In-Situ Measurement of the Relative Thermal Contributions of Chemical Reactions and Ions During Plasma Etching

Plasma and CVD Processes 17

213th Meeting of the Electrochemical Society

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Qimonda

Overview

- Background: Chemical + Physical Removal
- Experimental Method
- Results and Discussion
- Conclusions

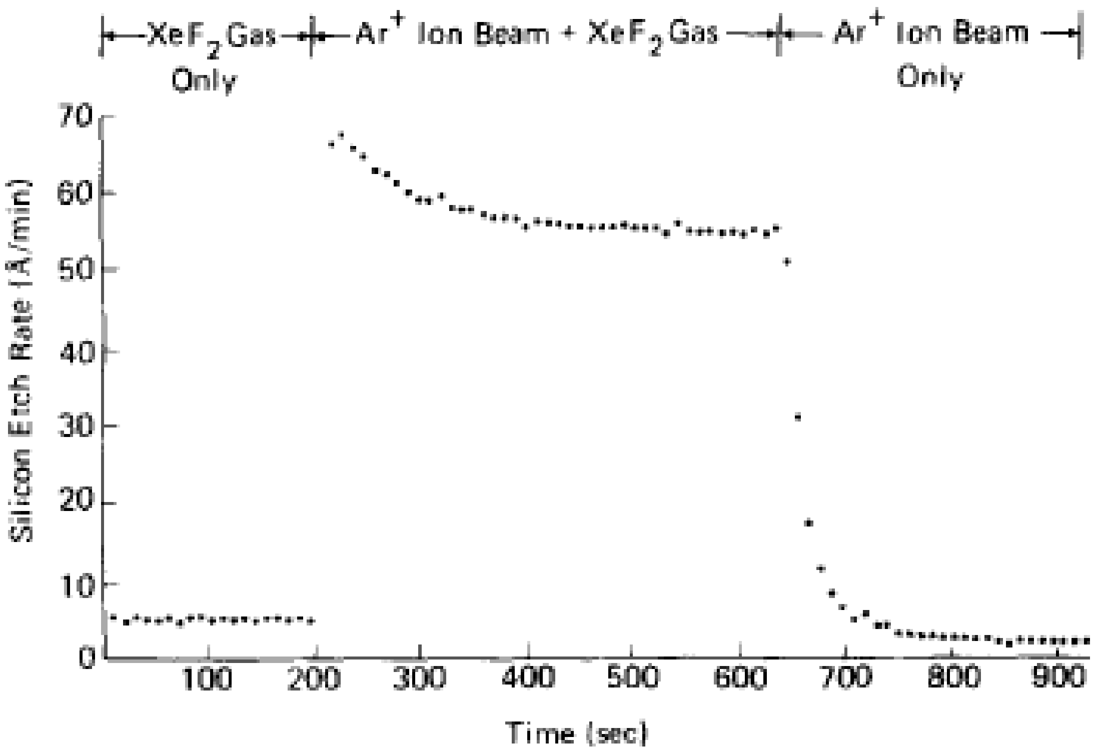
Background: Chemical + Physical Removal

Experimental Method

Results and Discussion

Conclusions

Chemical & Physical Removal



- **Synergistic Effects**
  - Chemical
    - Species
    - Temperature
  - Physical
    - Ion Current
    - Ion Energy

J.W. Coburn, H. Winters J. Appl. Phys 50(5) May 1979

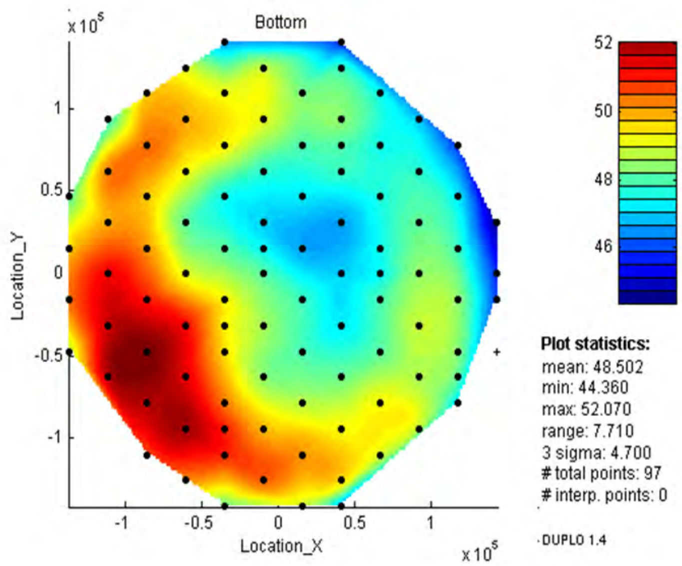
Attributes of Substrate Temperature Measurement

$T_{substrate}$ = Heat in - Heat Out

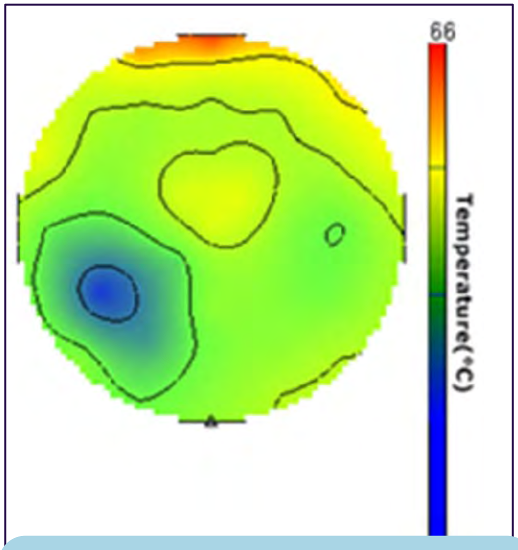
- **Heat in**
  - Ion current (incl. recombination)
  - Heat of condensation
  - Exothermic reactions
  - Process gas convection
  - Radiation

- **Heat Out**
  - Convection to process gas
  - Loss through electrostatic chuck
  - Radiation

Why we care about this topic



In-line CD



Sensor Wafer Temperature

- **Evidently temperature spatial correlation to CD variation.**
- **Routine recipe variation does not change response.**
- **Many hardware components are potentially responsible**
- **Objective: Identify mechanism and cut troubleshooting time.**

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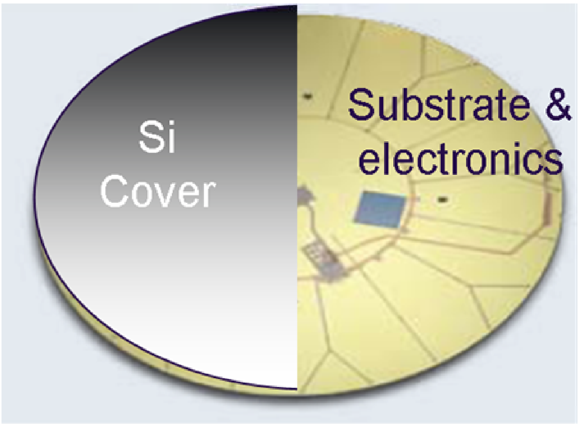
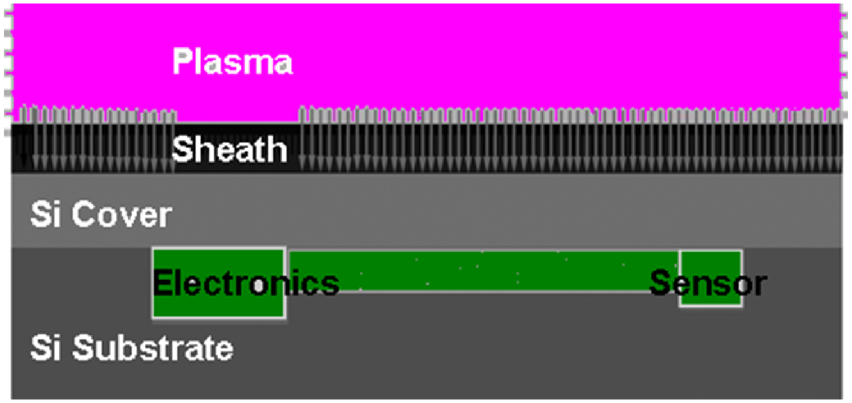
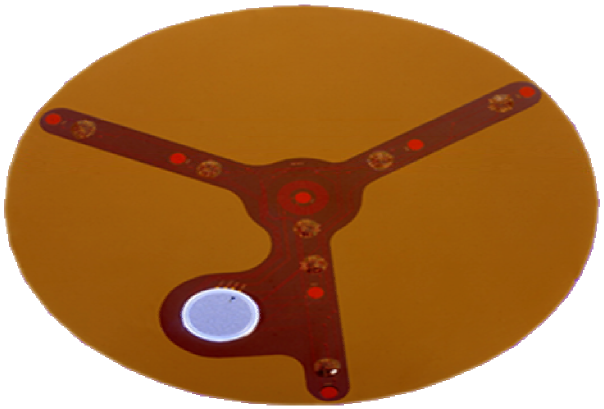
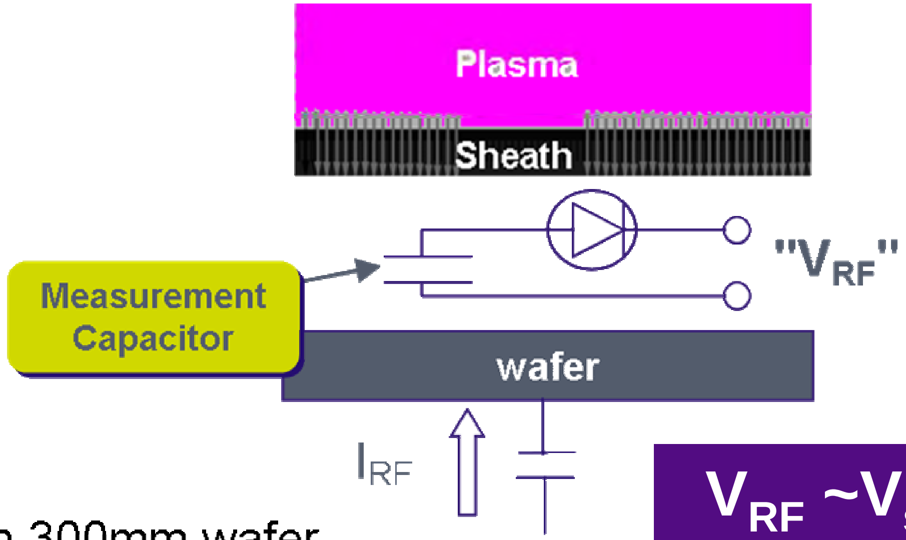
Sensorwafer Description





Temperature Measurement: 65 sites on 300mm wafer



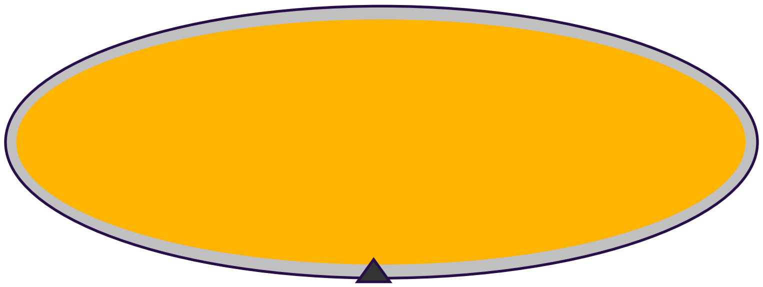


$$V_{RF} \sim V_s \cdot n_s \cdot \omega^2$$

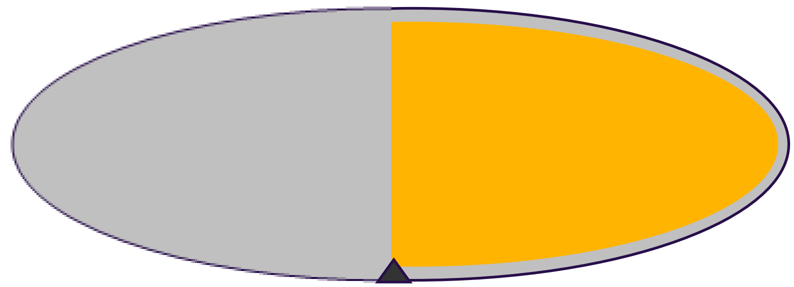
Voltage Measurement: 7 sites on 300mm wafer

Sensor Wafer Pre-Processing

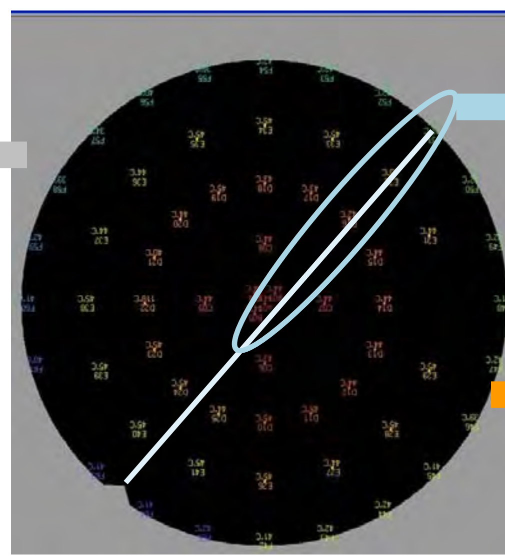
Integral Sensor Wafer
Coated with 3um PFR IX420H
i-line Resist, 2mm EBR



Manual Solvent Removal
of Resist on Wafer Half
Left of Notch



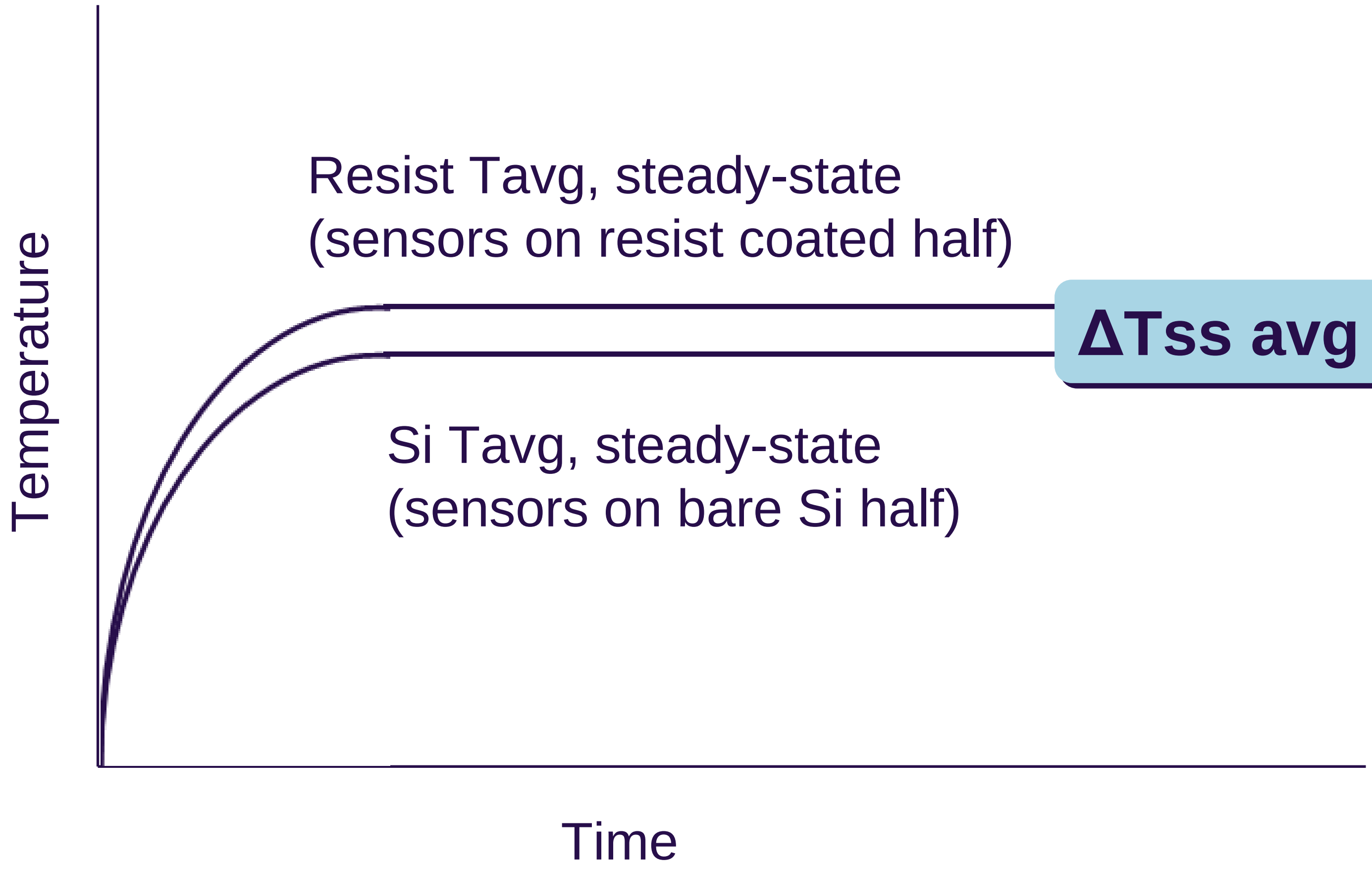
"No Resist"
Sensor Group



Data Not Used

"Resist"
Sensor Group

Exothermic Chemical Etch Components: Measurement Theory



ΔT_{ss} avg = k1A(Φr – ΦSi)

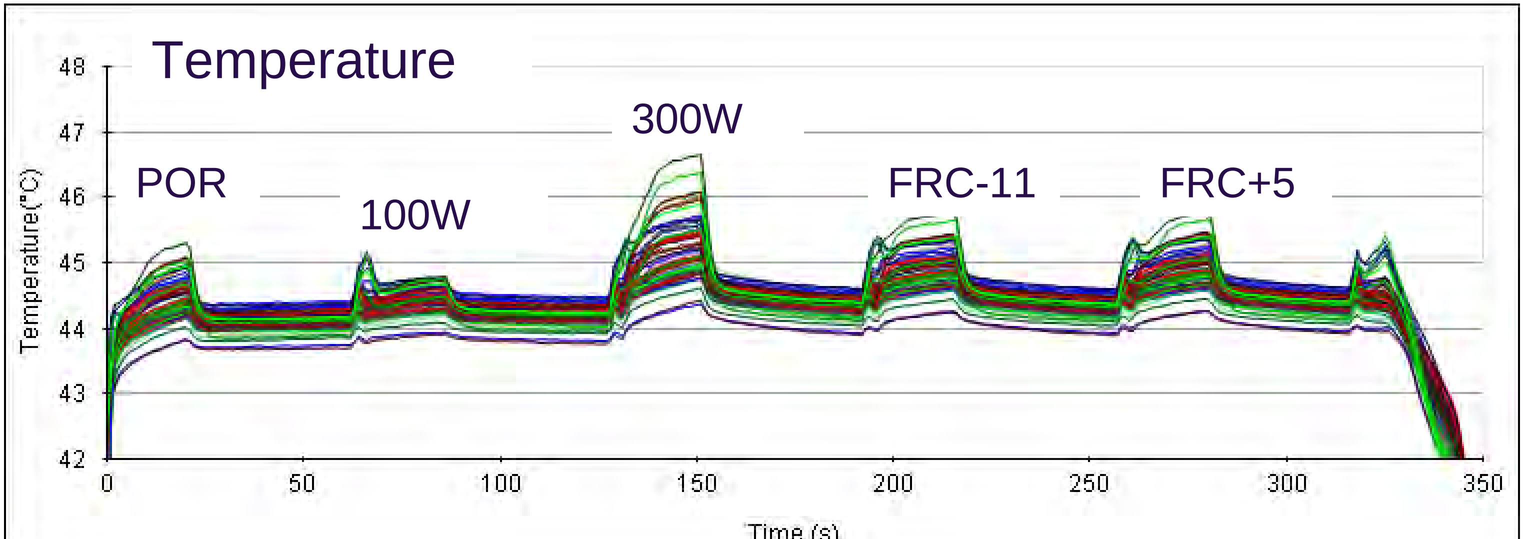
Assumption: for resist etch highly selective to Si:
(Φr – ΦSi) = Heat of Chemical Reaction

Experimental Run Summary

Both sensorwafers were run through the following conditions

1. **Coat temperature wafer – remove resist from left side**
2. **CCP Etch: 11 step N_2 / H_2 DOE**
3. **CCP Etch: 5 single-factor N_2 / H_2 test runs**
4. **CCP Etch: 5 step N_2 / H_2 screening test**
5. **CCP Etch: 5 step Ar / O_2 screening test**
6. **CCP Etch: 2 step N_2 / H_2 & Ar / O_2 high pressure test**
7. **ICP Etch: 2 step Cl_2 test (5mT, 50mT)**
8. **ICP Etch: 2 step O_2 test (5mT, 50mT) – 50mT to endpoint**

Sensorwafer data traces

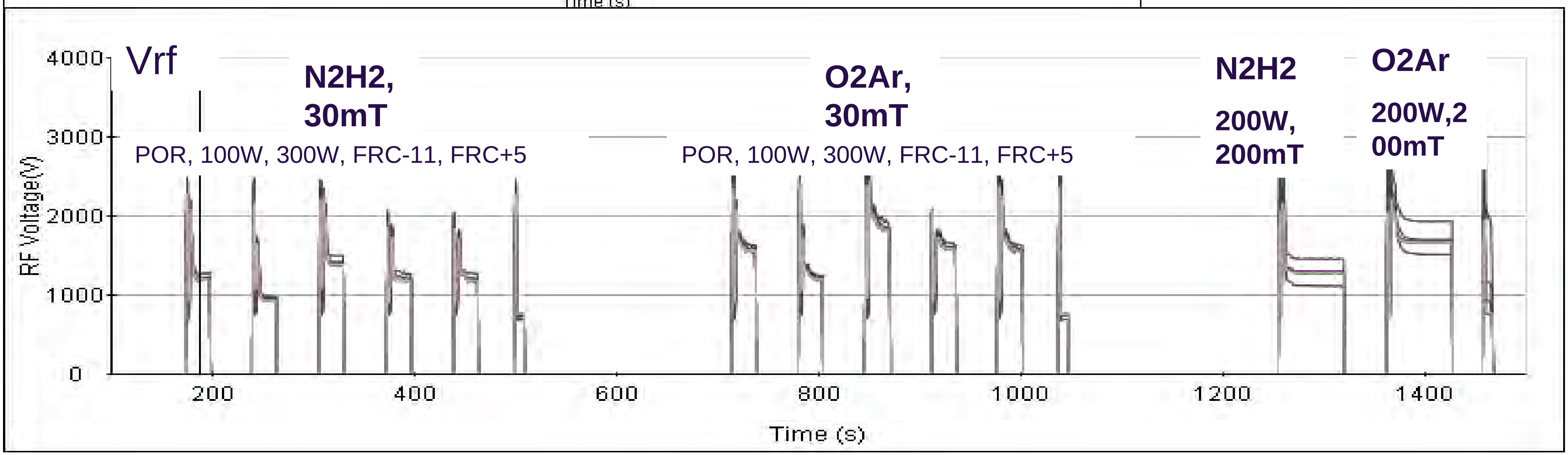


CCP reactor

P=200mT, 200Wb,

a)N2=200, H2=250,

b) Ar=100, O2=10



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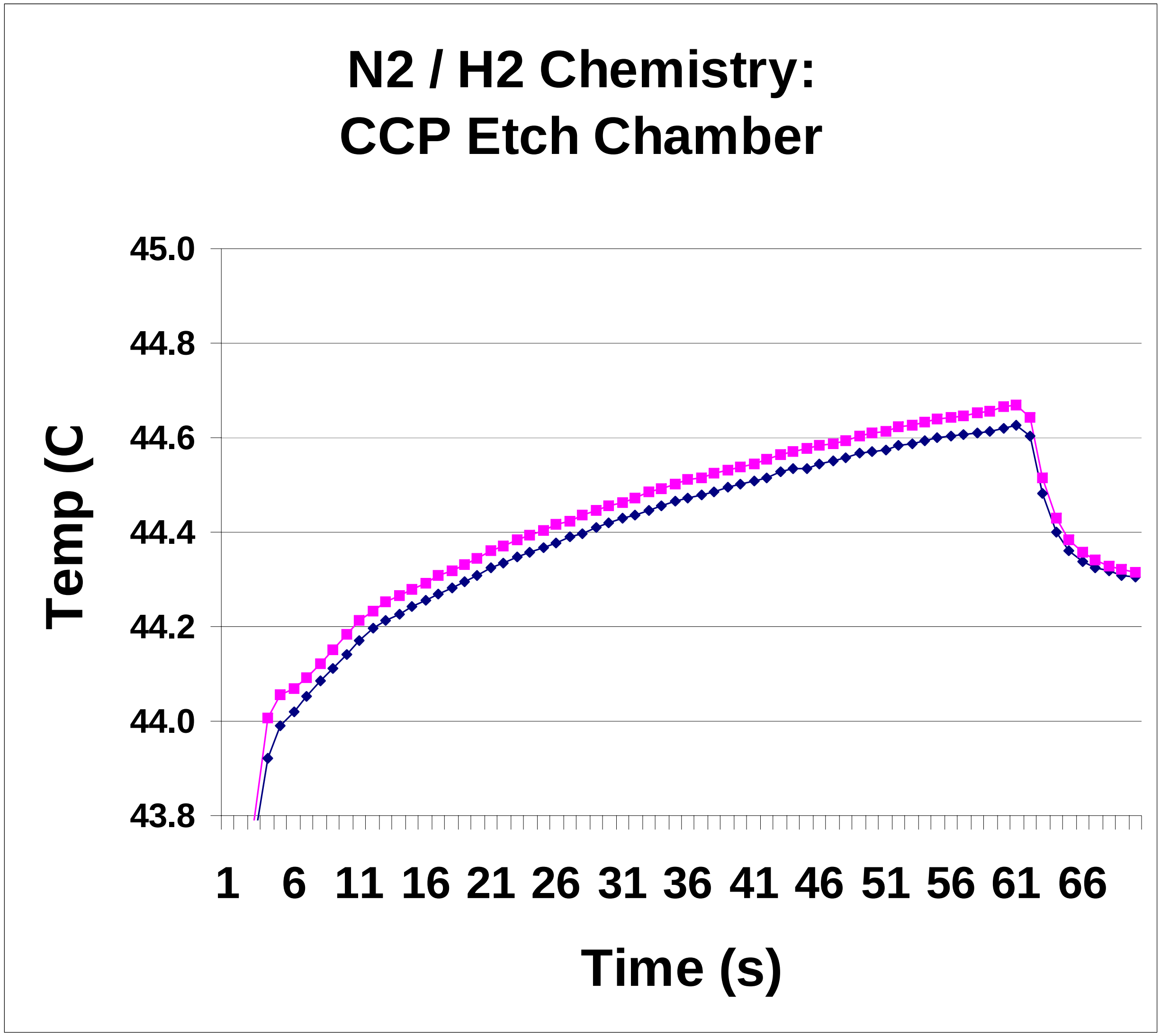
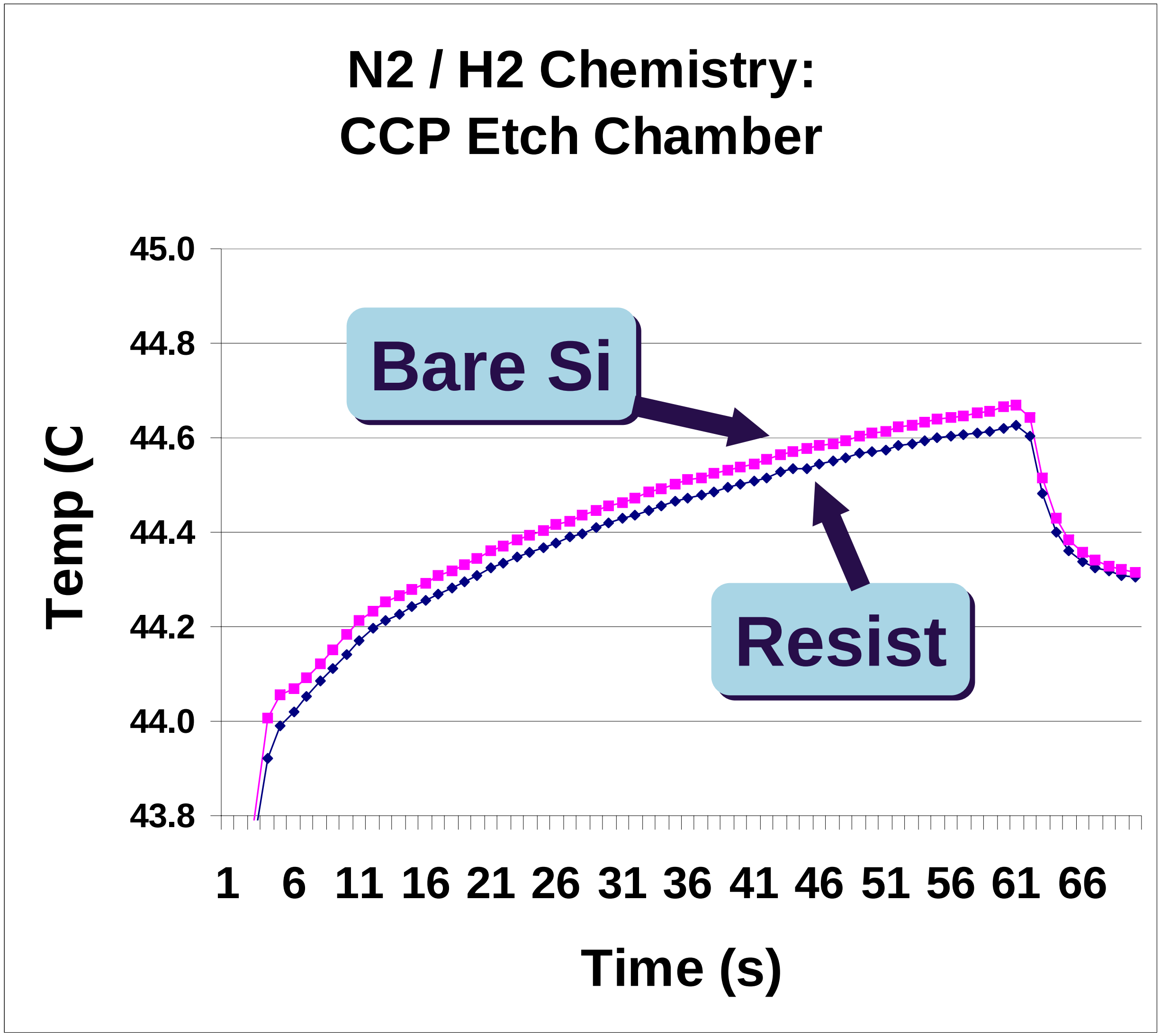
Exothermic Chemical Etch Components: Experimental Data



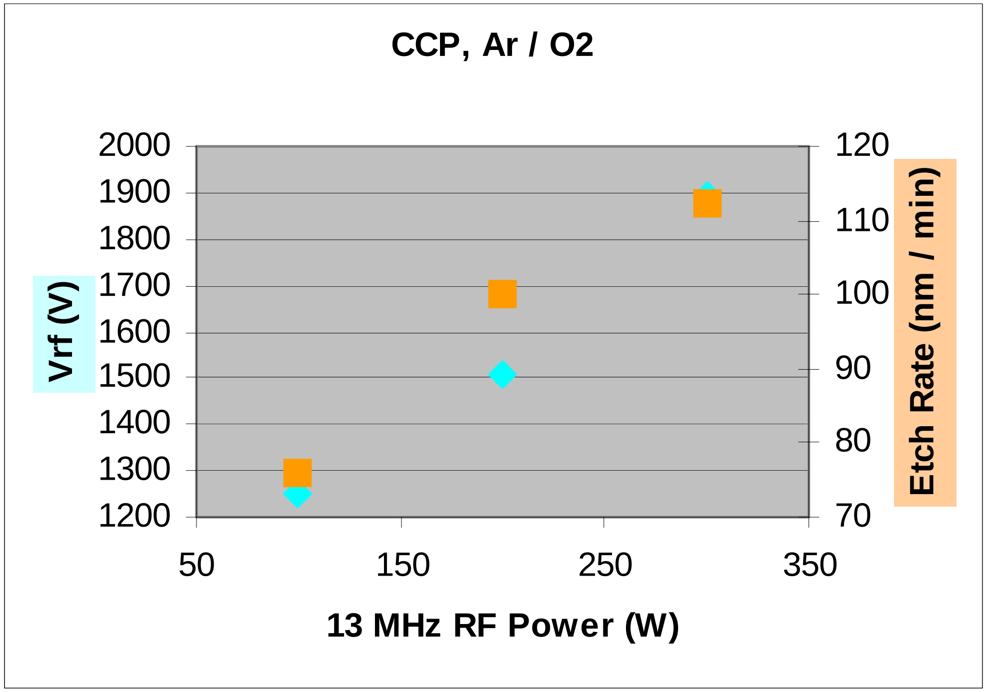
1. Exponential Data Fit
2. Extrapolate to Steady-State
3. Calculate (Φr – ΦSi)
4. Estimate removal rate based on C-C bond strength

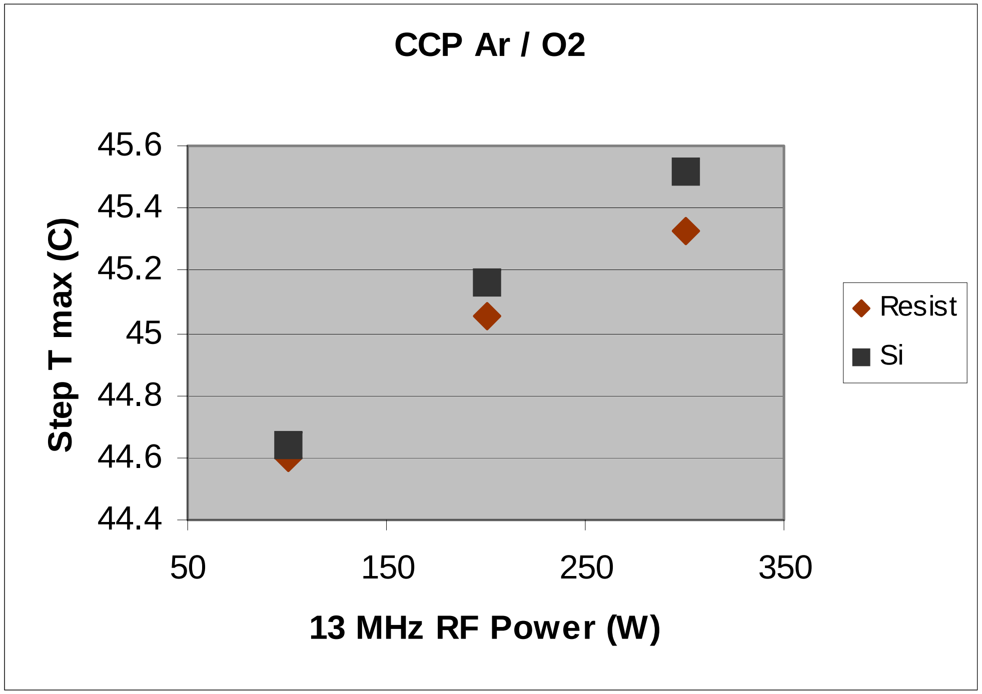
Exothermic Chemical Etch Components: Experimental Data



- However, the Si half of sensorwafer was hotter!
- Assumption is that thick resist (~3µm) acts as an insulator to ion bombardment

Etch Rate / Vrf and Temperature Response to RF Power (CCP chamber)

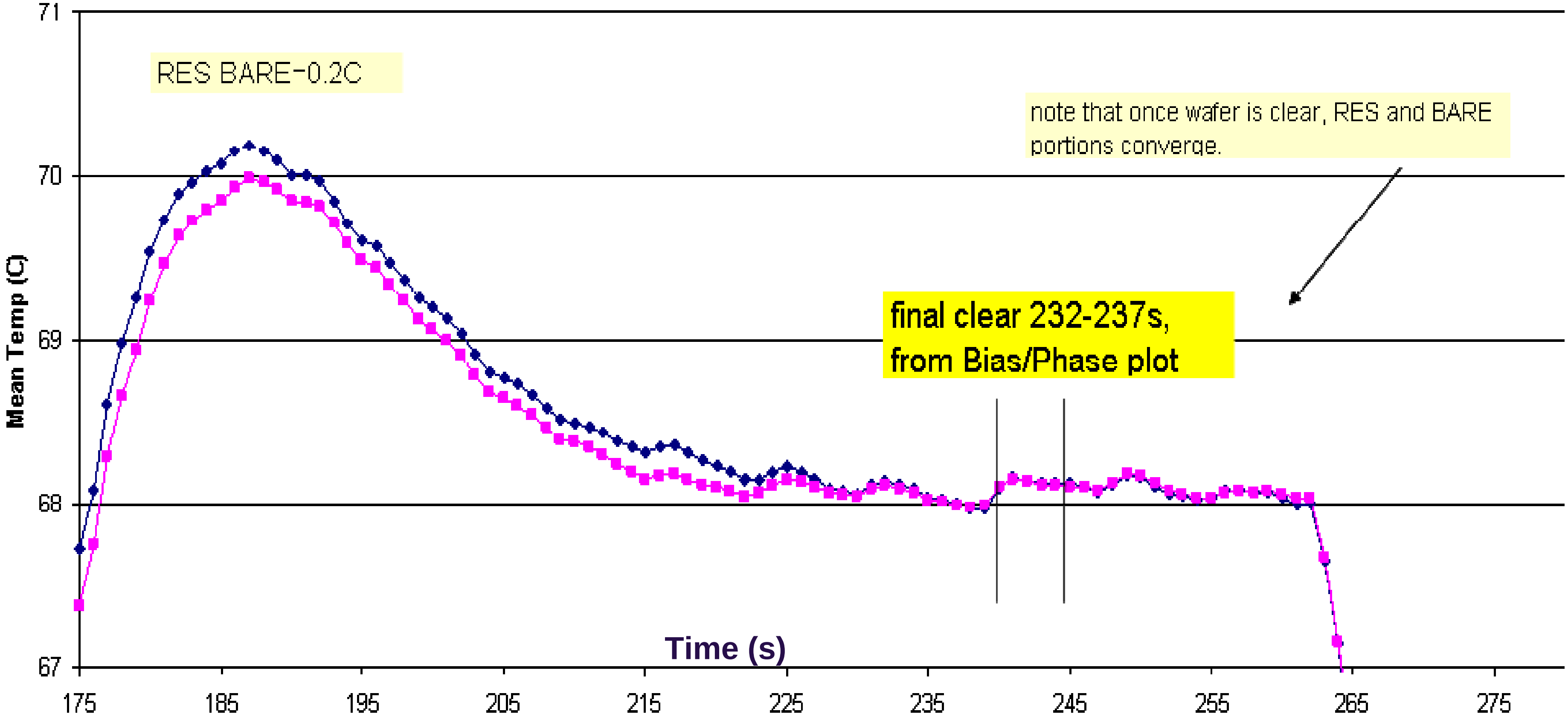




Both Etch rate and Vrf show strong response to RF Bias power.
Temperature has a modest response to RF power.
This data supports the notion that Etch Rate is dominated by physical mechanism.

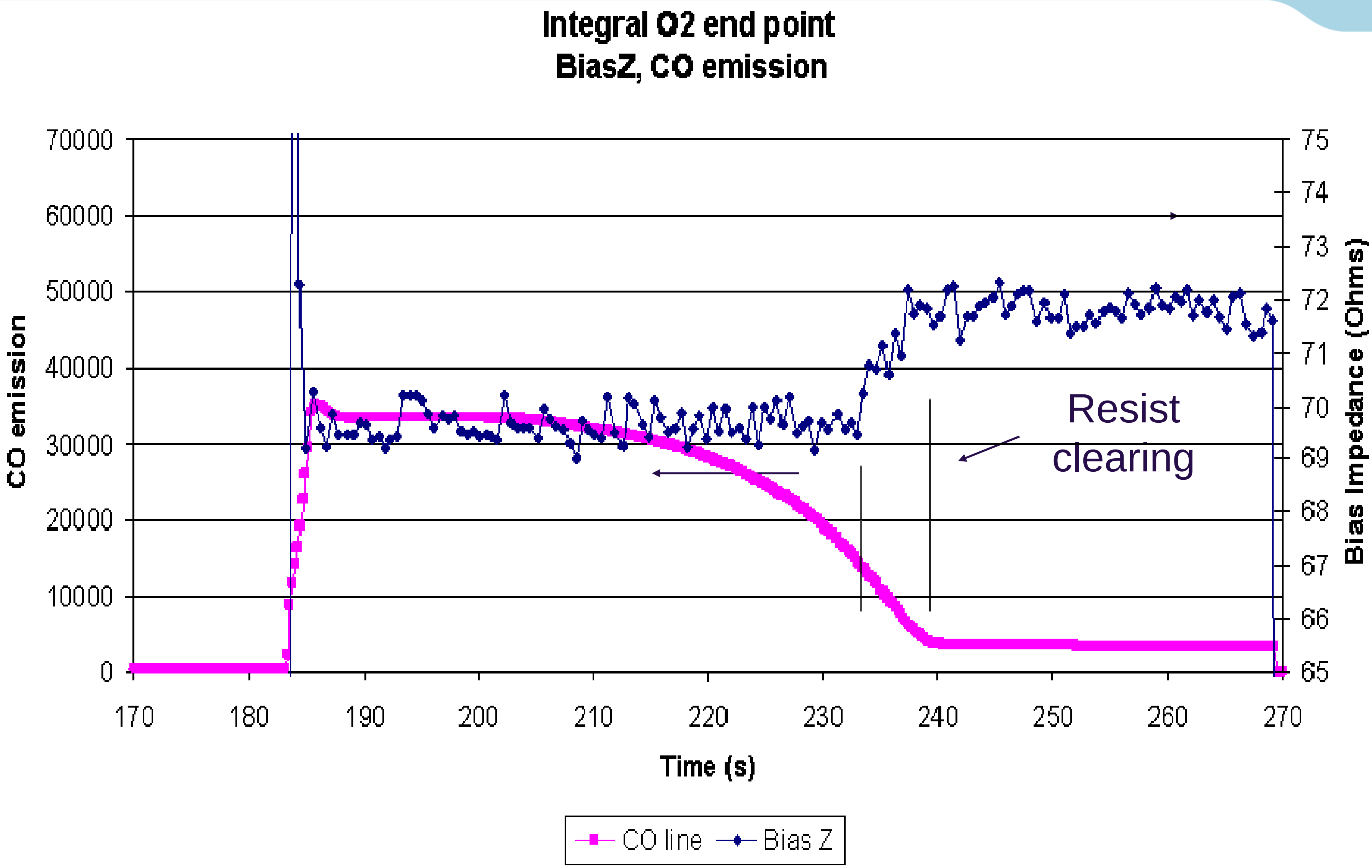
Sensorwafer Response: Resist Clearing
Mean temperature by half wafer zones …

… ICP reactor, 50mT O2   Clearing Resist from sensorwafer

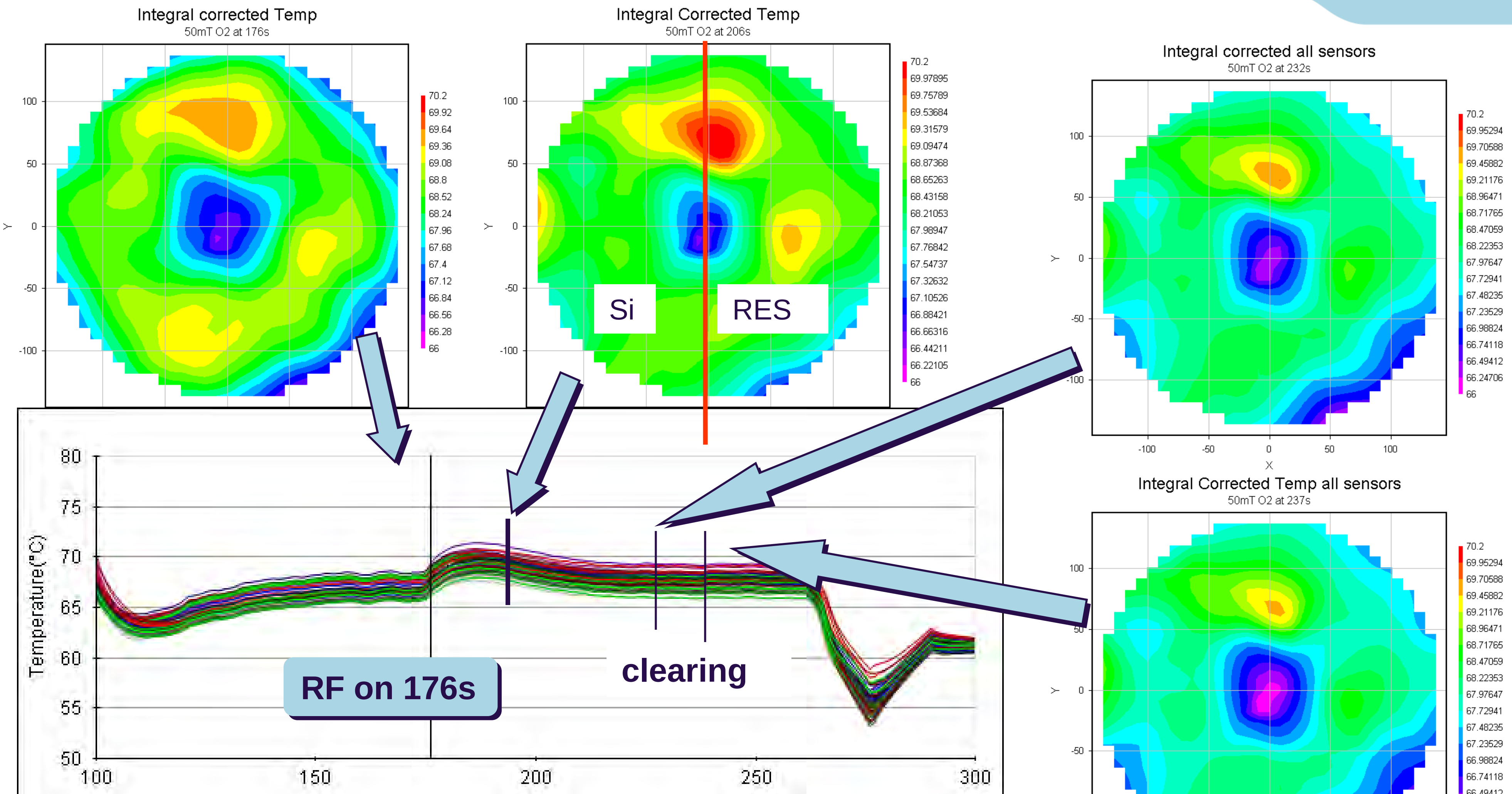


Now that resist is thinned (≤ 550 nm), resist half runs hotter than bare Si. Temperatures of each half converge as resist clears.

ICP Etch Chamber signals for Resist etch end point O_2 Chemistry

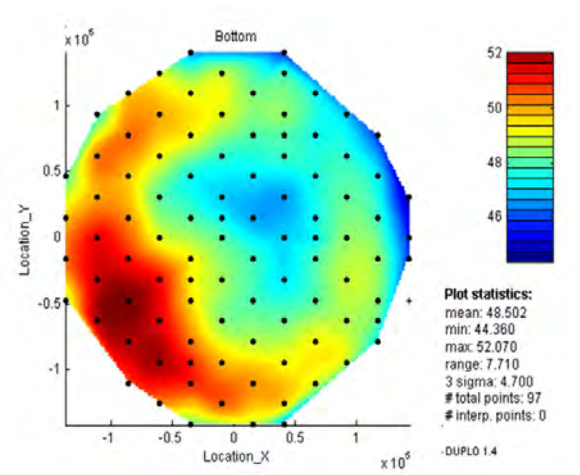


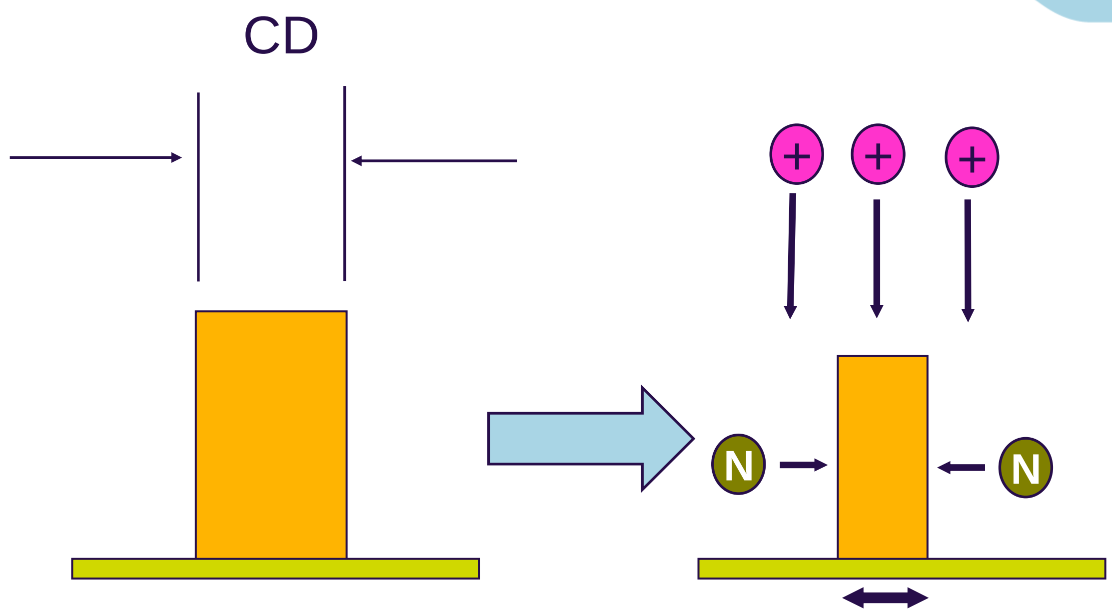
Etch-to-Clear Resist, 50mT O_2 (All sensors, same scale throughout)



"Hot spot" disappears as resist clears

Case Study: Chemical / Physical Components and Isotropic Mask Trim Etch





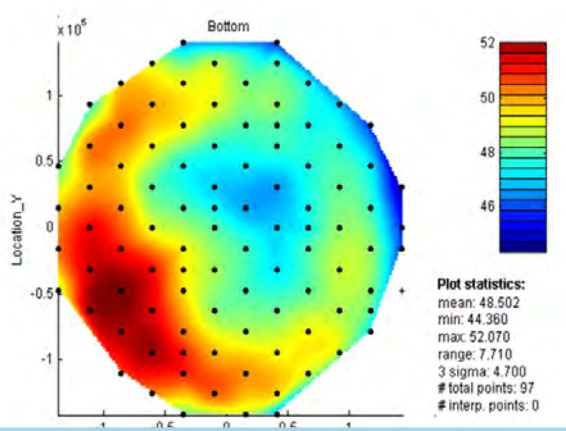
Poor In-line CD Uniformity

Width CD Depends on

Isotropic Etch Component

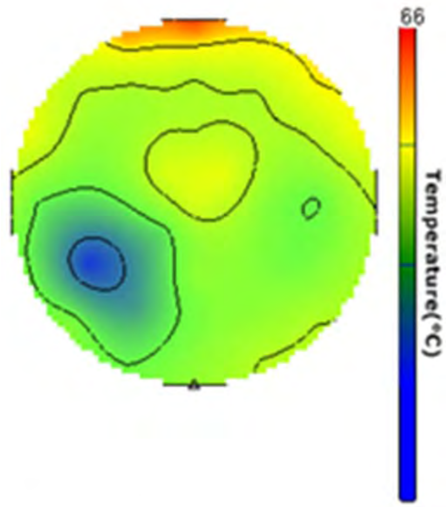
Lower substrate temperature=reduced isotropic etch rate=wider CD

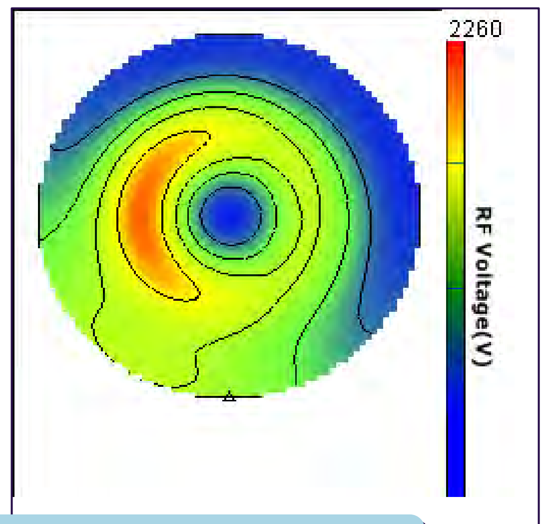
Case Study: Root Cause Identification



Poor In-line CD Uniformity

Sensorwafer response

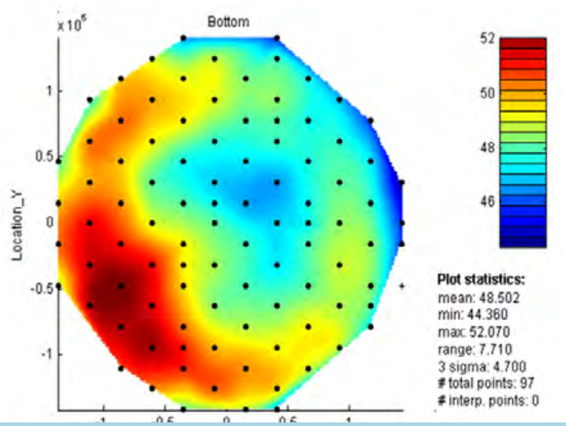




Temperature Vrf

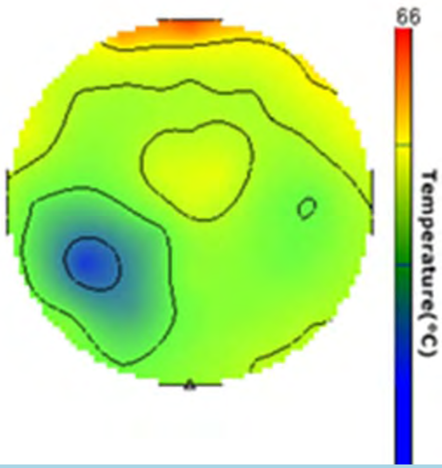
"Heat Out" problem not "Heat In"

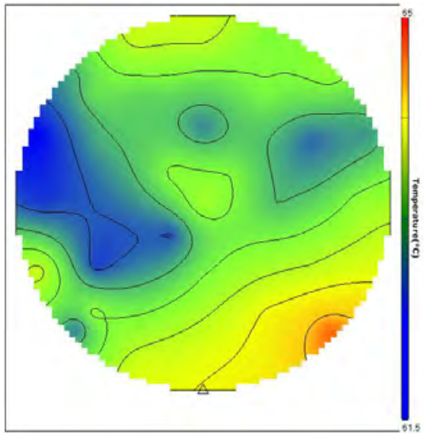
Correction Verification



Poor In-line CD Uniformity

Sensorwafer response





Temp 20C Cathode

range = 10 C

Temp 40C Cathode

range = 3.5 C

CD non-uniformity problem localized to heating/cooling apparatus of ESC

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Conclusions / Summary

The Resist/Bare Sensorwafer Method Shows Promise

- **Can detect small but consistent differences in temperature**

and Could benefit from:

- **Thinner coating for improved sensitivity**
- **"Checkerboard" pattern to avoid chamber-related asymmetries**
- **Examine isotropic removal vs. vertical removal**

Use of Temperature & Volt Sensorwafers together is proving useful

- **Quickly ascertain source of chamber asymmetry**

Acknowledgements

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