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

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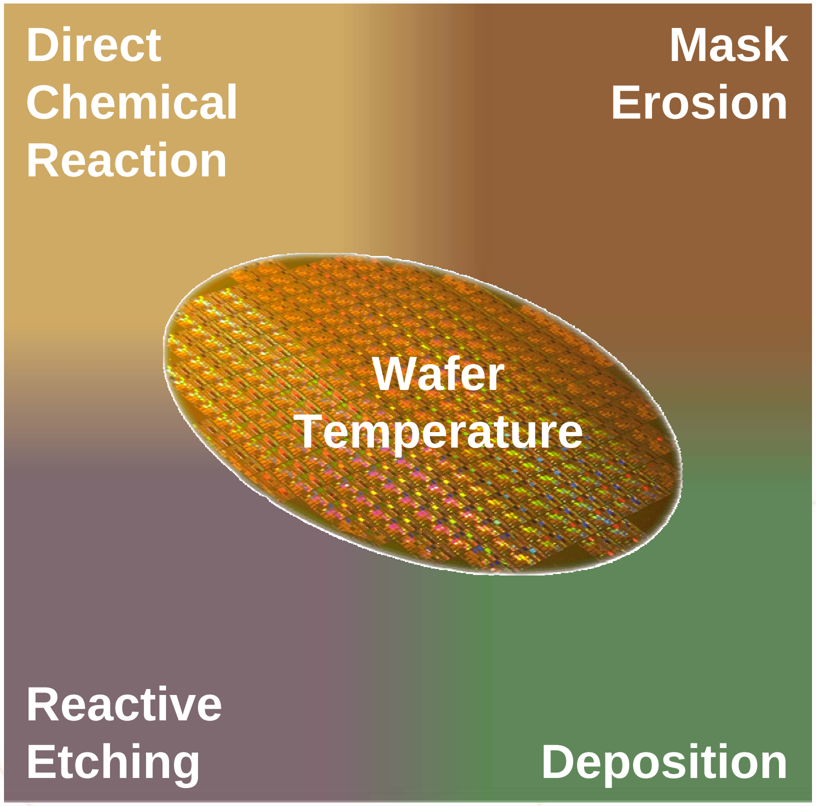
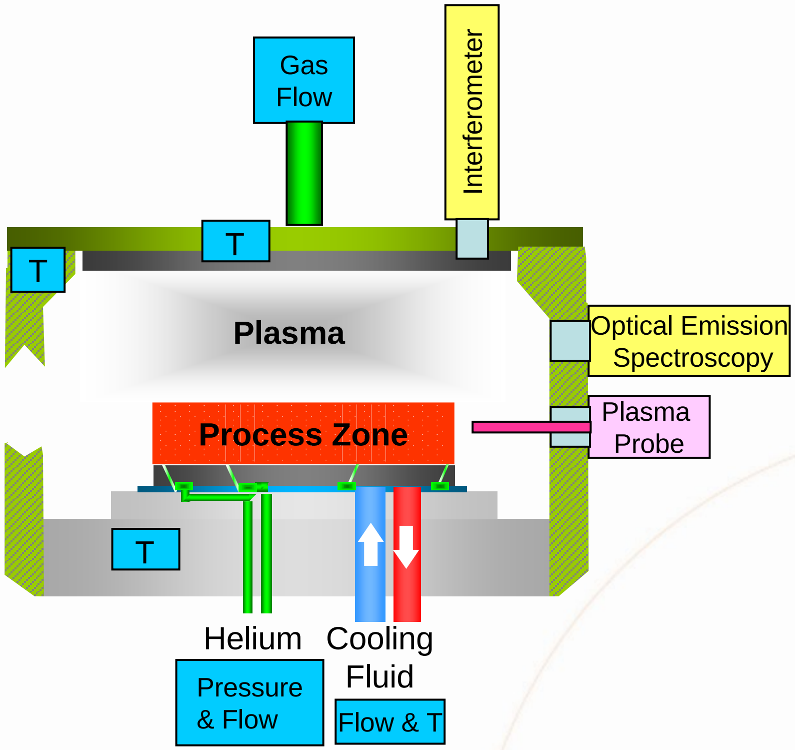
Monitoring Wafer Temperature in a Plasma System to Diagnose Chamber Problems



- 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

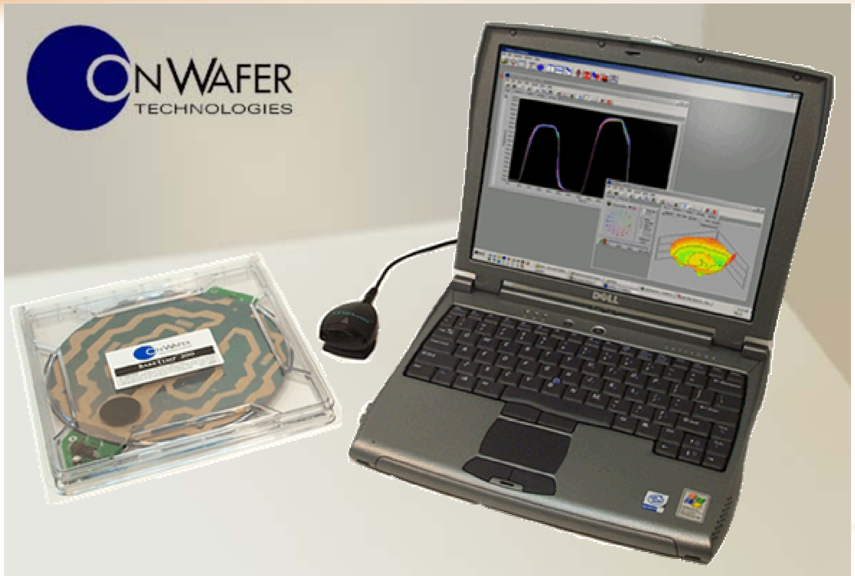
Monitoring Wafer Temperature in a Plasma System to Diagnose Chamber Problems



Typical Plasma Etch Environment

- *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

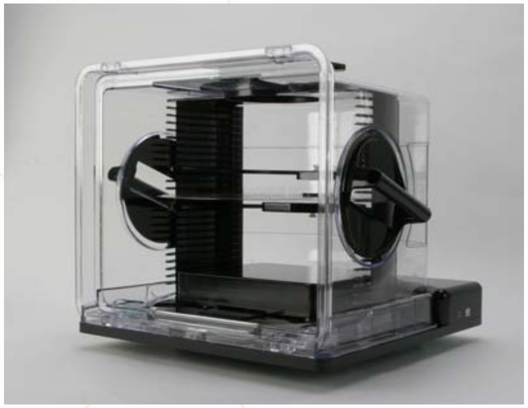
PlasmaTemp® *In Situ* Metrology Overview



- 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

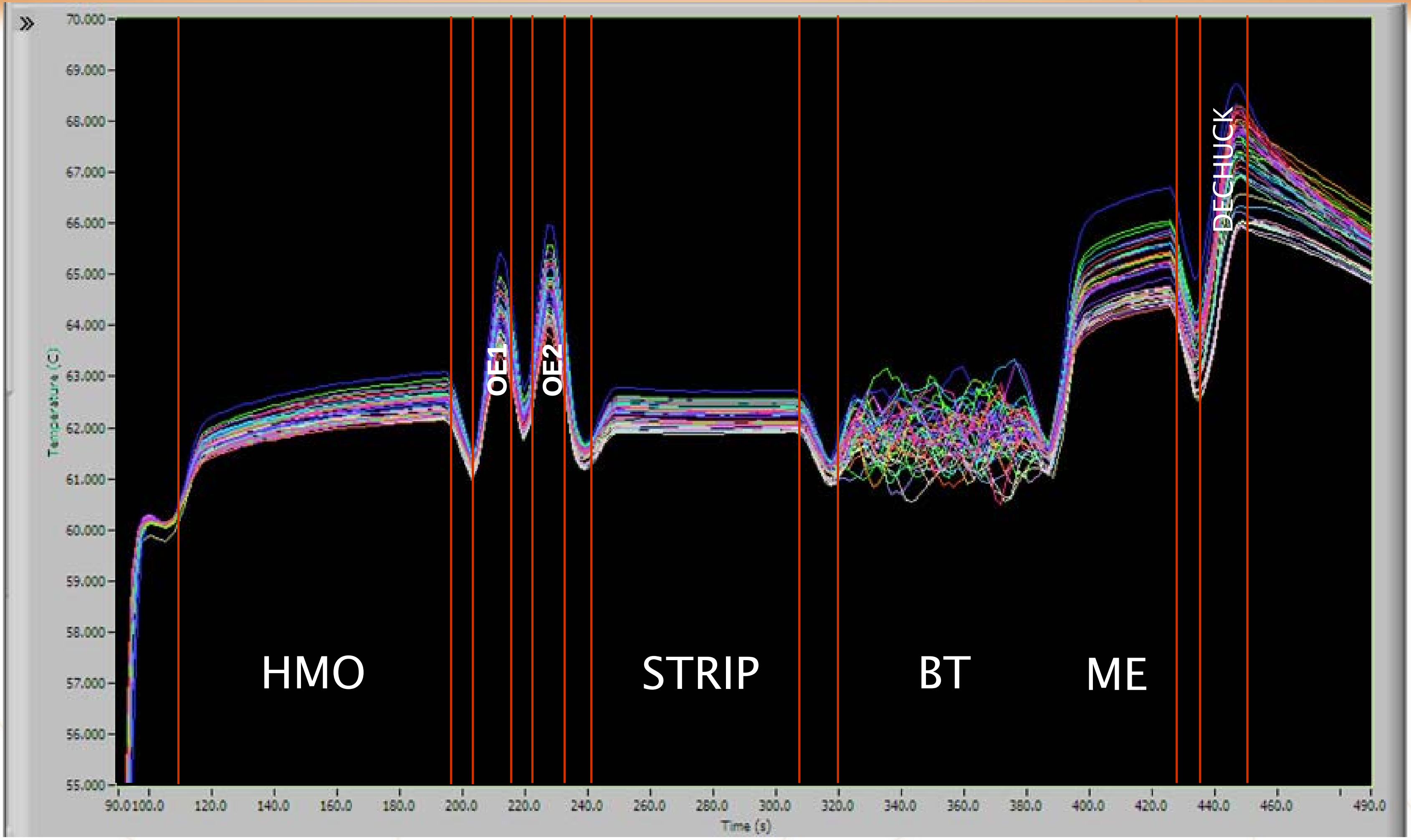
- PlasmaTemp Used to Build Response Model
- Proprietary Software Analyzes Component Health Against the Model
  - Begin Mission
    - Load PlasmaTemp® Wafer in Standard Cassette or FOUP
    - Launch Automatic Transfer Sequence
    - Run Specialized Etch Recipe for Thermal Modeling
      - Variation of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



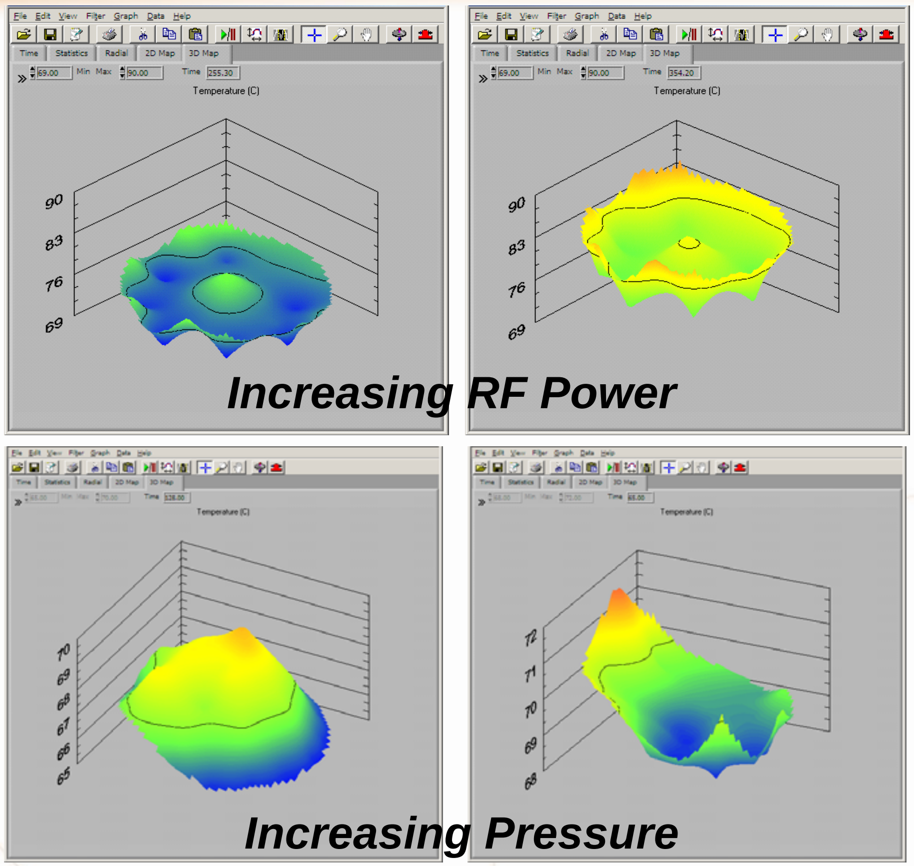
OnWafer built all the required services for the SensorWafer metrology system right into a SEMI standard 300mm FOUP. Product is shown with its docking station.

A REAL LOOK INSIDE YOUR PROCESS

In Situ Metrology
Sample Mission Data – Multi-Step Silicon Etch



Thermal Profile Response Monitoring



$$c_p \bullet dT_{wafer}/dt = (P_{plasma}) + (P_{chuck})$$

- 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

- 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

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

PlasmaRx™

Input

$f(W_b, W_s, P, \ldots)$

Hardware
Component
Analysis Engine

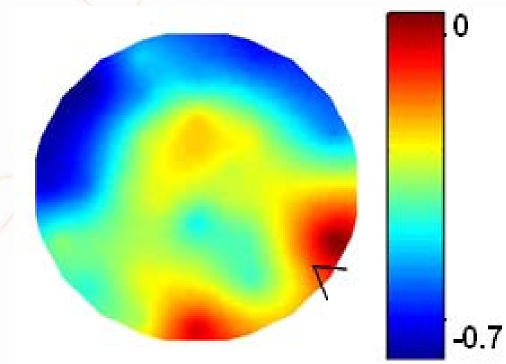
Output

Deviation
Identification
Faulty Hardware
Identified for
Immediate
Corrective Action

Input

Thermal
Response
Surface

PlasmaTemp™
&
OnView™

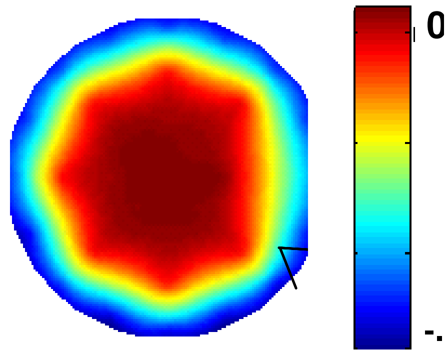


Problem Edge Cooling Effect

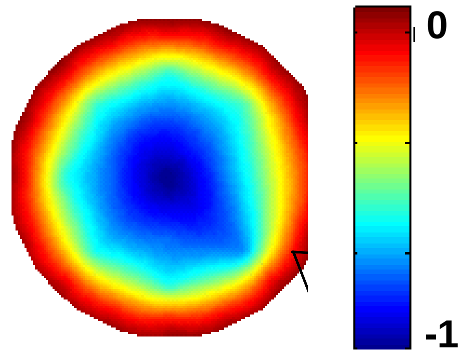
Modeled Etch Parameters

- 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

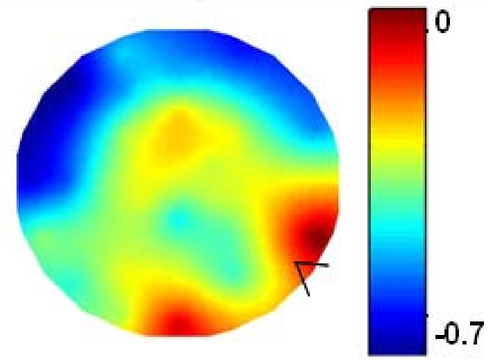
Helium Cooling System Model



Nominal Edge Cooling Effect



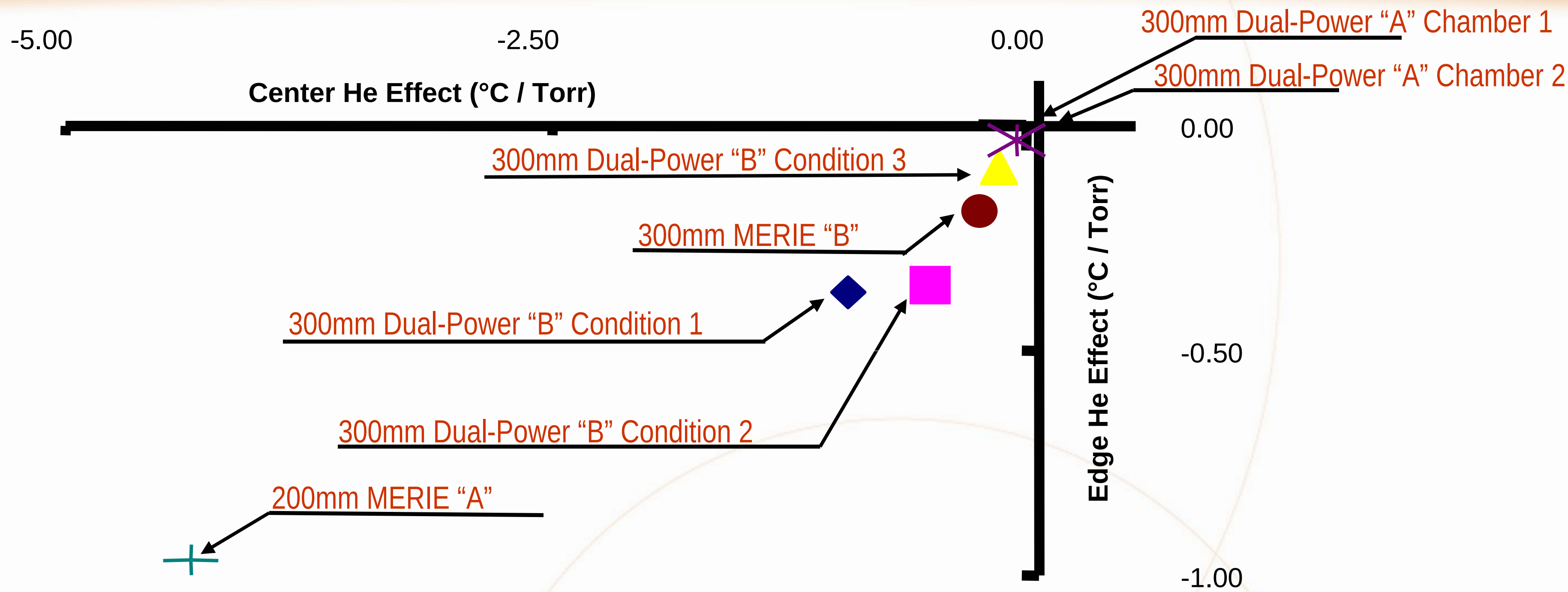
Nominal Center Cooling Effect



Problem Edge Cooling Effect

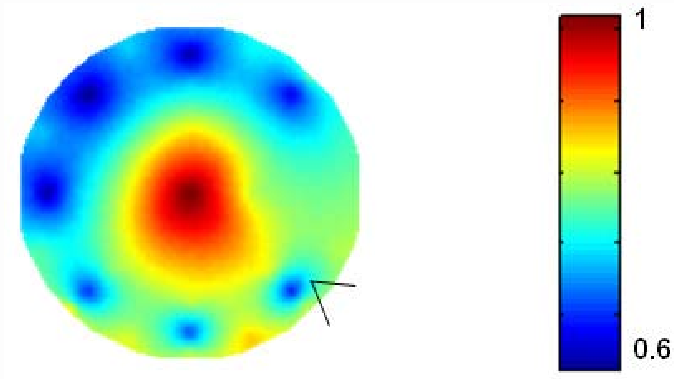
- Helium Cooling System is Configured in Two Concentric Rings
  - Nominal Response Shown for Zone Response
    - Units are Normalized in °C / Torr of He
- Deviant Edge Cooling Effect Is Easily Characterized
  - Nominal Response Opposite from the Notch
  - Notch Area Unresponsive to He Pressure
    - Indicates System Failure or Obstruction
  - Center Shows Significant Effect
    - Indicates Leakage from Outer to Inner Zone

Helium Cooling System Model

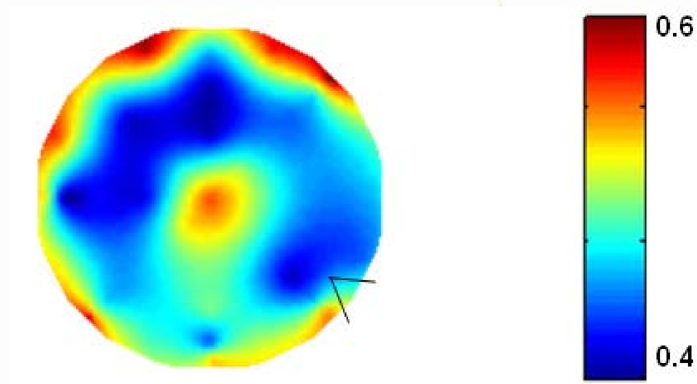


- Magnitude of the He cooling Effect for Each Zone Depends on the ESC and Cooling System Design
- For all Characterized Reactors, Inner Zone Response Dominates the Outer Zone Response
  - Maximum Response is Delivered by 200mm MERIE A
    - Inner Zone Response of Over 4°C / Torr.

RF Power System Model



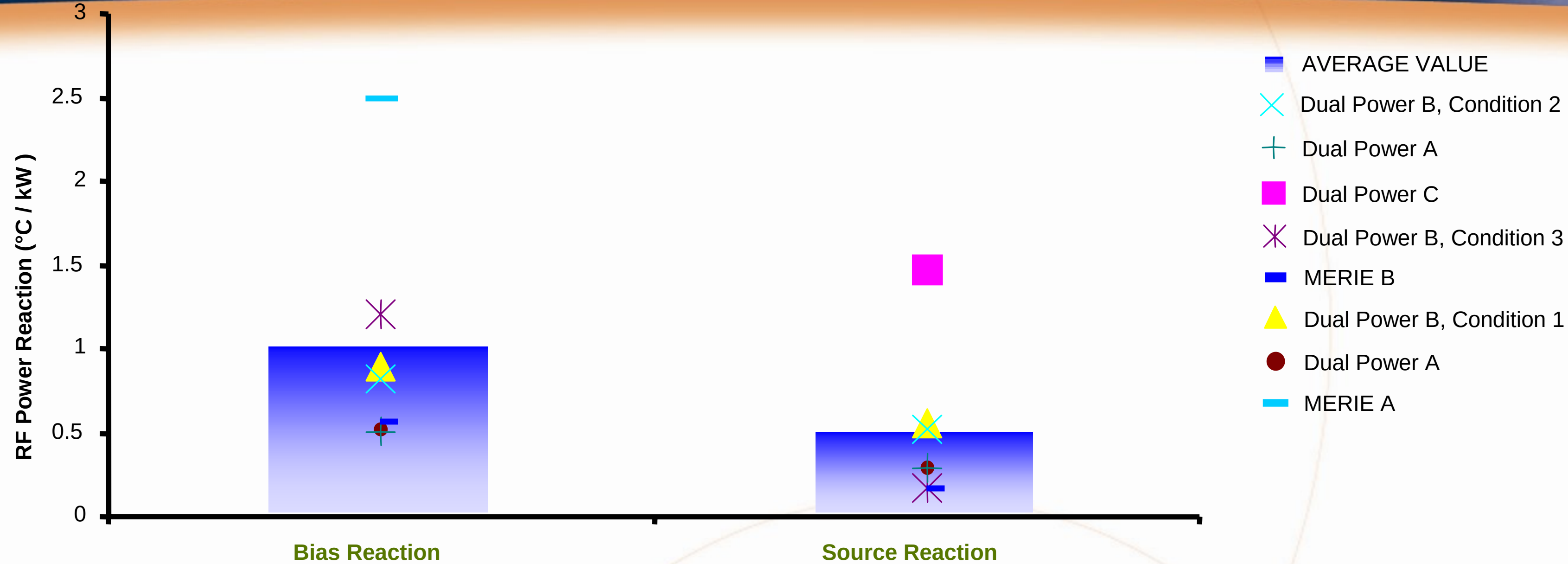
Nominal Bias Power Effect



Nominal Source Power Effect

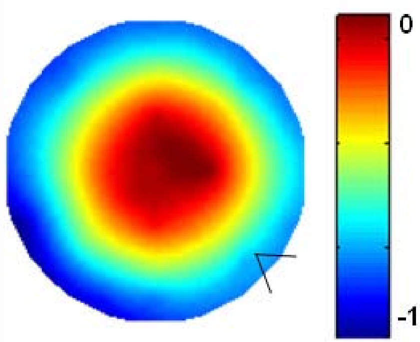
- RF Power System Directly Increases Wafer Temperature
  - Bias Power Provides a More Concentrated Effect at the RF Input Feed
  - Source Power Provides a More Concentrated Effect at the Edges of the Wafer
    - Units are Normalized in °C / Watt
  - Comparison of Two Different Etch Systems

RF Power System Model

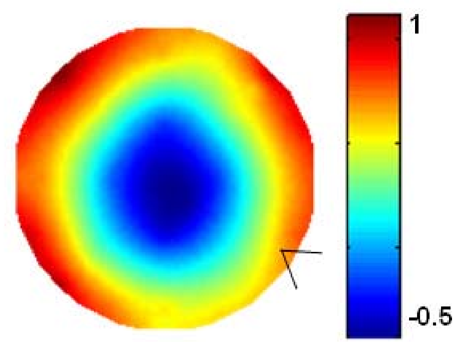


- Magnitude of the RF Power Effects Depend on the System Design
  - Bias Power Controls the Level of Ion Bombardment
  - Source Power Controls Plasma Density and is Less Direct
    - Average Bias Response is 1.6 - 7X Source Response
    - Notable Exception is Dual Power Reactor C
      - Well Known to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

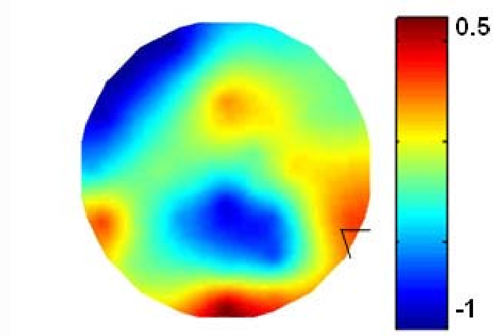
Pressure Control System Model



Nominal
LAR Pressure Effect



Nominal
HAR Pressure Effect



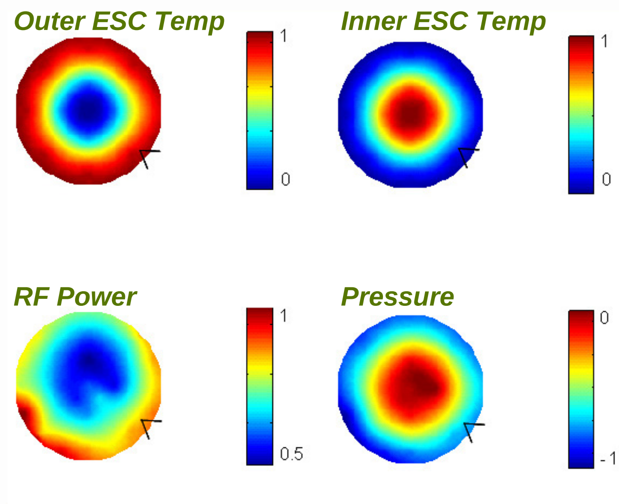
Problem Pressure Effect

- 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 2mT 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



Chamber Model

$f(ESC_{t1}, ESC_{t2}, W, P)$

Output

Process Optimization

Tune Input Parameters to Obtain Required Thermal Profile

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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