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

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M.R. Tesauro   Qimonda Dresden GmbH & Co. OHG, Germany
G.A. Roche     KLA-Tencor, SensArray Division
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

Attributes of Substrate Temperature Measurement

\[ T_{substrate} = \text{Heat in} - \text{Heat Out} \]

- **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

- 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.
Sensorwafer Description

Temperature Measurement: 65 sites on 300mm wafer

Voltage Measurement: 7 sites on 300mm wafer

\[ V_{RF} \sim V_s \cdot n_s \cdot \omega^2 \]
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
Temperature

Resist $T_{avg}$, steady-state
(sensors on resist coated half)

Si $T_{avg}$, steady-state
(sensors on bare Si half)

$\Delta T_{ss \ avg} = k_1A (\Phi_r - \Phi_Si)$

Assumption: for resist etch highly selective to Si:
$(\Phi_r - \Phi_Si) = \text{Heat of Chemical Reaction}$

Assumption: for resist etch highly selective to Si:
Both sensor wafers were run through the following conditions:

1. Coat temperature wafer – remove resist from left side
2. CCP Etch: 11 step N2 / H2 DOE
3. CCP Etch: 5 single-factor N2 / H2 test runs
4. CCP Etch: 5 step N2 / H2 screening test
5. CCP Etch: 5 step Ar / O2 screening test
6. CCP Etch: 2 step N2 / H2 & Ar / O2 high pressure test
7. ICP Etch: 2 step Cl2 test (5mT, 50mT)
8. ICP Etch: 2 step O2 test (5mT, 50mT) – 50mT to endpoint
Sensorwafer data traces

 Temperatures

 POR 100W 300W FRC-11 FRC+5

 Temperatures

 POR 100W 300W FRC-11 FRC+5

 Vrf N2H2, 30mT O2Ar, 30mT
 POR, 100W, 300W, FRC-11, FRC+5 POR, 100W, 300W, FRC-11, FRC+5

 CCP reactor
 P=200mT, 200Wb,
 a) N2=200, H2=250,
 b) Ar=100, O2=10
Exothermic Chemical Etch Components: Experimental Data

N2 / H2 Chemistry:
CCP Etch Chamber

1. Exponential Data Fit
2. Extrapolate to Steady-State
3. Calculate ($\Phi_r - \Phi_{Si}$)
4. Estimate removal rate based on C-C bond strength
Exothermic Chemical Etch Components: Experimental Data

N2 / H2 Chemistry:
CCP Etch Chamber

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

Integral O$_2$ end point
BiasZ, CO emission

CO emission vs Time (s)

Resist clearing

Bias Impedance (Ohms)

CO line
Bias Z
Etch-to-Clear Resist, 50mT O₂
(All sensors, same scale throughout)

"Hot spot" disappears as resist clears

Integral corrected Temp 50mT O₂ at 176s
Integral Corrected Temp 50mT O₂ at 200s
Integral corrected all sensors 50mT O₂ at 232s

Integral Corrected Temp all sensors 50mT O₂ at 257s

RF on 176s clearing

Si RES
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

Sensorwafer response

Poor In-line CD Uniformity

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

Temp 20C Cathode
range = 10 C

Temp 40C Cathode
range = 3.5 C

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