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

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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 be quickly and easily match etch reactors
Monitoring Wafer Temperature in a Plasma System to Diagnose Chamber Problems

- 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**

**MERIE Chamber**
- 1500W with 30 sec O2 ash
- 0°C chuck temperature

**Typical 3-D View**

- BT
- Main-Etch
- Ash
PlasmaTemp Process Regime
Sample Installed Base Data

PlasmaTemp Process Regime

Pressure (mT)

Total Power (W)

Strip
High Power Si Etch
Silicon Etch & Metal Etch
Oxide Etch

PlasmaTemp Sensor Wafer Operates in All Plasma Process Regimes

200mm
300mm
PlasmaTemp Precision
Factory Calibration

- 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 Sensor
- Absolute Accuracy and 3σ Spread Better than 0.3°C
  - Data Sample of Last 361 Wafers Built as of 1/1/04

PlasmaTemp Sensor Wafers Demonstrate Superior Calibration Repeatability
**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* Sensor Wafers
    - Same Recipe, Same Chamber
Plasma Reactor Optimization and Hardware Troubleshooting

Typical Applications

- Mis-Adjusted Lift Pins
- Faulty Source Match
- Backside Particle Detection

- He Cooling Influence
- Process Kit Selection
- Chucking Voltage Selection

- Reactor Optimization
  - 6Torr He BSC
  - 25Torr He BSC
- Si Process Kit
- SiO₂ Process Kit

- Hardware Troubleshooting
  - He Cooling Influence
  - Faulty Source Match
  - Backside Particle Detection

A REAL LOOK INSIDE YOUR PROCESS
### Data Analysis & Correlation

**Example Data**

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

#### CD Bias and Thermal Profile

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>CD Bias (nm)</th>
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<tbody>
<tr>
<td>40RFH</td>
<td></td>
</tr>
<tr>
<td>59RFH</td>
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</table>

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

- 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”
• 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

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
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