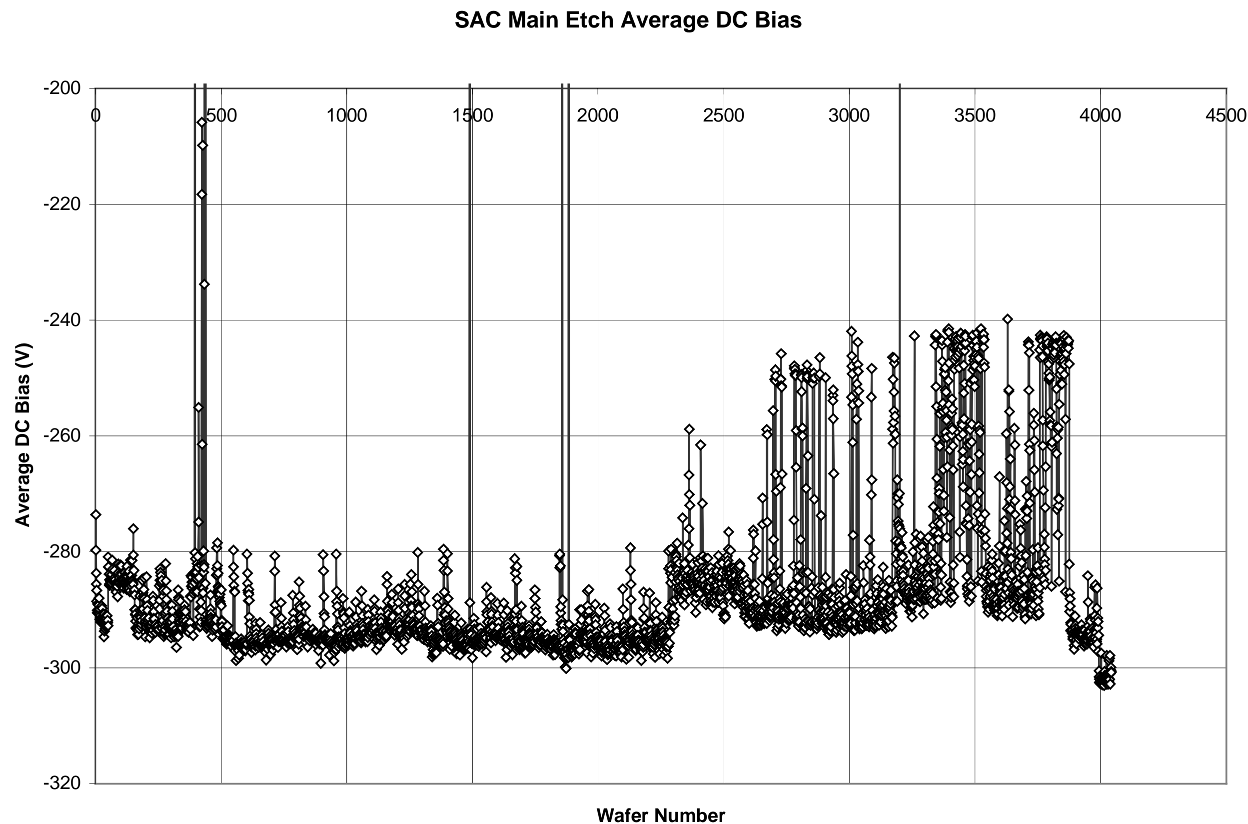
20	**ESCLeakageCurrentMonitor_AI**	2	Highest	A rather useful tracking parameter to assess degradation of anodized chucks, almost certainly useful for ceramic chucks as well….
21	**ESCTemperatureMonitor_AI**	1	Highest	An excellent diagnostic signal for "fingerprinting" thermal performance of the total lower electrode system; a key parameter for tool matching
22	**ESCTotalVoltage_AI**	2	Highest	For the monopolar chuck circuit, tracking this over time is an excellent idea until we establish complete confidence in the accuracy of the measured DC bias
23	**ForelineManometer_AI**	2	Highest	An excellent cross-check signal when gas flow performance questions arise…. e.g. If the steady-state throttle valve position is drifting with time, this signal can be used to help answer if the effluent gas load is staying constant
24	**Gas_"X"_Flow_AI**	2	Highest	Crucial for verifying MFC transient behavior and stability. Collect all channels so you don't lose information if the gas box is re-configured
25	**GateValveTemperatureMonitor_AI**	1	Moderate	Good as a archival reference when the unavoidable chamber-to-chamber matching issues arise in volume production…… Can eliminate a lot of busy-work in the future
26	**HeBacksideFlow_AI**	2	Highest	Probably the best integrated indicator of chuck performance and cleanliness….. An absolute must
27	**HeBacksidePressure_AI**	2	Highest	May seem boring at first but transient behavior during initial settling has been correlated to CD variation and "Hot spotting" on the wafer
28	**IB1Value**	2 to 5	Highest	Often serves as the "Rosetta stone" for analyzing the rest of the machine parameter signals. 2 Hz is totally adequate for all but the fastest transients
29	**IB2Value**	2 to 5	Highest	" "

30	**ManifoldTemperatureMonitor_AI**	1	Moderate	Good as a archival reference when the unavoidable chamber-to-chamber matching issues arise in volume production…… Can eliminate a lot of busy-work in the future
31	**ProcessManometer_AI**	2	Highest	Should be tracked until absolute confidence in the autozero function and acceptable ranges for the zero offset are established
32	**ProcessManometerAdjustedPressure**	2	Highest	" "
33	**TCPMatchC1CapPosition_AI**	2	Highest	Excellent integrated indicator of tool stability and essential for tracking/diagnosing RF system transient behavior
34	**TCPMatchC3CapPosition_AI**	2	Highest	" "
35	**TCPMatchCurrentSense_AI**	2	High	Potentially excellent for correlating to subtle process performance shifts in volume production
36	**TCPMatchVoltageSense_AI**	2	High	" "
37	**TCPMatchImpedanceMagnitude**	2	High	" "
38	**TCPMatchImpedancePhase**	2	High	" "
39	**TCPMatchVoltageProbe_1_AI**	2	Highest*	Absolute values are useful as an assessment of source impedance stability. The Probe_1/Probe_2 ratio characterizes the RF voltage node/antinode position(s) and thus the spatial distribution of capacitive RF coupling
40	**TCPMatchVoltageProbe_2_AI**	2	Highest*	" "
41	**TCPRFGenForwardPower_AI**	1	Highest	A very basic check of fundamental RF generator performance
42	**TCPRFGenReflectedPower_AI**	2	Highest	A very basic check of fundamental RF match performance
43	**TCUMonitor_AI**	1	High	A good tracking parameter for coolant temperature stability and a very helpful piece of information for characterizing installation-specific thermal losses
44	**ThrottleValvePosition_AI**	2	Highest	Excellent for monitoring overall pressure/flow control system performance…. A must!

- Properly defining the metrics calculations is the second key to success; if the metrics do not meaningfully represent the tool's behavior at the key moments of processing, all further analysis will be flawed



- This is an example of the kind of metrics output generated from good trace analysis on real production wafers. In this case the tool in question suffered a die yield excursion between wafers ~2300 and ~3900



Remember the process sensitivity pareto? For this recipe DC bias during the main etch was the single most important process parameter controlling the dominant yield loss mechanism

"PROCESS" FAULT DETECTION AND EXCURSION PREVENTION METHODOLOGY (II)

- The metrics trend charts are the key analysis output; the raw trace data is too difficult to deal with and the act of calculating the metrics enhances the signals.
- Wafer I.D. accountability to the metrics data and correlation to traditional in-line monitors and relative yield data unlock the full potential of the technique

"PROCESS" FAULT DETECTION AND EXCURSION PREVENTION METHODOLOGY (II)

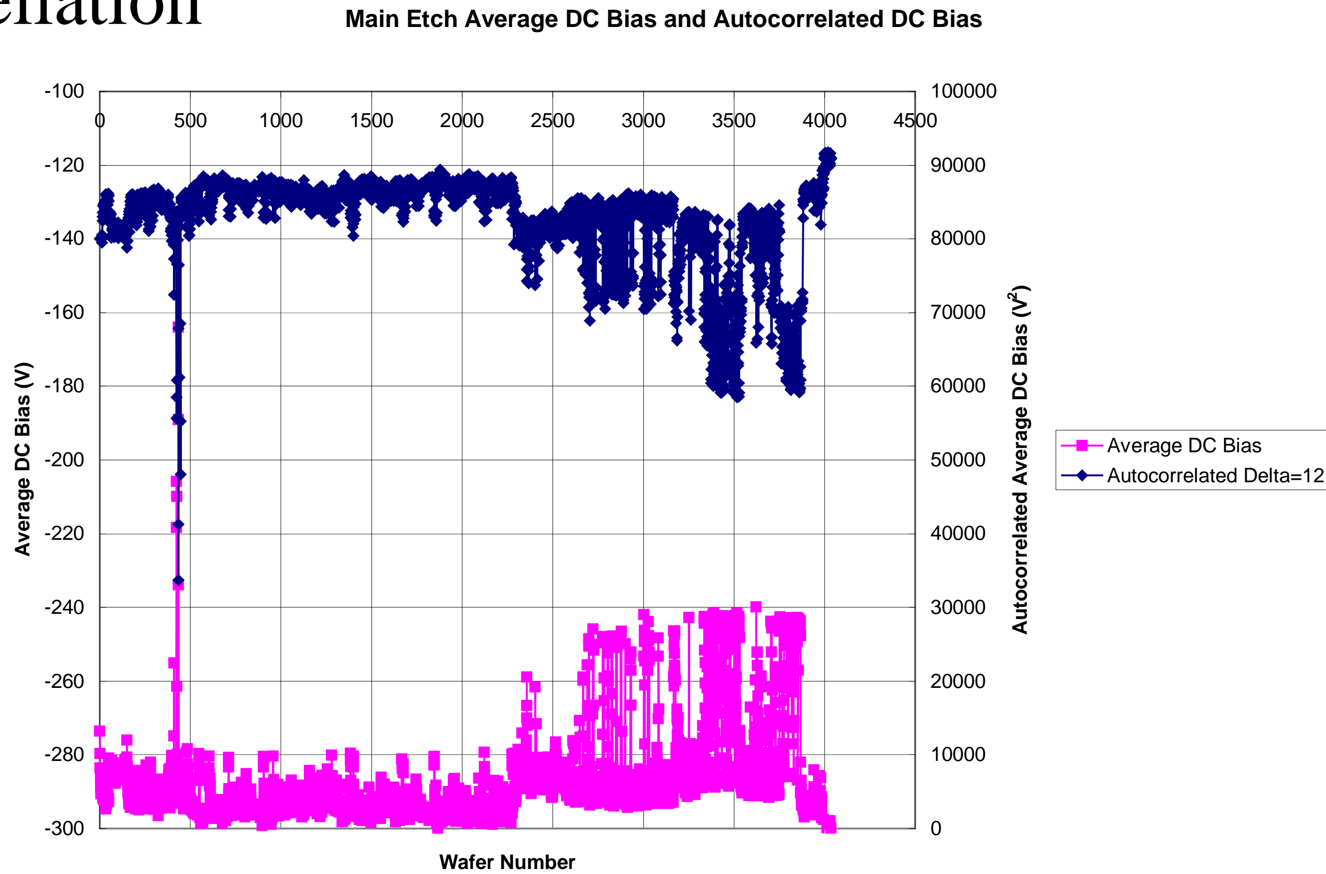
- Once the failure/excursion is characterized using the trace analysis metrics, ***we can go back to the customer to explain what happened and demonstrate how it will not happen again.***
- Direct correlation of the trace analysis metrics trend charts to process results and high-volume manufacturing yield provide data-driven objectives for equipment CIP.

FUTURE CHALLENGES

- Metrics trend chart signal enhancement:
  - ➢ Often we can see the excursion clearly “by eye” on the trend chart but simple control limits are foiled by background noise.
  - ➢ Use of DSP algorithms and other signal conditioning techniques is largely unexplored.

FUTURE CHALLENGES

- EX: Autocorrelation for “White Noise” cancellation



FUTURE CHALLENGES

- The control systems of processing tools need to be enhanced to support *in-situ* performance monitoring; industry-wide consensus on requirements would help
- Executing this “Proof of Concept” into a mature system consistently implemented throughout a Fab will almost certainly require standards
- Correlation of tool “Sensor” data to customer line monitor and yield data poses a great intellectual property/security challenge

"Wish List"

- Access and resources to collect/analyze sensor data that exists within the control system
- Protocol/performance standards to mitigate "Specials"
- High bandwidth connectivity
- Ability to correlate with Fab in-line monitor and yield data for critical low-yield analysis