In-Situ Production Process Detection and Chamber Matching Using Temperature Metrology Sensors and Diagnostics

NCCAVS
Plasma Etch Users Group
February 12, 2004

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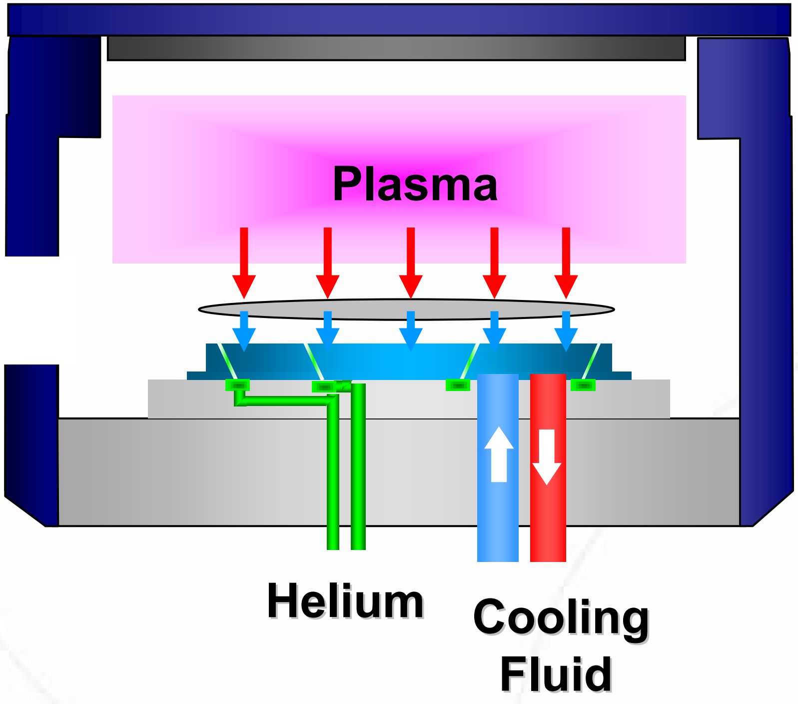
Abstract

- Concrete Methodologies and Technology Enabling *In-Situ* Detection of Process Excursions
  - *Wafer-Based* Metrology System Overview
- Multiple Production examples that illustrate in-line process excursion detection and chamber matching.
  - Process monitoring
    - Process deviations identified before any device wafers were scrapped
    - Thermal signatures shown to be early indicators of process instability and drift
  - Chamber Matching
    - Chambers at sites on different continents are easily matched to ensure process transferability
    - Thermal signatures shown to quickly and easily match etch reactors

Monitoring Wafer Temperature in a Plasma System to Diagnose Chamber Problems

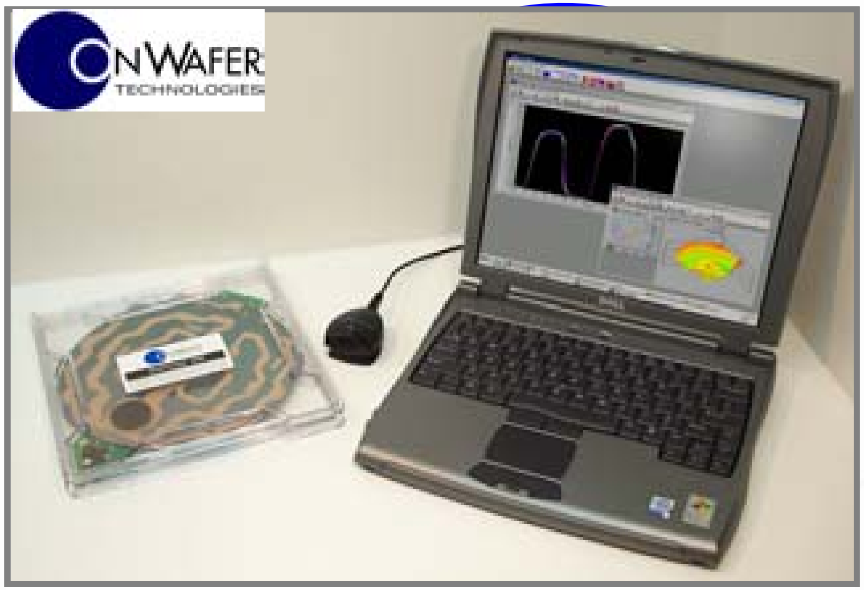


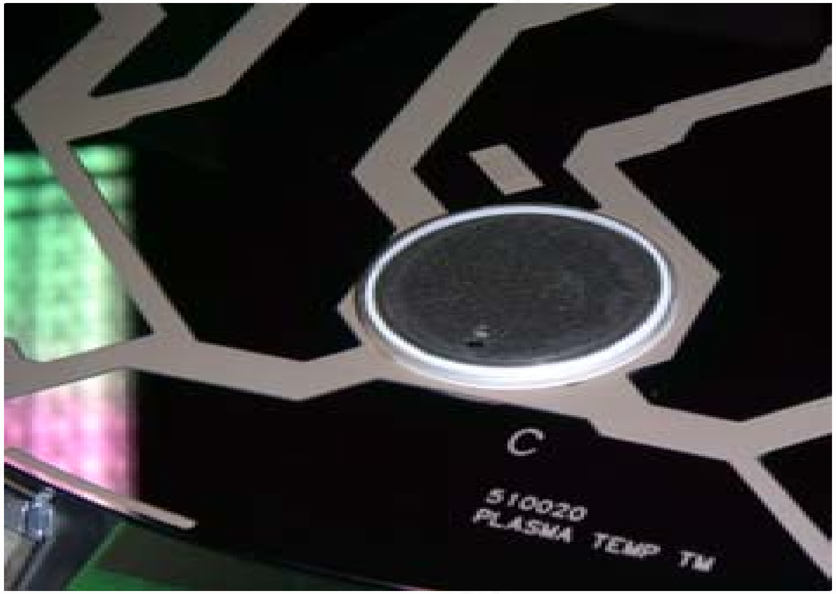
Typical Plasma Etch Environment

- Etching is Impacted by Various Interacting Mechanisms
  - Direct Chemical Reaction, Reactive Etching, Deposition, Mask Erosion
- Same Etch Mechanisms are Extremely Sensitive to Temperature
  - Temperature is a first order indicator of etching progress or “Health”
- *Wafer-Based* Metrology of Spatially Resolved Temperature Profiles for all Operating Conditions
- Utilization of *Wafer-Based* Metrology is Vital for Realizing Real-Time Fault Detection and Isolation

PlasmaTemp® *In Situ* Metrology

Hardware Overview



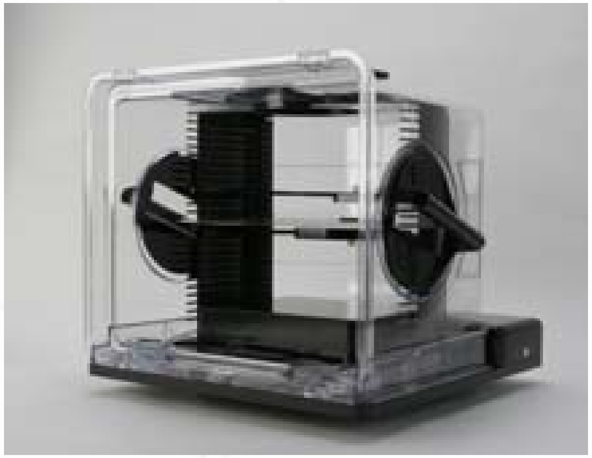


- Base material is SEMI standard wafer with thermal oxide layer
- Thermistors located for high resolution thermal profiling
- Sensor network isolated using a high purity polyimide coating
- “System on a Wafer” electronics module for high speed, autonomous data acquisition & wireless data transfer

Typical Usage

In High Volume Production Fabs and R&D Environments

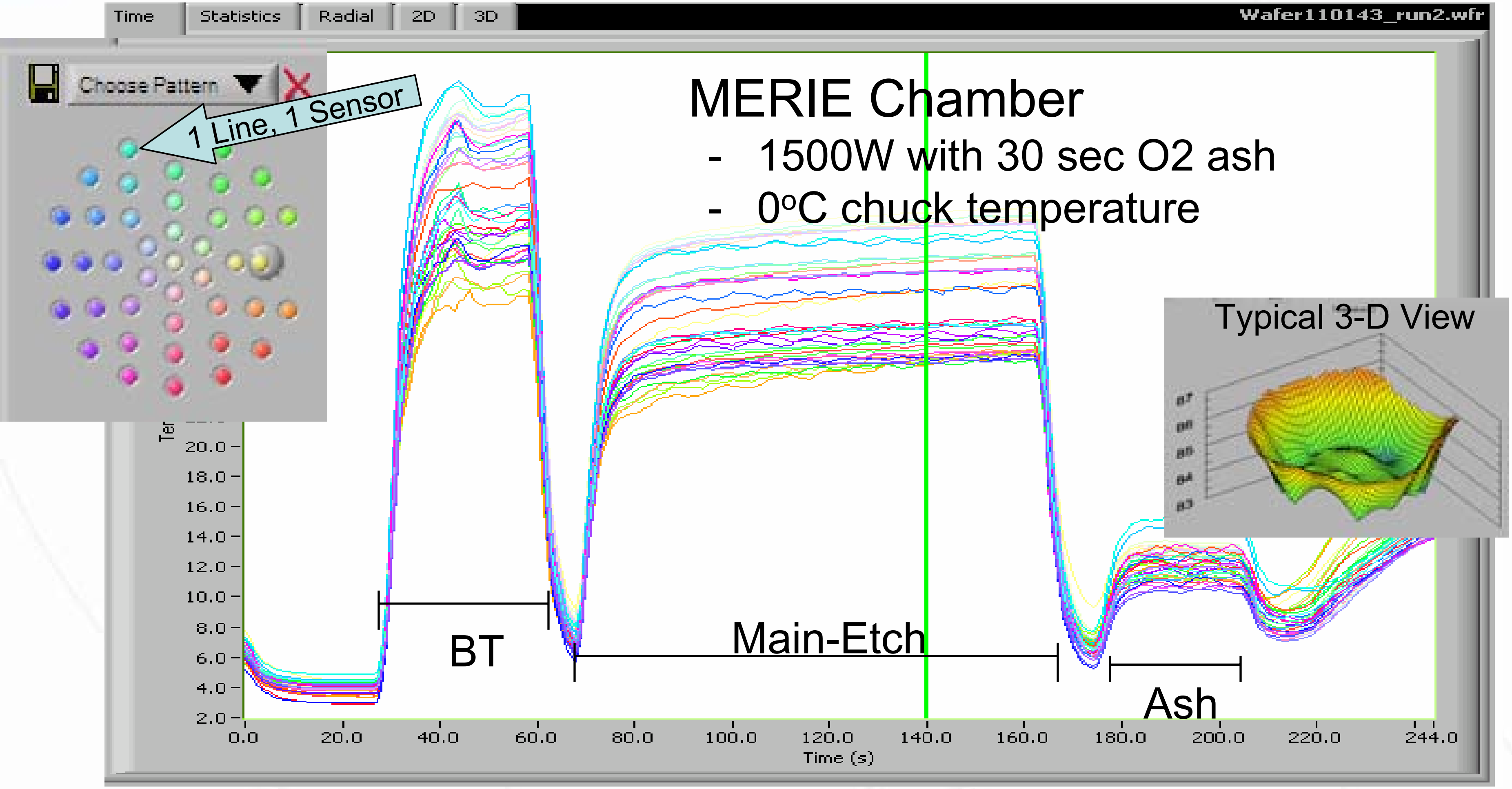
- PlasmaTemp SenorWafers are Used like any Other Production Monitor
  - Data Collection Sequence
    - Load PlasmaTemp® Wafer in Standard Cassette / Place FOUP in Load Port
    - Launch Tool's Automatic Transfer Sequence
    - Run the Standard Production Plasma Etch Recipe
      - Standard Power, Pressure, Temperature, etc.
    - Remove Cassette / FOUP
    - Download Data
  - Immediately Bring Tool Back to Production
    - No Dummy Wafer
    - No Particle Test



OnWafer built all the required services for the SensorWafer metrology system right into a SEMI standard 300mm FOUP. Product is shown with its convenient "docking station".

In Situ Metrology

Sample Mission Data



1 Line, 1 Sensor

MERIE Chamber

- 1500W with 30 sec O2 ash
- 0^{o}C chuck temperature

Typical 3-D View

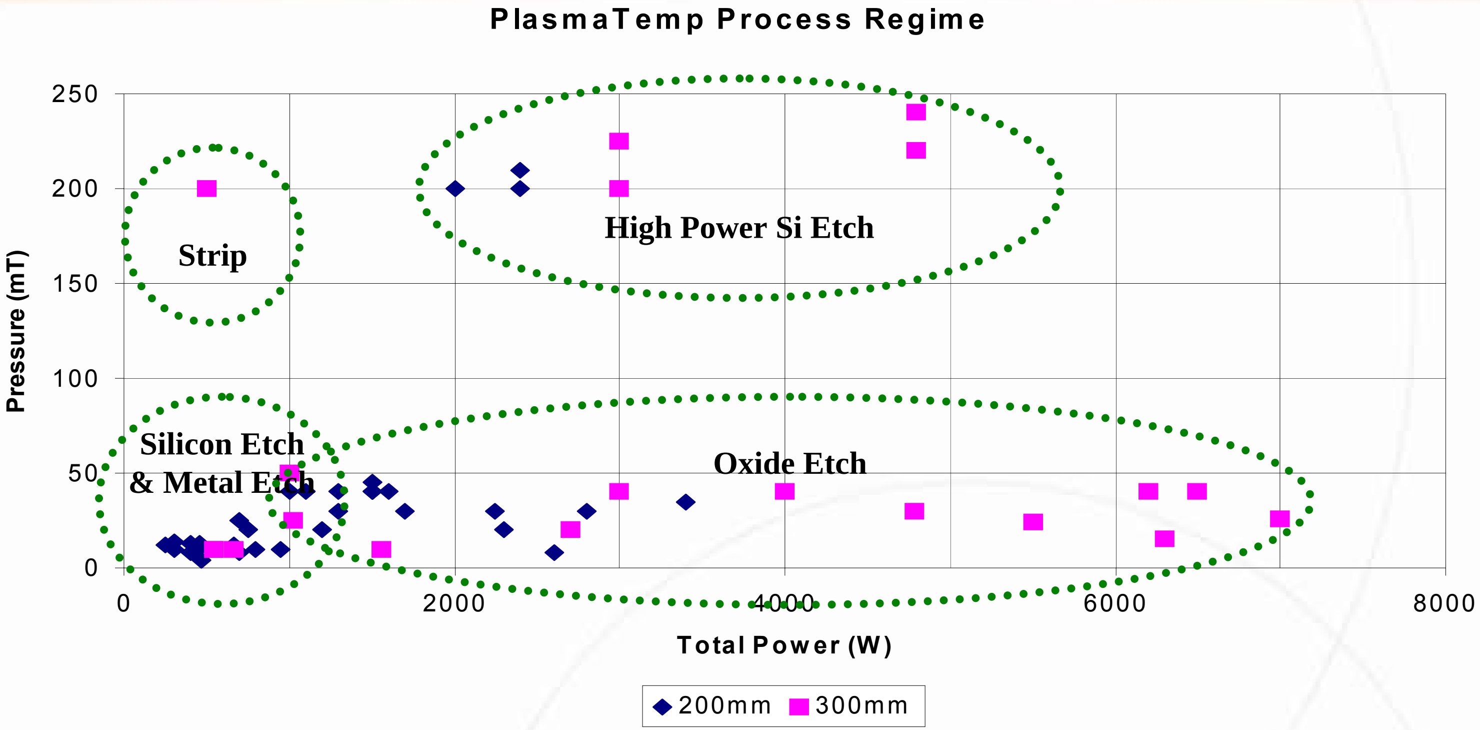
BT

Main-Etch

Ash

PlasmaTemp Process Regime

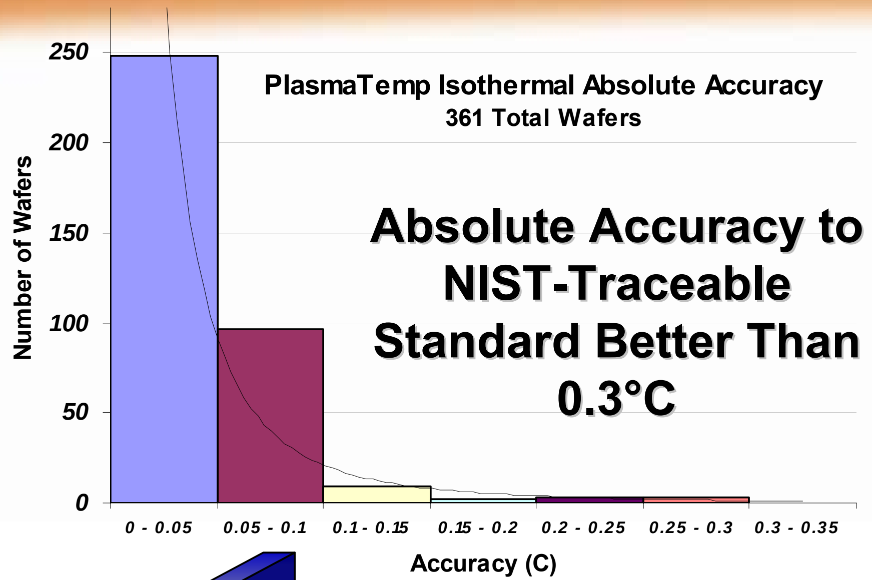
Sample Installed Base Data



PlasmaTemp SensorWafer Operates in All Plasma Process Regimes

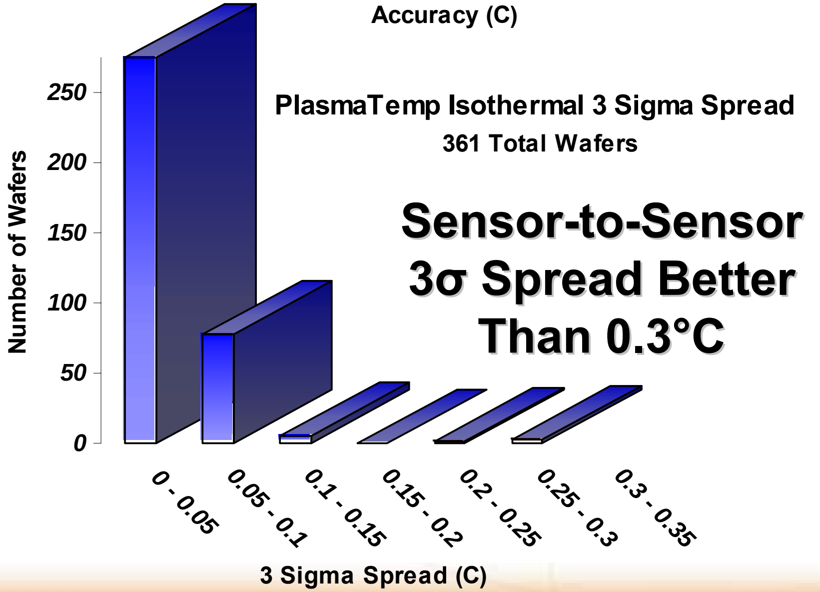
PlasmaTemp Precision

Factory Calibration



PlasmaTemp Isothermal Absolute Accuracy
361 Total Wafers

Absolute Accuracy to NIST-Traceable Standard Better Than 0.3°C



PlasmaTemp Isothermal 3 Sigma Spread
361 Total Wafers

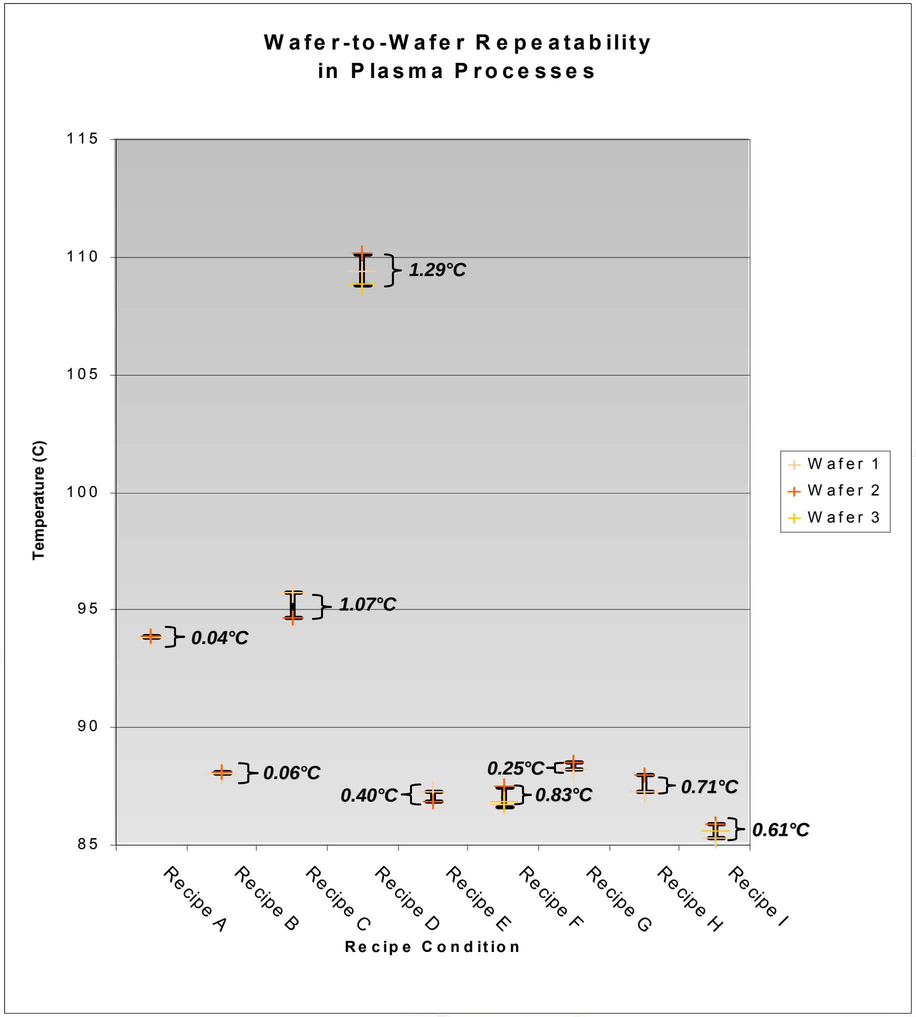
Sensor-to-Sensor 3σ Spread Better Than 0.3°C

- PlasmaTemp Calibration Completed in Stable Thermal Environment
  - NIST-Traceable Calibration Standard
- Why Calibrate in Isothermal Environment?
  - Small Variations in Plasma Processing are Detected by Sensitive, Accurate SensorWafers
- Absolute Accuracy and 3σ Spread Better than 0.3°C
  - Data Sample of Last 361 Wafers Built as of 1/1/04

PlasmaTemp SensorWafers Demonstrate Superior Calibration Repeatability

PlasmaTemp Precision

Wafer-to-Wafer Repeatability

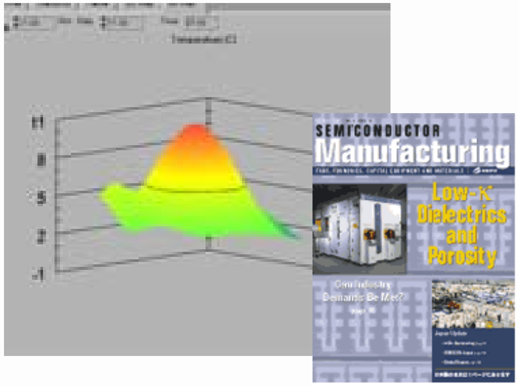


- Wafer-to-Wafer Repeatability
  - Wafer-to-Wafer Repeatability is Limited by Chamber Repeatability – Typically 2-3%
    - Plasma Reactor Variation of Only 1% Equates to as Much as 1.09°C Thermal Variation
  - Wafer-to-Wafer Repeatability Better than 1.30°C
    - Within 0.21°C of Plasma Reactor Stability Threshold
  - Each Data Sample Includes Multiple Runs under Same Conditions
    - *Different* SensorWafers
    - Same Recipe, Same Chamber

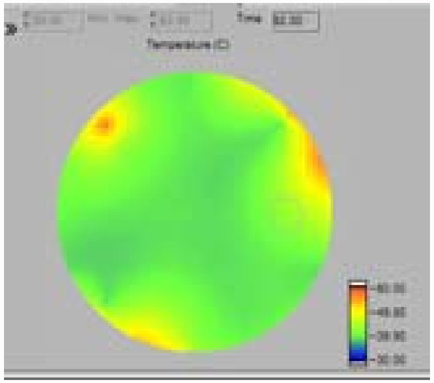
Plasma Reactor Optimization and Hardware Troubleshooting

Typical Applications

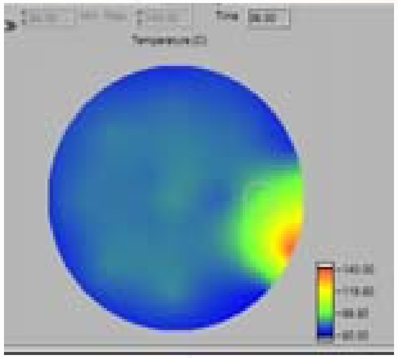
Hardware Troubleshooting



Mis-Adjusted Lift Pins

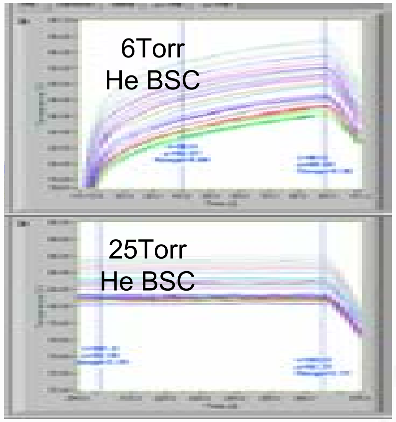


Faulty Source Match

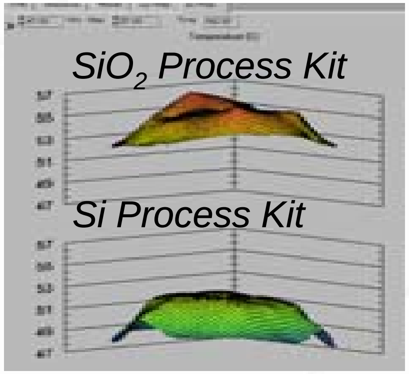


Backside Particle Detection

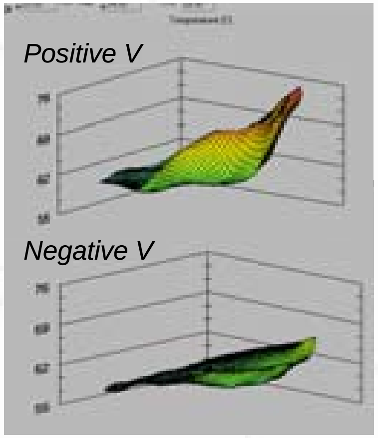
Reactor Optimization



He Cooling Influence



Process Kit Selection

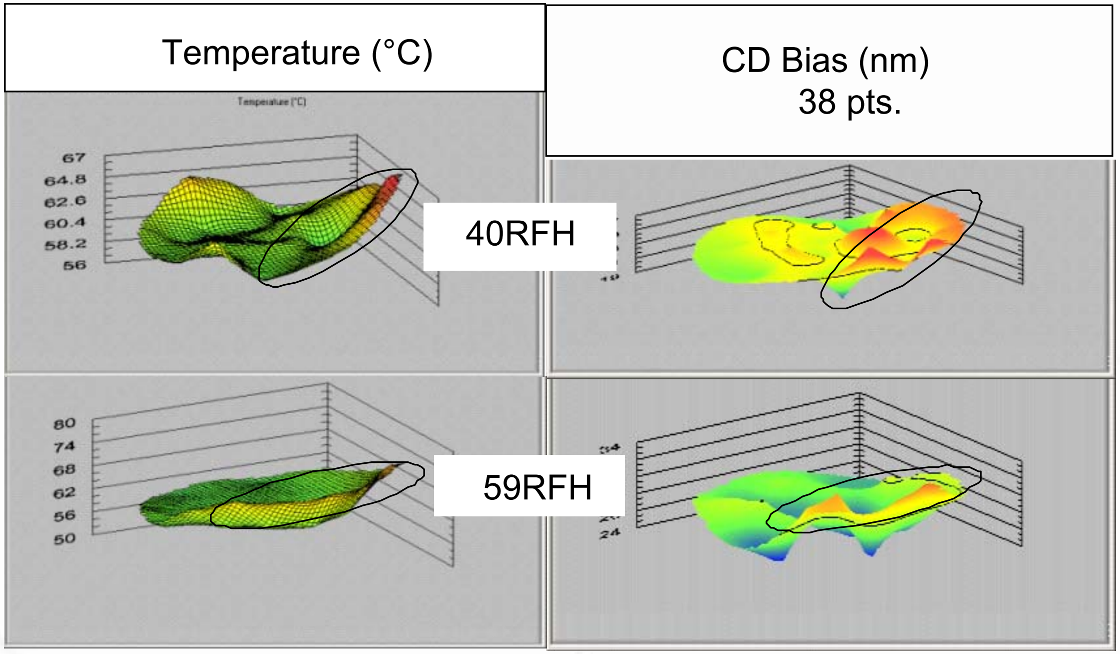


Chucking Voltage Selection

Data Analysis & Correlation

Example Data

CD Bias and Thermal Profile

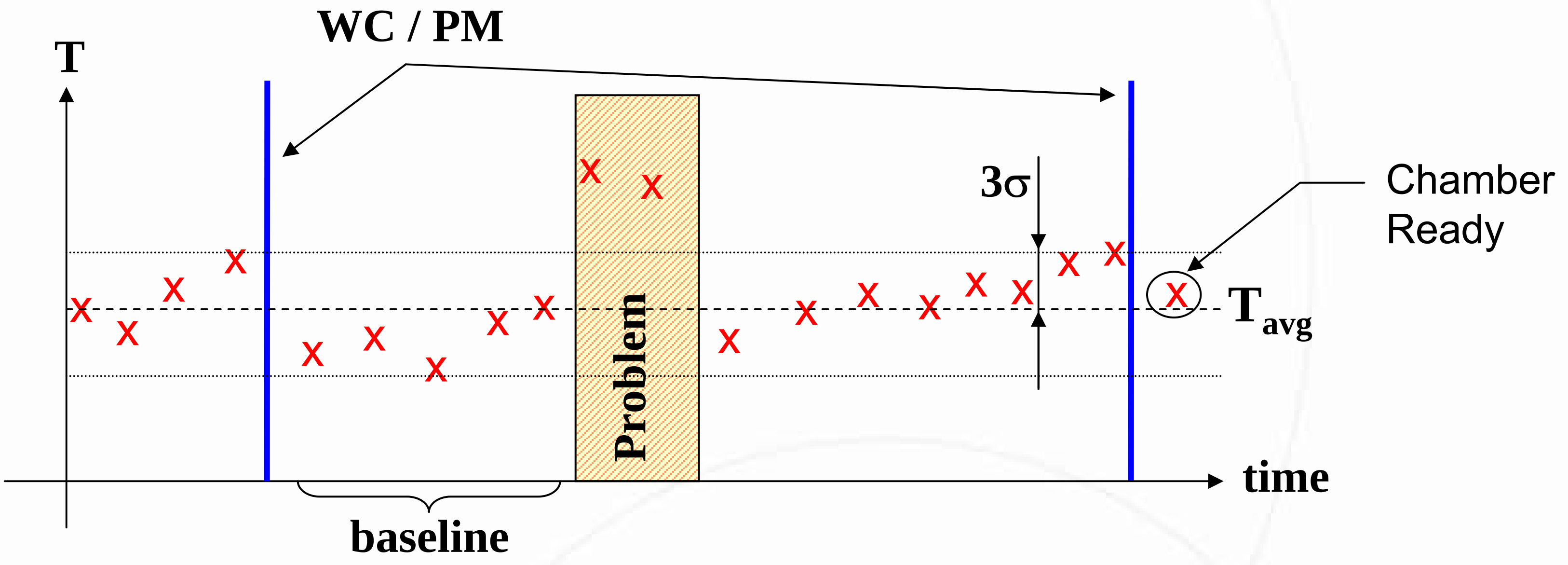


- Thermal profiles and CD bias are closely related
- Data indicates issue with the CD at the Notch (circled)

Spatially-Resolved CD Data can be Easily Analyzed for Correlation to Thermal Profiles

Routine Temperature Monitoring

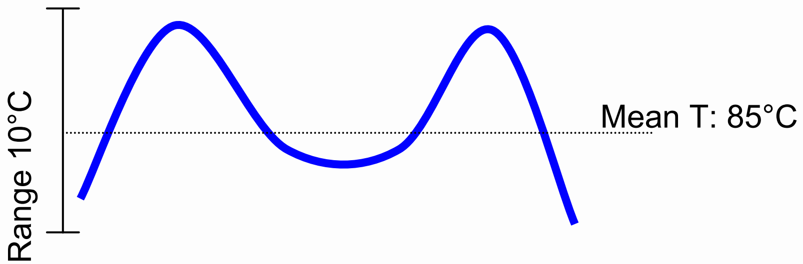
In-Line Fault Detection



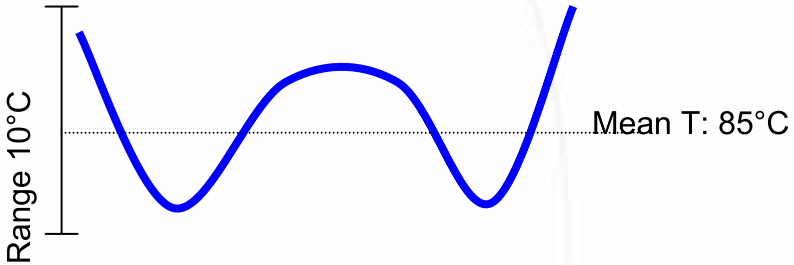
- Regular monitoring after known good wafer lots defines baseline tool performance (“fingerprinting”)
- Detect tool problems
  - Apply Diagnostics Package
- Determine appropriate time for PM and/or WC
- Help bring tool back online after PM and/or WC

Spatial Modeling Methodology

Improving Signal-to-Noise Ratio



2-D Temperature Profile A

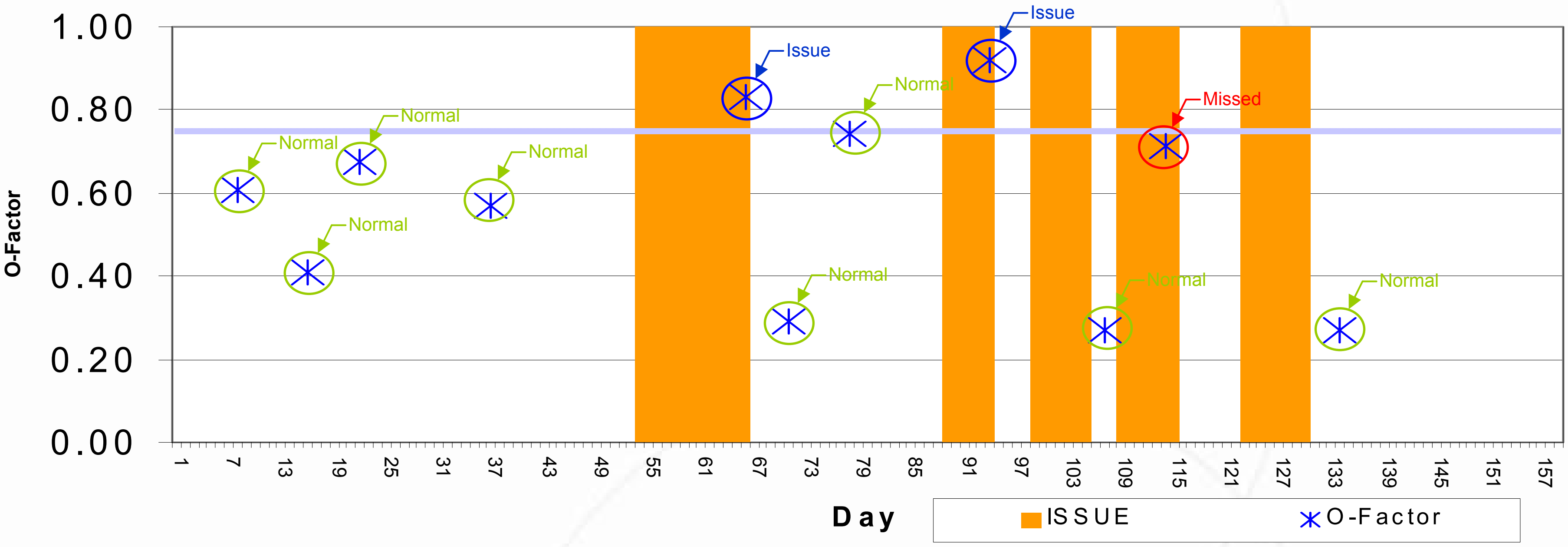


2-D Temperature Profile B

- Profile A and Profile B Show the Same Mean and Range but *VERY* Different Thermal Profiles
- OnWafer has Developed a Modeling Approach to Determine Spatial Chamber Health Signal and Minimize Normal Noise Due to Chamber Variations
- Metric Must be Able to Capture Change in the “Shape” of the Thermal Profile while Filtering Standard Chamber Fluctuations
- Shape-Fitting Metric is Denoted in the Next Slide by “O-Factor”

Process Deviation Identification

Example 1

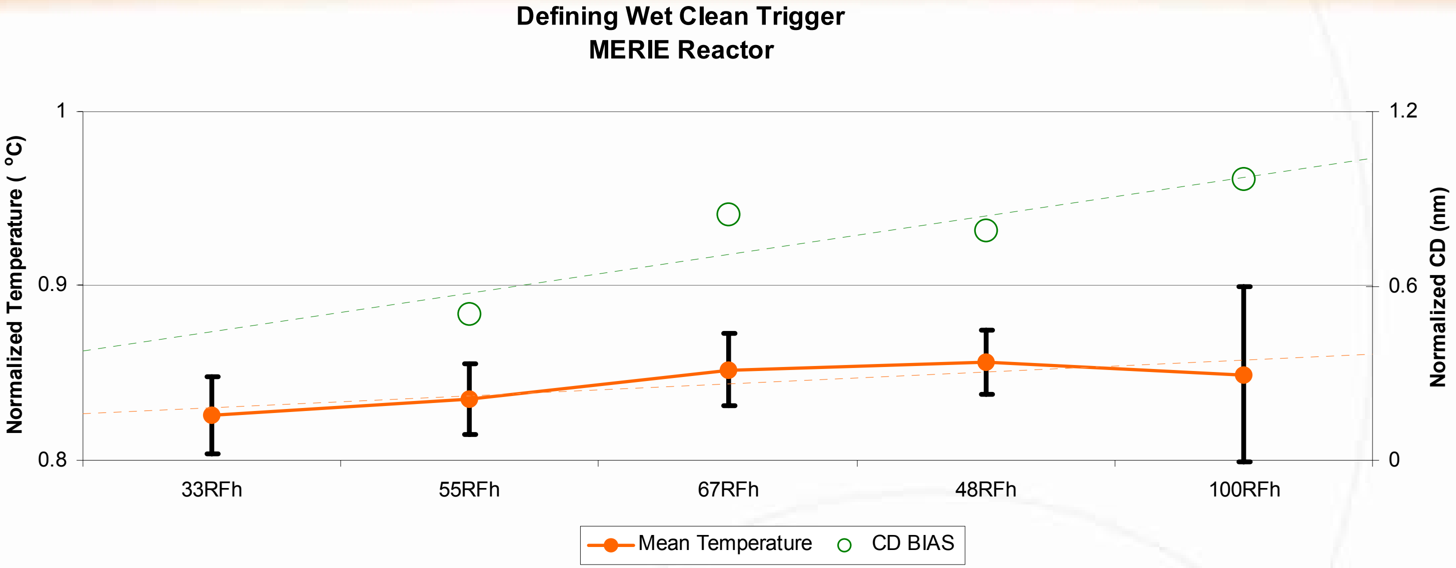


Thermal and Fab Data Correlation

- Thermal Data and Fab Data Collected over 140 days
- Temperature is Used as a Proxy for Chamber Health
- *In-Situ* Thermal Measurements Identified 2 out of 3 Fab Issues Prior to Any Other In-Line Measurements
  - Increasing Data Collection Frequency Improves O-Factor Resolution

Process Drift

Wet Clean Cycle

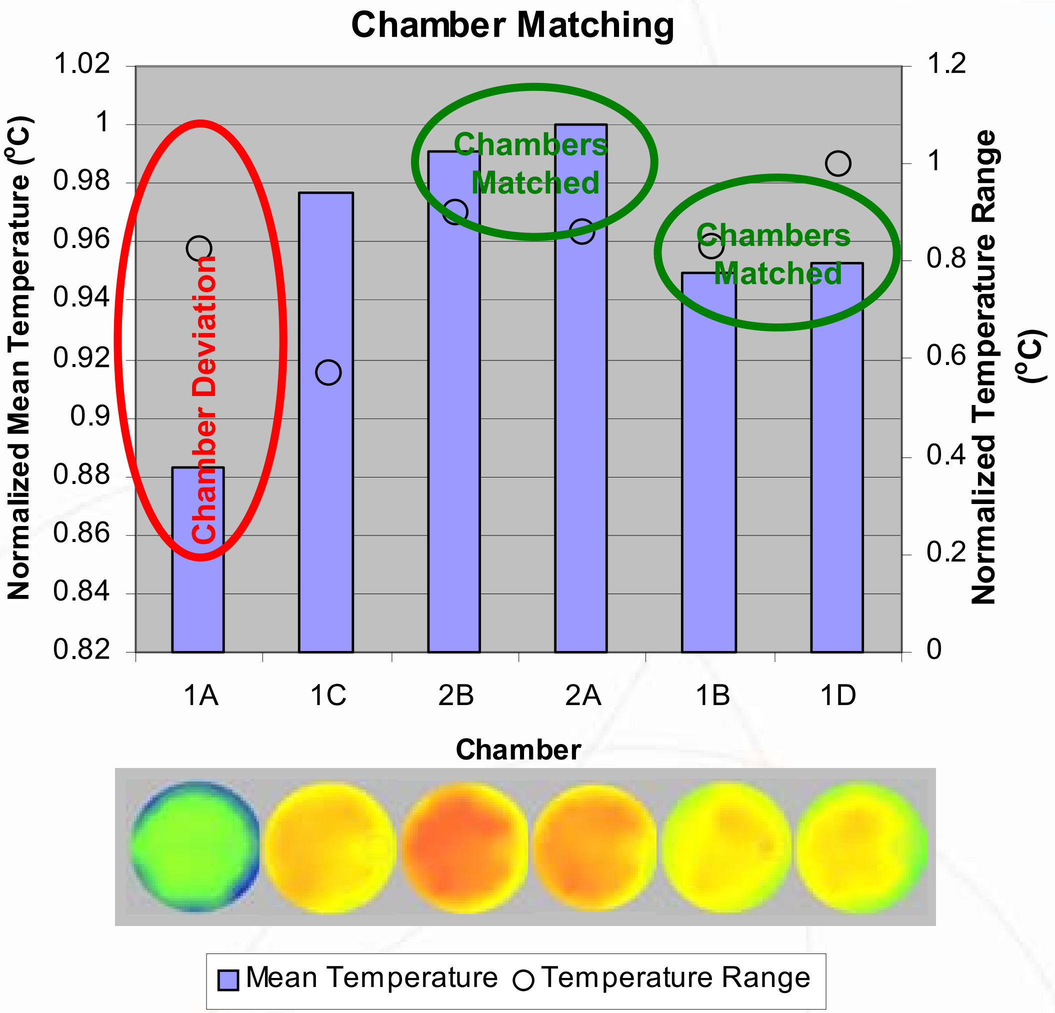


- Temperature Mean and CD Bias Mean Show Steady Increase over Wet Clean Cycle
- Wet Clean Trigger Point Determined to 90RFh
  - CD Within Spec @ <.85nm (normalized)
  - Thermal Range within Spec @ <0.05°C (normalized)

Chamber Matching

6 Chamber Population – Single Site

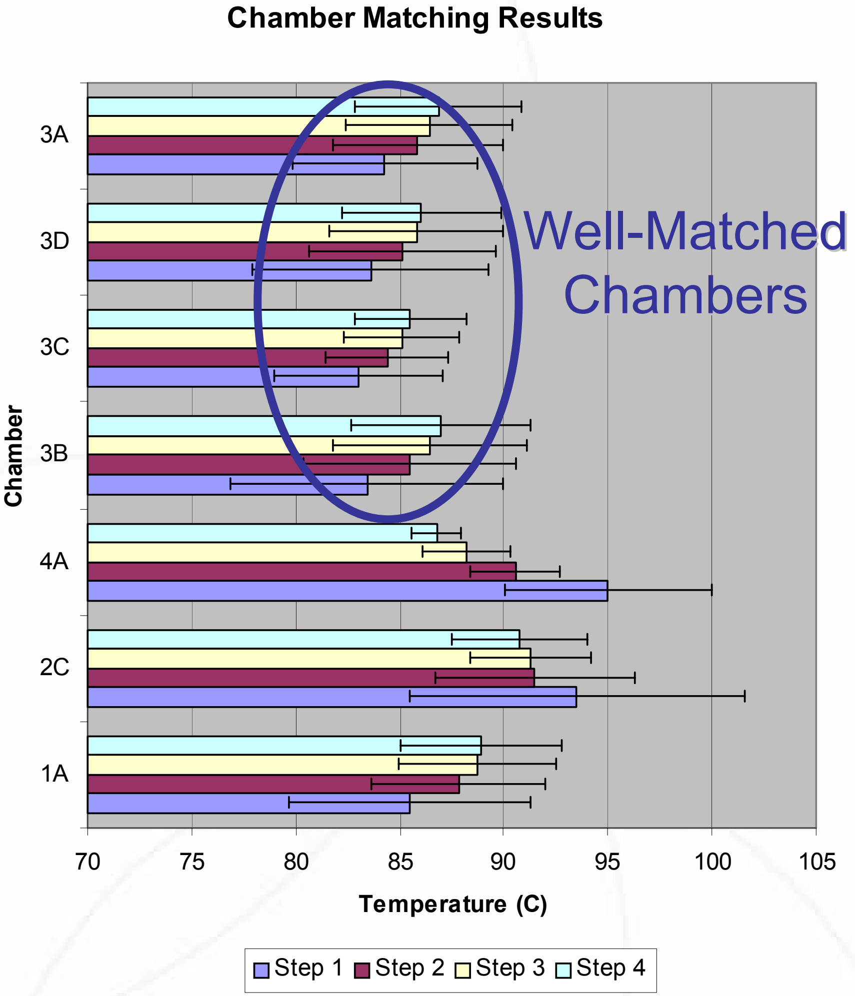
- 6 Chambers Examined
  - One Chamber Clearly Out of Distribution
    - Custom Process Kit
  - Two Pairs of Chambers Well Matched
  - Last Chamber at Distribution Median
- Hardware Changes Implemented to better Match Chambers
  - Chiller Adjustment Resolved Tool 1 and Tool 2 Thermal Disparity



Chamber Matching

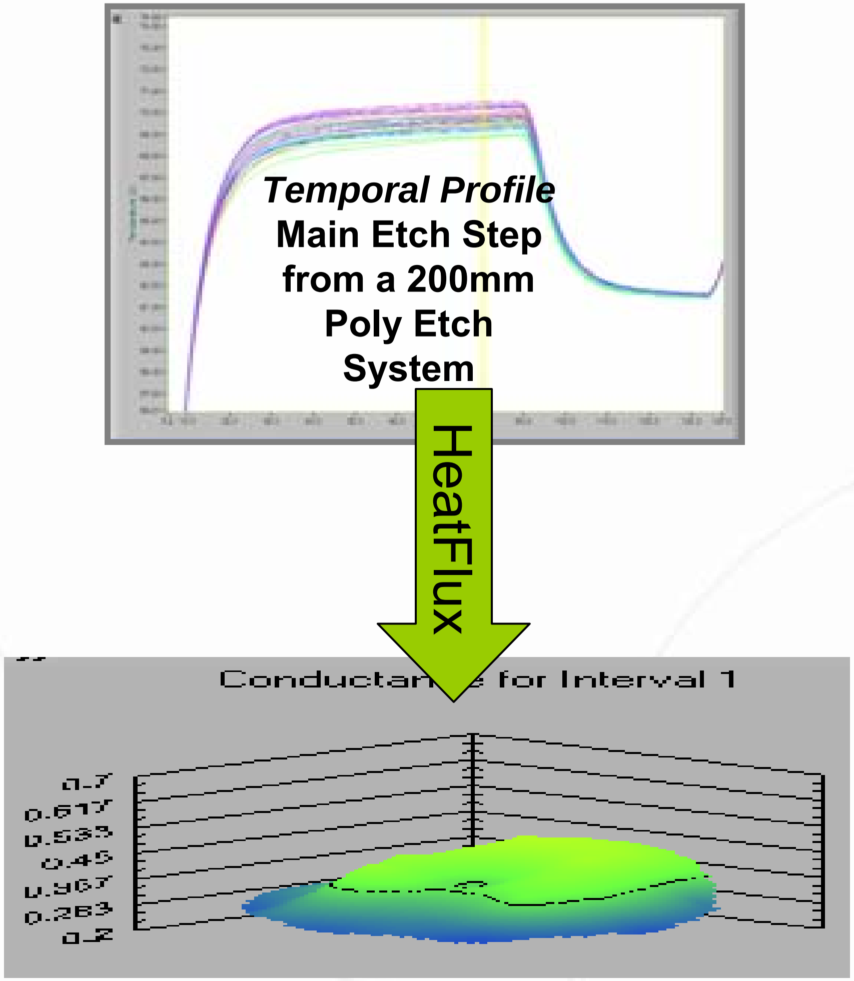
7 Chamber Population – US and Europe Sites

- 7 Chambers, Multiple Steps Examined
- Tool 3 Shows Excellent Mean Matching
    - Within 1.29°C for all Steps
- Chambers 4A and 2C Did Not Respond Normally to Process Steps
- Chamber 1A was Running 2°C Warmer than Tool 3
- All Deviations Required Hardware Repair



HeatFlux™

Advanced Analysis Tool


Temporal Profile
Main Etch Step from a 200mm Poly Etch System

HeatFlux

Chuck's Conductance Profile

Plasma Application Module

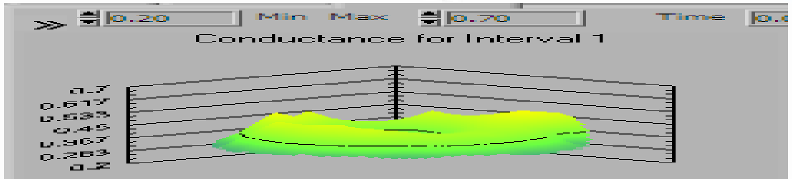
- Analyzes the data from a single PlasmaTemp run
- Determines:
  - Cooling efficiency across the area of the chuck
  - Heating uniformity of the plasma
- This enables:
  - Differential diagnosis of chuck or plasma-related heating problems in production
  - Analysis of chamber/chuck geometries during equipment design
  - Identify the Root Cause of Reactor Issues

Chamber Matching

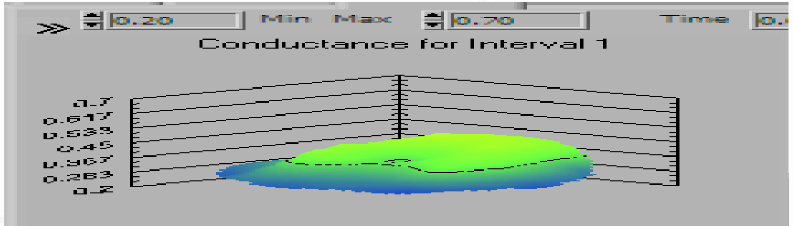
Acting on Thermal Data

- Thermal Profile Shift in Thermal Profile In Chamber
- Action is Required to Resolve Discrepancy
- Correlated to Edge-Specific Yield Issue
- HeatFlux™ is Applied to Separate Plasma and Chuck Effects on the Wafer
  - Conductance Analysis Clearly Show Chuck Thermal Transfer Efficiency Change in Weeks 2 – 4
  - Process Kit Change Resolves Issue

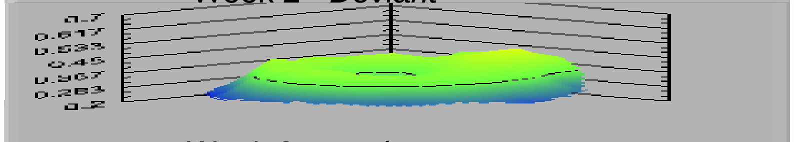
Conductance Analysis



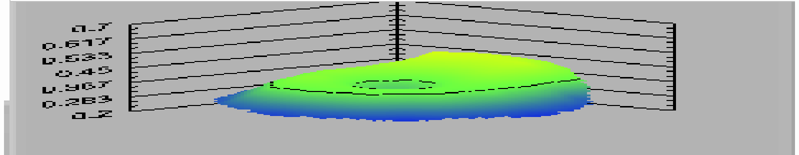
- Week 1



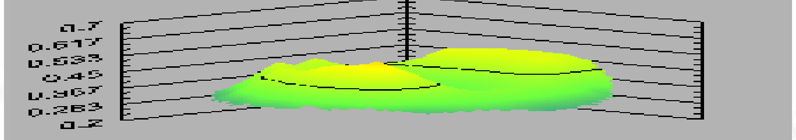
- Week 2 - *Deviant*



- Week 3 - *Deviant*



- Week 4 - *Deviant*



- Week 5 - Resolved

Summary

- Concrete methodologies for *in-situ* detection of process excursions and rapid chamber matching demonstrated
- Multiple examples that illustrate in-line process excursion detection and chamber matching.
  - Process monitoring
    - Process deviations are identified in-line
    - Temporal/spatial temperature signatures show early indicators of process instability and drift
  - Chamber Matching
    - Chambers at one site, and chambers at sites on different continents are matched
    - Temporal/spatial temperature signatures quickly and easily match etch reactors
    - Advanced modeling allows component-level troubleshooting

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