Component Health Monitoring and Diagnostics in Plasma Etch Chambers using In-Situ Temperature Metrology

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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

- Etch Mechanisms are Extremely Sensitive to Temperature
  - Modern Plasma Reactors Control All Critical Parameters Externally
  - Temperature is a First Order Indicator of Etching Problems
Monitoring Wafer Temperature in a Plasma System to Diagnose Chamber Problems

- **In-Situ** Metrology Provides Wafer-Level Spatially Resolved Profiles for All Operating Conditions
  - External Controls and Probes Provide Limited Insight Into Chamber

- **In-Situ** Metrology is Vital for Fault Detection and Isolation

Typical Plasma Etch Environment
PlasmaTemp® *In Situ* Metrology Overview

- Base Material is SEMI Standard Wafer with Thermal Oxide Layer
- Thermistors Positioned for High Resolution Thermal Profiling
- Sensor Network Protected With High Purity Polyimide Coating
- “System on a Wafer” Electronics Module for High Speed, Autonomous Data Acquisition & Wireless Data Transfer
PlasmaTemp Usage For Thermal Modeling and Component Health Identification

• PlasmaTemp Used to Build Response Model
• Proprietary Software Analyzes Component Health Against the Model
  – Begin Mission
    • Load PlasmaTemp® Wafer in Standard Cassette or FOUP
    • Launch Automatic Transfer Sequence
    • Run Specialized Etch Recipe for Thermal Modeling
      – Variation of All Critical Parameters
    • Remove Cassette or FOUP
  – Analyze Data for Component Health
    • Repair / Replace Faulty Component(s)

OnWafer built all the required services for the SensorWafer metrology system right into a SEMI standard 300mm FOUP. Product is shown with its docking station.
In Situ Metrology
Sample Mission Data – Multi-Step Silicon Etch
Thermal Profile Response Monitoring

Increasing Pressure

• Hardware Components’ Output Directly Effects Wafer Thermal Profile
  – Increasing RF Power Increases Mean Wafer Temperature
    • Small Change in Uniformity
  – Increasing Pressure Alters Thermal Profile from Center-Hot to Edge-Hot
    • Small Change in Mean Temperature
• Thermal Variation During Constant Process Condition Indicates Hardware Deviation

\[ c_p \cdot \frac{dT_{wafer}}{dt} = (P_{plasma}) + (P_{chuck}) \]

- \( T_{wafer} \): Wafer Temperature at a Given Physical Location
- \( P_{plasma} \): Heat Input from the Plasma
- \( P_{chuck} \): Heat Transfer to the Chuck
- \( c_p \): Specific Heat Capacity of Silicon
Modeling Methodology

• Standard Analytical Methods Used
  – Critical Variables are Selected
  – Series of Designed Experiments is Constructed
  – SensorWafer is Run in the Plasma Reactor with Designed Recipe

• Proprietary Software Algorithms Are Used to Deconstruct the Thermal Information
  – Thermal Shape Modeling Engines Break Down Data Spatially
    • Provides Across-Wafer Information for Each Modeled Parameter

• Resultant Output is Easy-to-Read Effect Maps
  – Uniformity and Magnitude Displayed for Review
  – Comparison to Baseline Model Information Identifies the Deviant Chamber Component, and the Specific Location of the Irregularity

• Time-to-Results is Less than One (1) Hour
OnWafer’s Complete Plasma Fault Detection System

Chamber Specific Thermal Profile Modeling Engine

Input: \[ f(W_b, W_s, P, ...) \]

PlasmaRx™

Hardware Component Analysis Engine

Output

Thermal Response Surface

PlasmaTemp™ & OnView™

Deviation Identification
Faulty Hardware Identified for Immediate Corrective Action

Problem Edge Cooling Effect
Modeled Etch Parameters

• Three Etch Effects Modeled for this Paper
  – He Cooling Pressure
  – RF Power
  – Chamber Pressure

• All Three Parameters Demonstrate Significant Effects on Thermal Profile and Etch Performance
Helium Cooling System Model

- Helium Cooling System is Configured in Two Concentric Rings
  - Nominal Response Shown for Zone Response
    • Units are Normalized in °C / Torr of He
- Deviant Edge Cooling Effect Is Easily Characterized
  - Nominal Response Opposite from the Notch
  - Notch Area Unresponsive to He Pressure
    • Indicates System Failure or Obstruction
  - Center Shows Significant Effect
    • Indicates Leakage from Outer to Inner Zone
• Magnitude of the He cooling Effect for Each Zone Depends on the ESC and Cooling System Design
• For all Characterized Reactors, Inner Zone Response Dominates the Outer Zone Response
  – Maximum Response is Delivered by 200mm MERIE A
• Inner Zone Response of Over 4°C / Torr.
RF Power System Model

- RF Power System Directly Increases Wafer Temperature
  - Bias Power Provides a More Concentrated Effect at the RF Input Feed
  - Source Power Provides a More Concentrated Effect at the Edges of the Wafer
  - Units are Normalized in °C / Watt
- Comparison of Two Different Etch Systems
RF Power System Model

- Magnitude of the RF Power Effects Depend on the System Design
  - Bias Power Controls the Level of Ion Bombardment
  - Source Power Controls Plasma Density and is Less Direct
    - Average Bias Response is 1.6 - 7X Source Response
    - Notable Exception is Dual Power Reactor C
      - Well Known to Have Strong Source/Bias Interactions
Pressure Control System Model

- Nominal Pressure System Characterized for LAR and HAR Etch Reactors
  - Both Reactors Exhibit Strong Radial Symmetry
  - Magnitude Varies by Reactor Design
- Deviant Pressure Effect Is Easily Characterized
  - Strong Slit-Valve to Pump Port Effect
- Pressure Shifts as Little as 2 mT Can Be Detected
  - All Units are Normalized in °C / mTorr
Improving Process Performance

• Control of Advanced Etch Processes Require an Understanding of the Effect of All Critical Input Parameters on the Wafer Surface

• Any Required Parameters Deemed Critical can be Modeled and Improved

Process Optimization
Tune Input Parameters to Obtain Required Thermal Profile

Chamber Model
\[ f(ESC_{t1}, ESC_{t2}, W, P) \]
Summary

• Thermal Variation During Constant Process Condition Indicates Hardware Deviation within the Plasma Chamber
• Compelling Methodology Demonstrated for Identification of Deviant Critical Chamber Components
  – Spatially Resolved, *In-Situ* Data
• Effects of Any Critical Input Parameter are Derived with Our Analysis
  – Provides Opportunity to Optimize Wafer Temperature Profile (In Progress)
    • Uniform Temperature Profile as Desired in Gate Etch
    • Designed Non-Uniform Profile as Desired in SAC Etch
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