Improved control of chamber condition through new Waferless Auto Clean

Sauabh Ullal, Shibu Gangadharan, Erik Edelberg, John Daugherty, Harmeet Singh, Vahid Vahedi

Lam Research Corporation, Fremont, CA 94538

Anna R. Godfrey, Eray S. Aydil

Department of Chemical Engineering

University of California Santa Barbara, Santa Barbara, CA 93106

Lam RESEARCH

Importance of Wall Condition

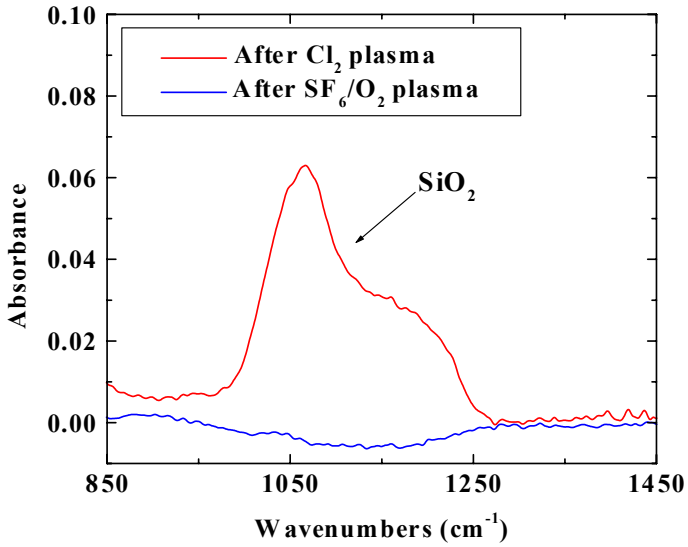
- Plasma reactor walls can play a crucial role in determining the plasma properties, such as the radical concentrations and ion densities, especially at low pressures
- This well-known plasma-wall interaction has caused problems ranging from process drifts in IC manufacturing to irreproducible data in fundamental studies employing plasma diagnostics.
- Terms such as “wall conditioning” and “reactor seasoning” have become accepted language in literature to describe art of avoiding such effects.

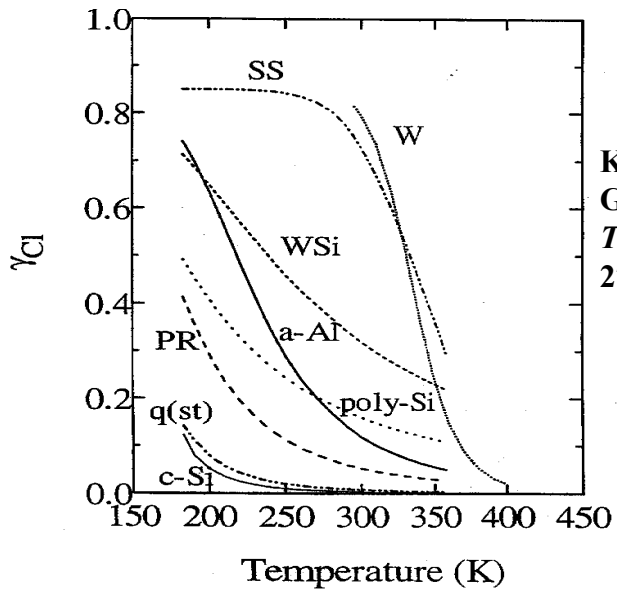
What is Wall Condition?

- Nature of deposition on walls
- Amount of halogens on the walls
- Amount of oxygen on the walls
- Other species present on the wall
  - H_2O

Etch Product re-deposition affects plasma chemistry

- 5 Å thick SiO_2 film is deposited on reactor walls even when Si wafer or O_2 are not present in the chamber: quartz window is the source of Si and O.
- Wall recombination probability of Cl is lowered drastically when walls are coated even with ~ a monolayer of SiO_2.
- γ calculated by fitting measured Cl concentration to a model is ~ 0.03 on SiO_2 covered walls.
- SF_6/O_2 plasma removes the SiO_2 film. γ ~ 1 after the SiO_2 is removed.
- Waferless Auto Cleans (fluorine rich plasma) are used to clean chamber deposition
  - Eliminate drifts in process due to deposition buildup

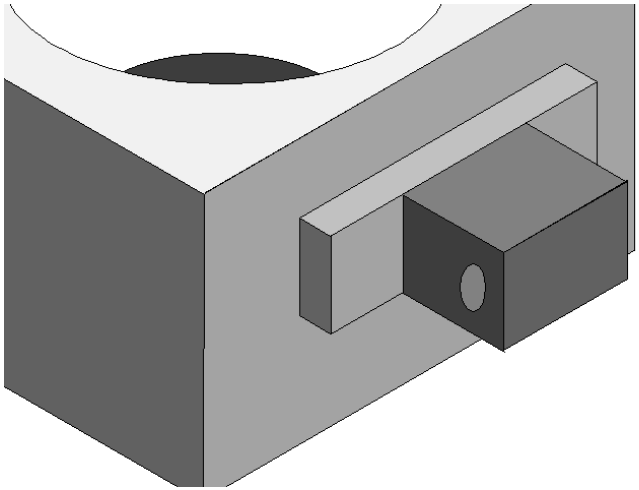


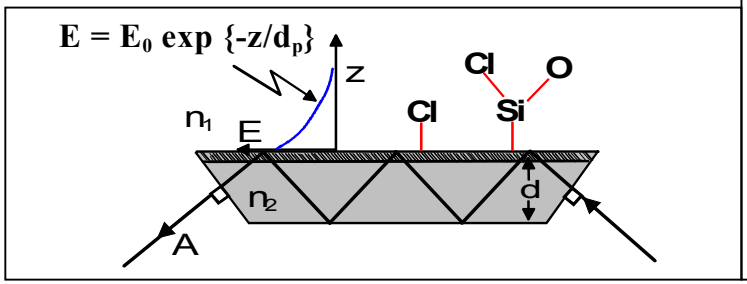


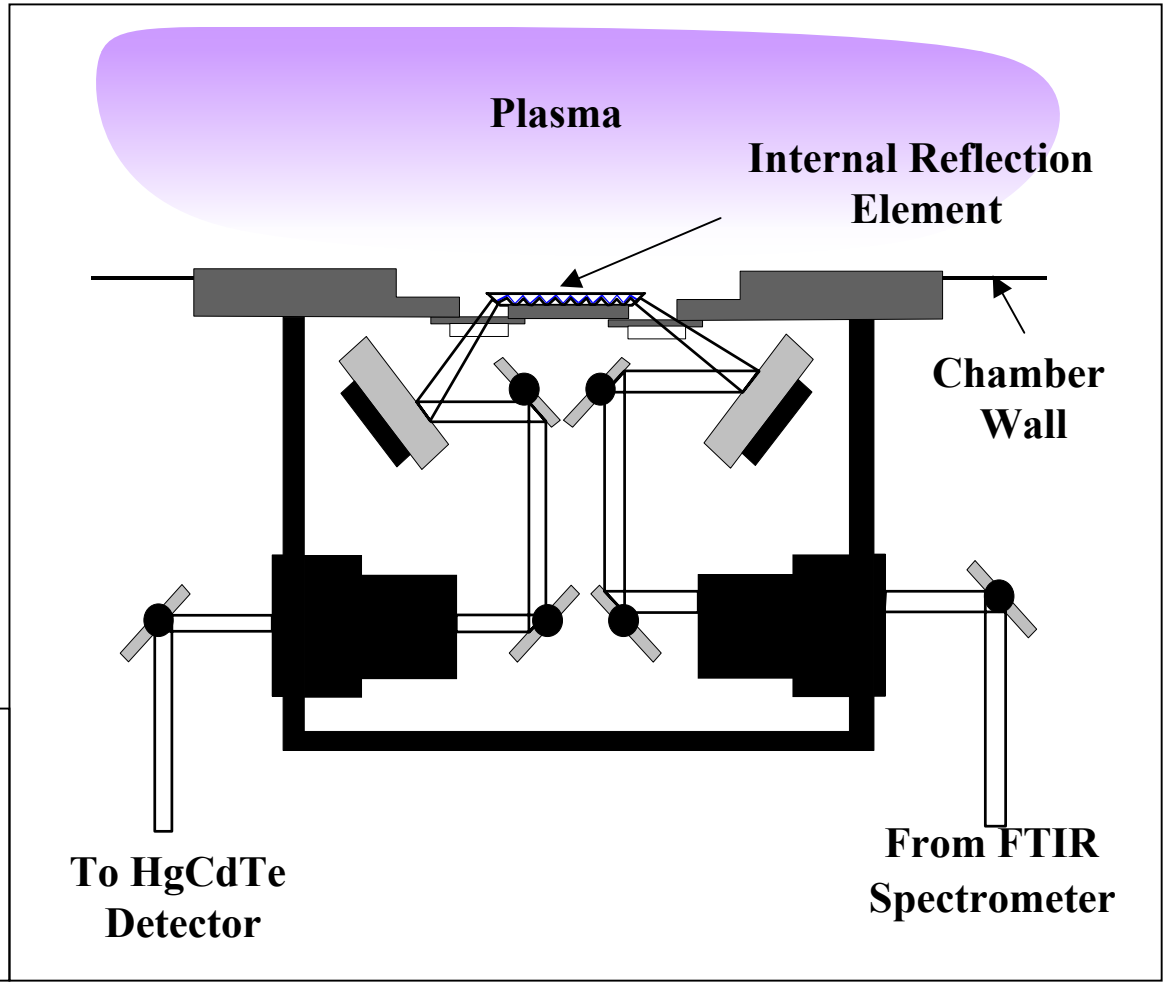
Kota, Coburn, Graves; *J. Vac. Sci. Technol.* A 16(1); 270-277 (1998)

MTIR-FTIR Surface Probe

- Multiple Total Internal Reflection Fourier Transform InfraRed Spectroscopy is used to monitor wall condition

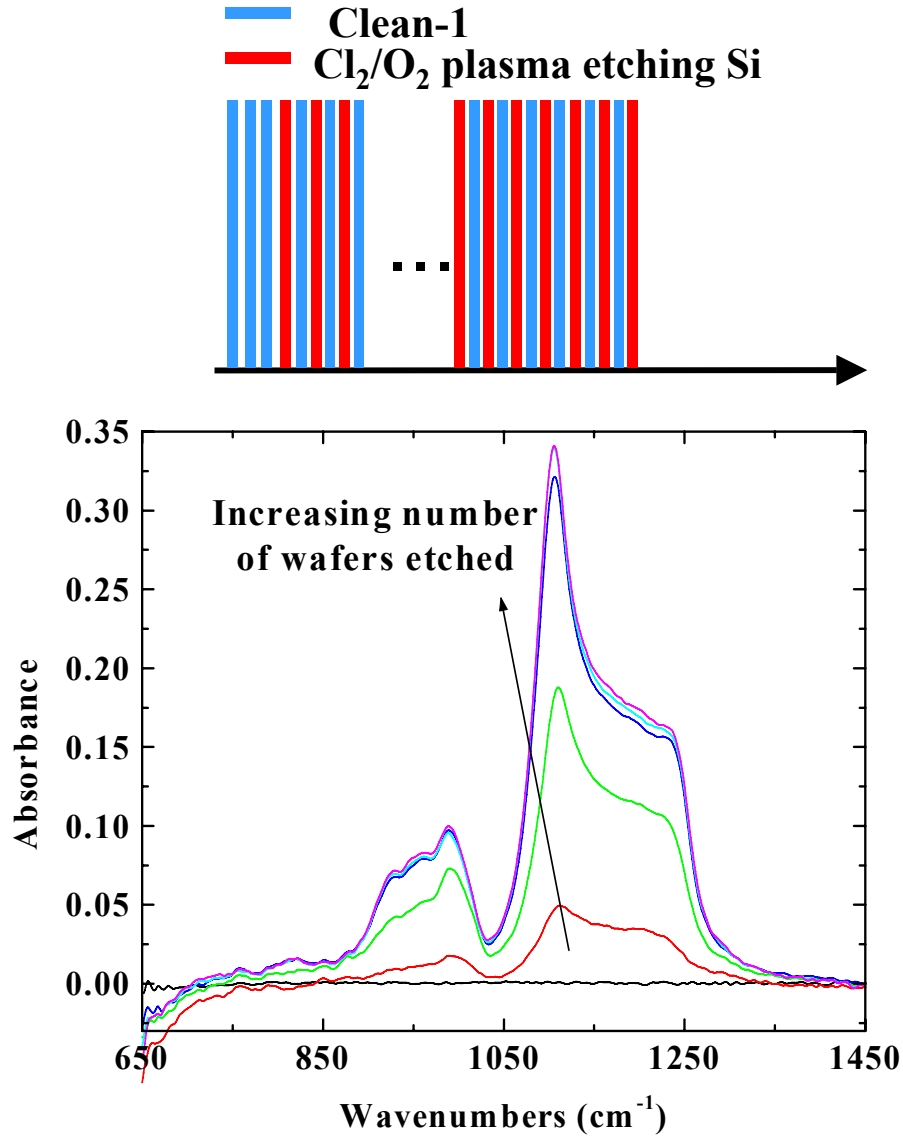






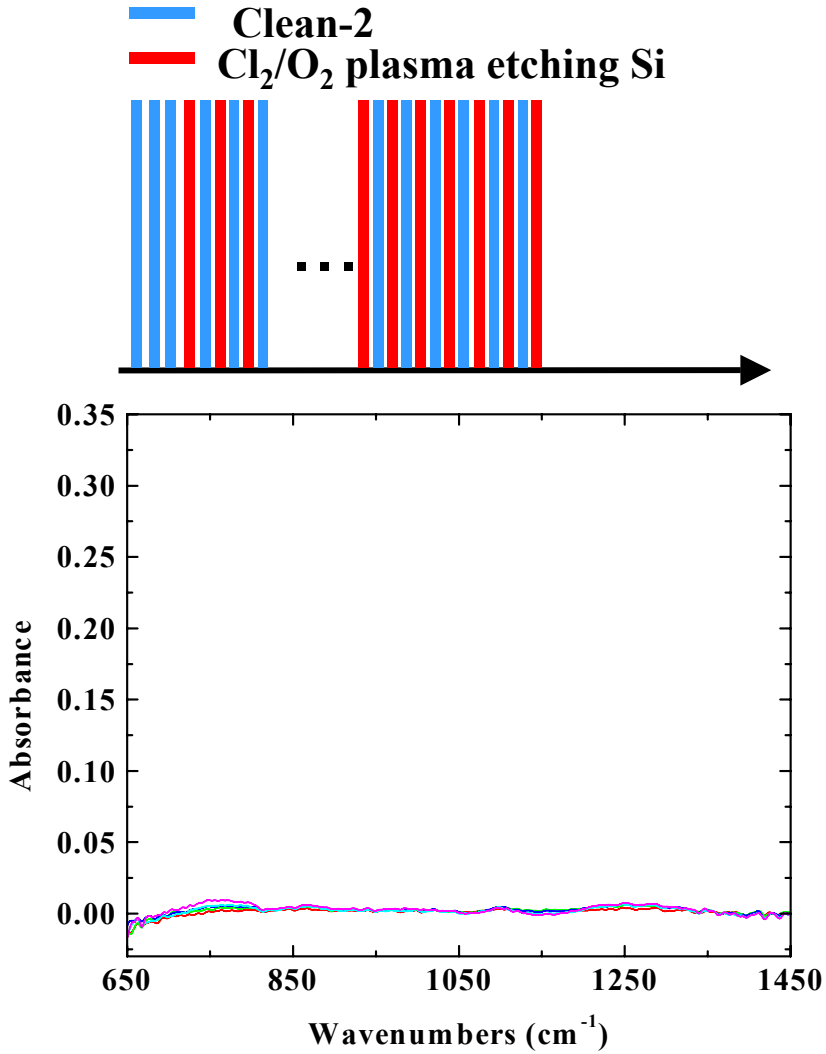
Waferless Auto Clean development

- Clean-1 is not sufficient to clean away all the wall deposits and hence leads to build up of deposition on the walls of the chamber
- O back bonded Si -F peak increases i.e. F incorporation increasing
- Clean-1 is not suitable for this etching process



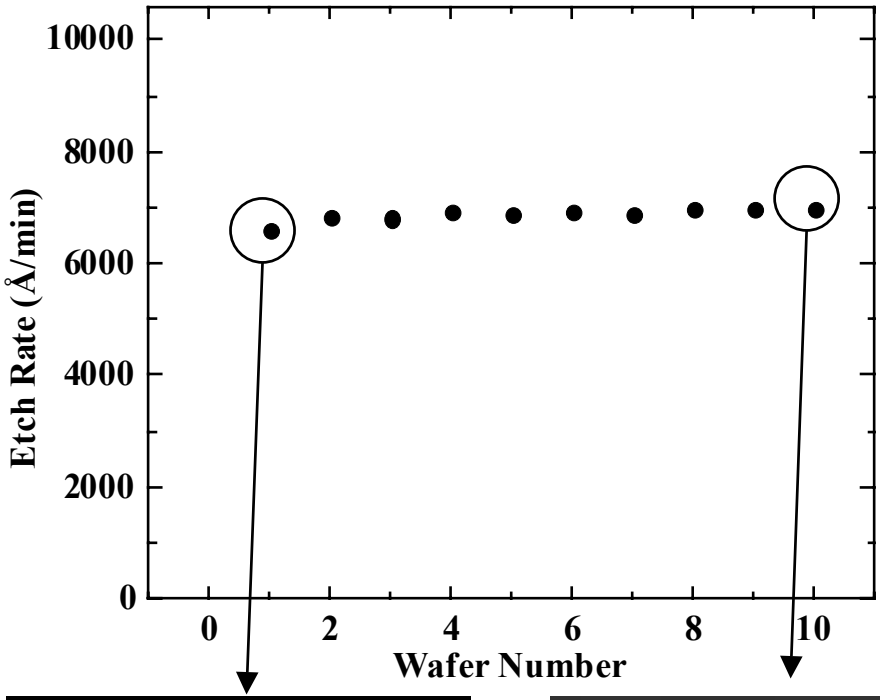
Waferless Auto Clean development (contd.)

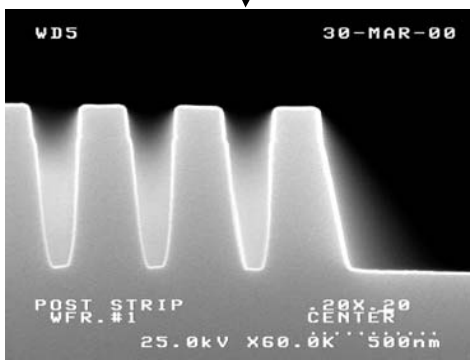
- Clean-2 eliminates all the wall deposits and prevents build up of deposition on the walls of the chamber.
- Clean-2 is suitable for this etching process.

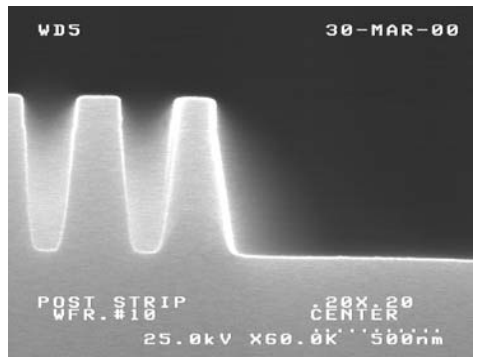


Shallow trench etch repeatablity

- Clean-2 eliminates all the wall 10 wafers etched with Cl_2/O_2 plasma with plasma cleaning of the walls in between each wafer i.e. Clean-2.
- Reproducible wall conditions ensured by the plasma clean: $Si_xO_yCl_z$ film is completely removed.
- Etch rate is very reproducible.
- However, close observation of the trench profiles show a subtle drift in the slope of the sidewalls.

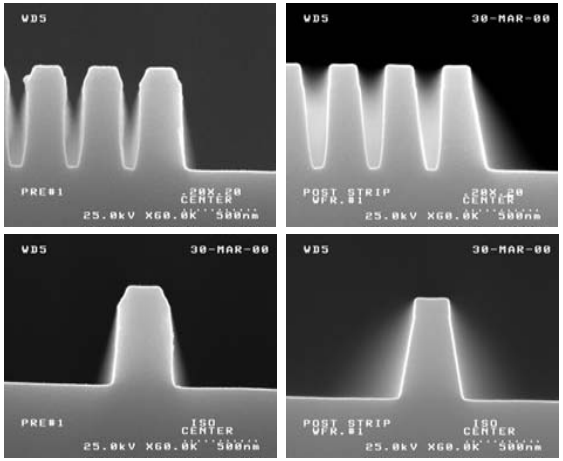






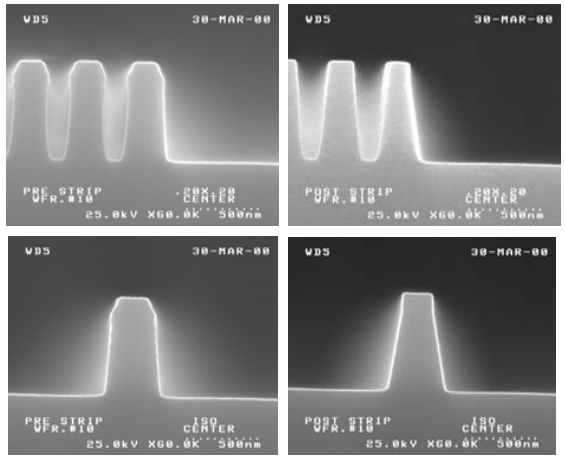
Etch Profile Drift

Wafer 1



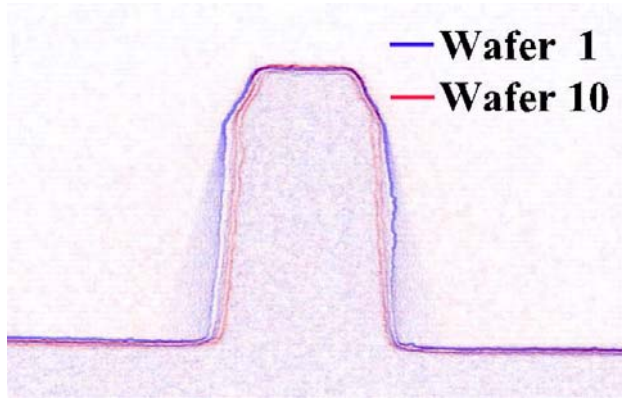
Pre-Strip Stripped

Wafer 10

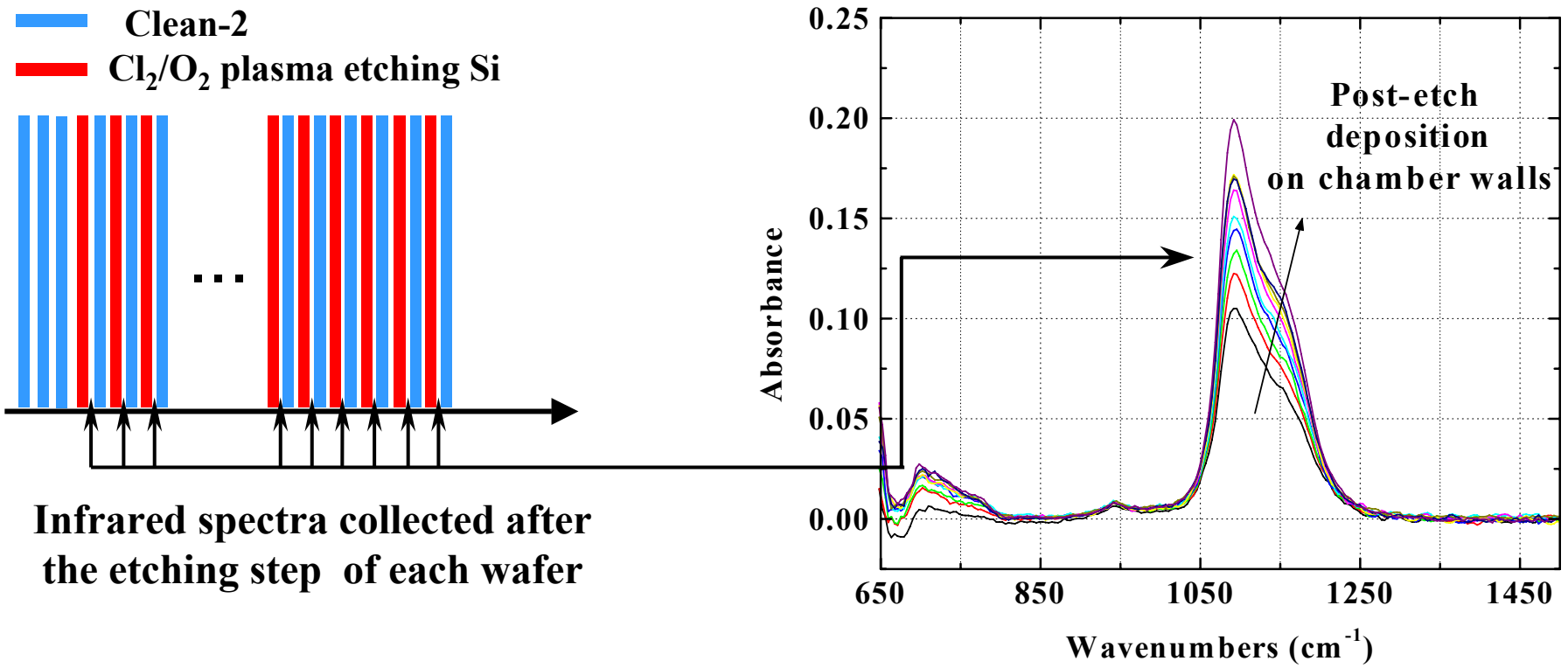


Pre-Strip Stripped

- Deposition on sidewalls of the trench decreases from wafer 1 to wafer 10

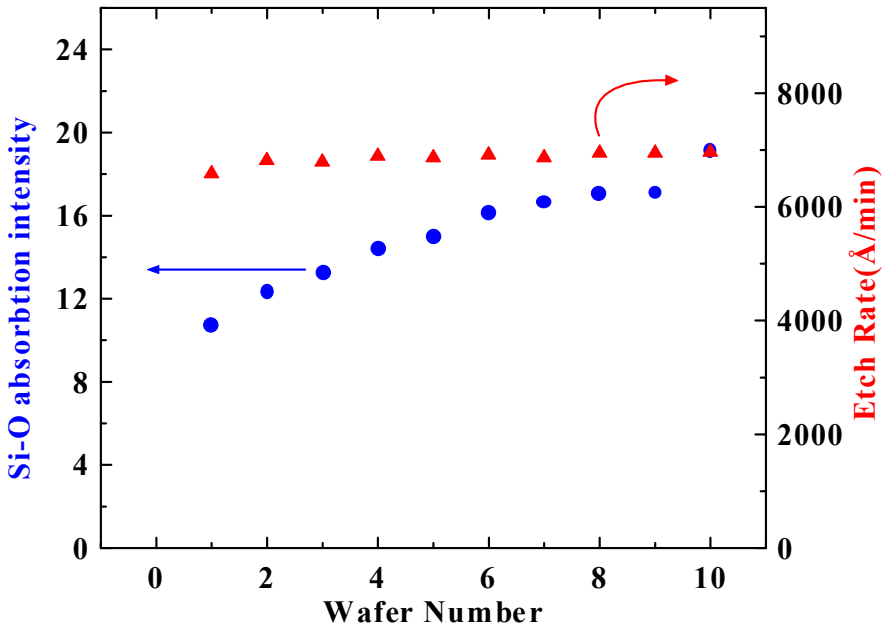


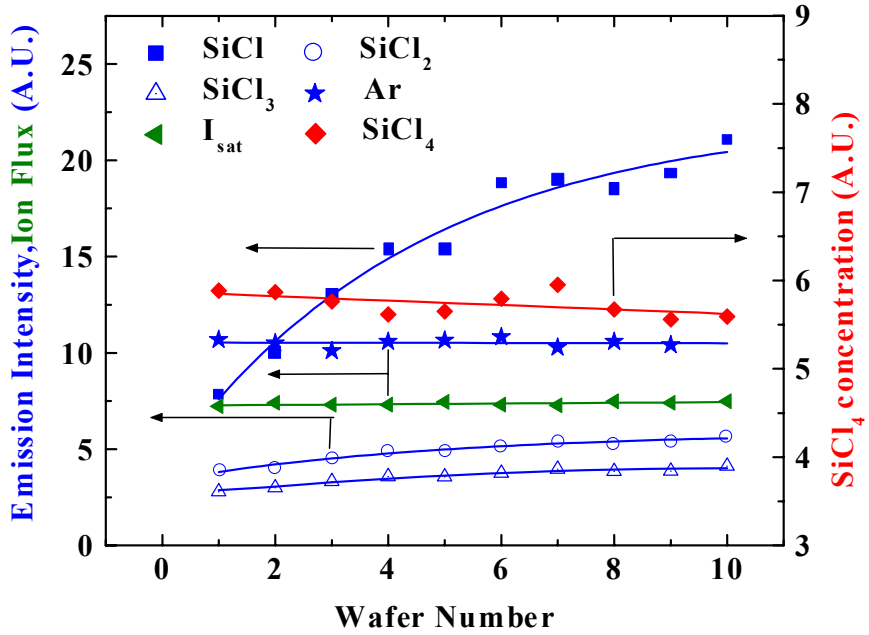
Monitoring wall deposition



- Chamber wall is clean before every wafer is etched i.e. Clean-2 removes all prior deposition from the chamber walls.
- Amount of deposition on chamber walls due to each wafer increases

Wafer to wafer drift in plasma properties

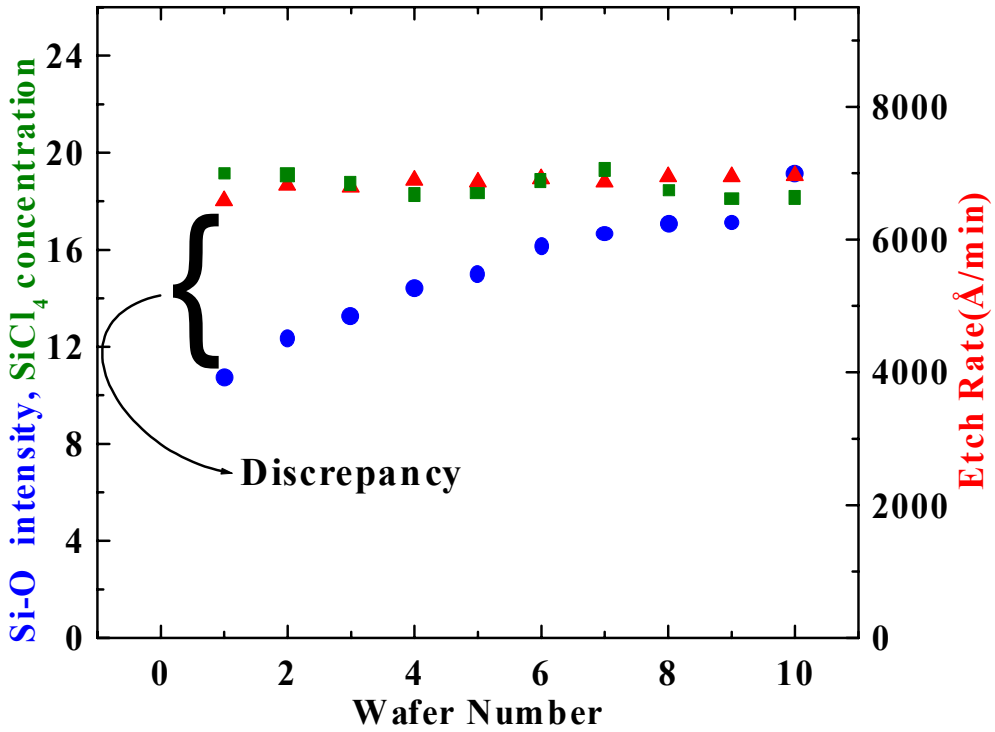




- With every successive wafer processed in the chamber
  - the amount of wall deposition due to each wafer increases;
  - etch rate and $SiCl_4$ concentration in reactor exhaust remain constant;
  - emissions from $SiCl_x$ etch products increase;
  - Ion density and Ar (750.4nm) emission remain constant;
    $\Rightarrow$ $SiCl_x$ concentration in gas phase increases.

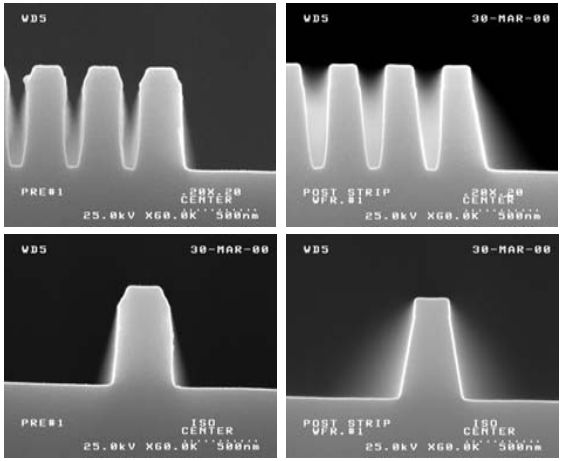
Decreasing deposition on the wafer

- Clean-2 Etch products generated either deposit on the surfaces exposed to the plasma or get pumped out of the chamber.
- E.R. constant ⇒ the amount of etch products generated is not changing.
- Downstream FTIR ⇒ $SiCl_4$ in the exhaust of the reactor does not change.
- MTIR-FTIR surface probe ⇒ the amount of wall deposition due to each wafer increases with every successive wafer processed.
- Etch product deposition on wafer decreases to be consistent with expected mass balance.



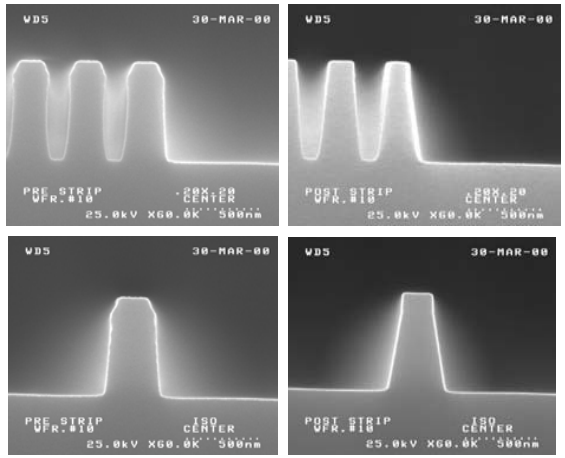
Etch Profile Drift

Wafer 1



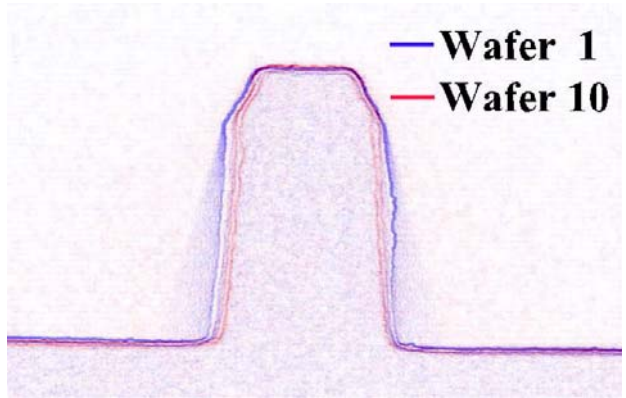
Pre-Strip Stripped

Wafer 10

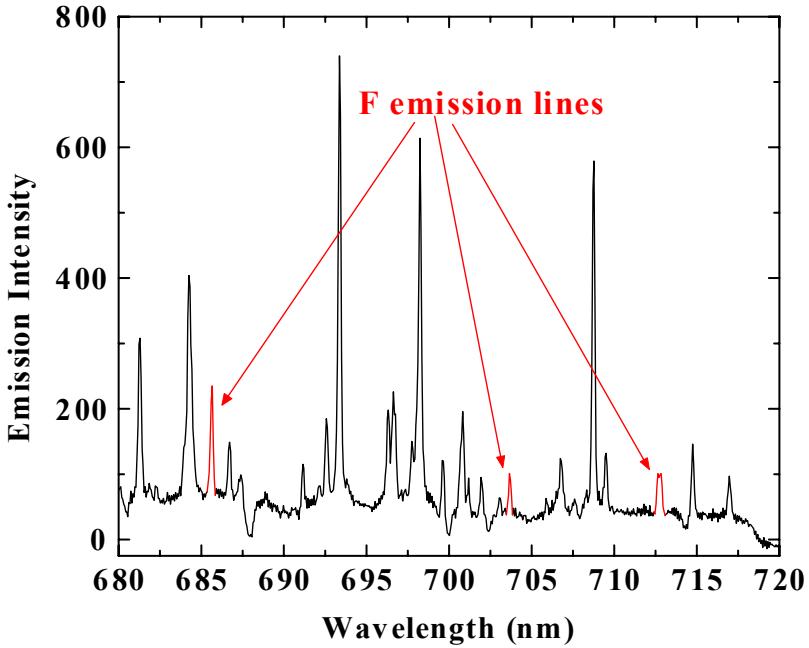


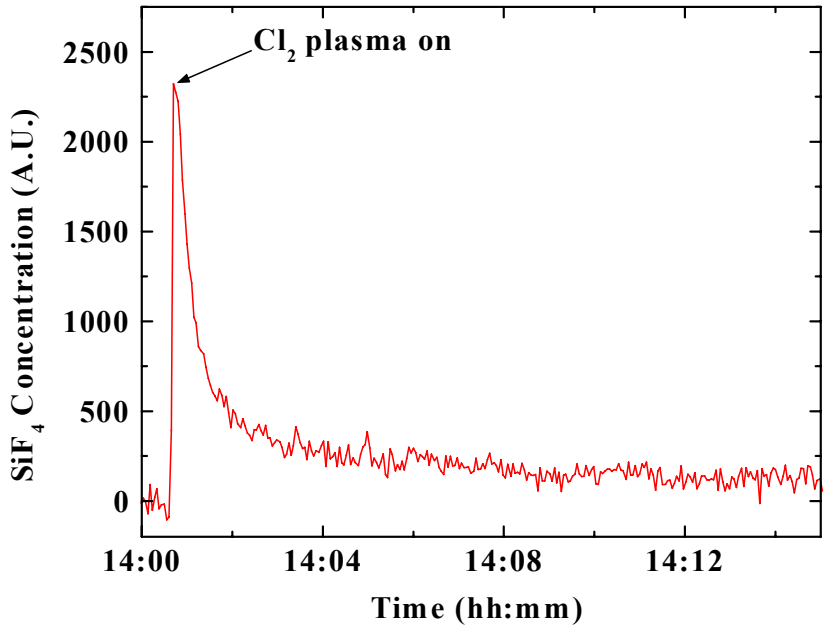
Pre-Strip Stripped

- Deposition on sidewalls of the trench decreases from wafer 1 to wafer 10



Residual Fluorine level in the plasma

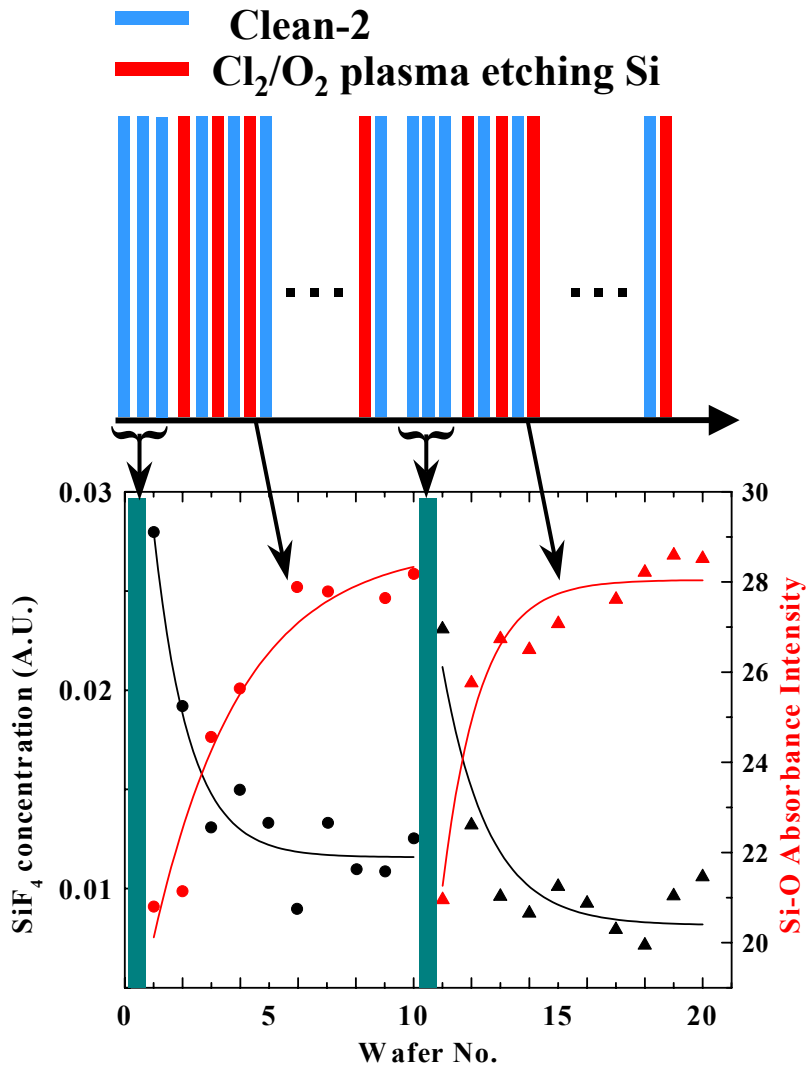




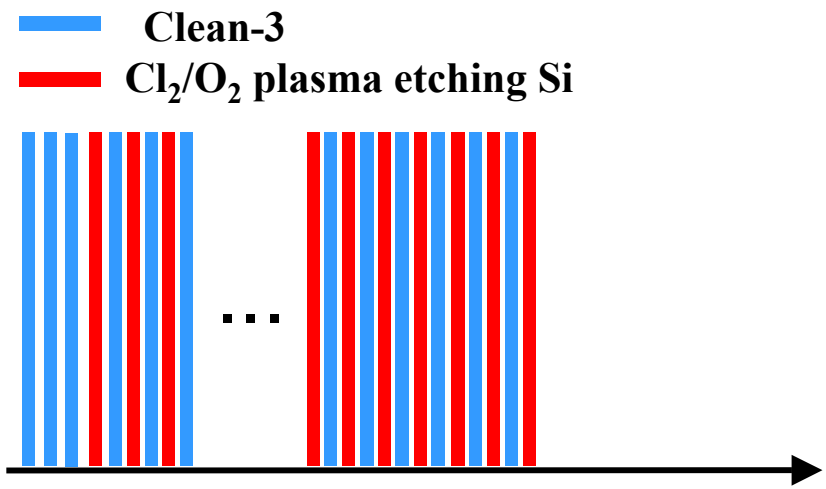
- SiF_4 is detected in the exhaust of the reactor; F emissions in the gas phase even though no fluorine containing species are introduced into the chamber.
- The decay in the SiF_4 concentration in the exhaust indicates that an exhaustible amount of fluorine is present in the reactor.
- F is liberated from reactor walls

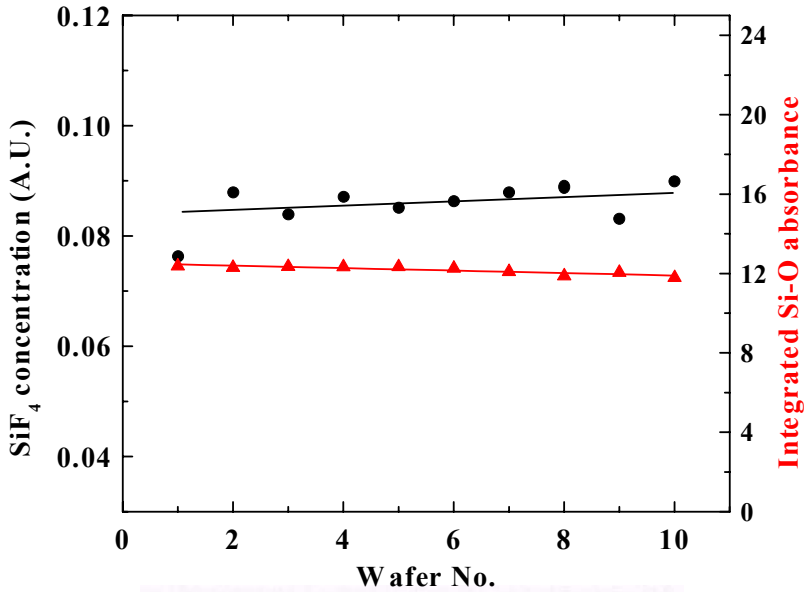
Wafer to wafer drift due to residual fluorine drift

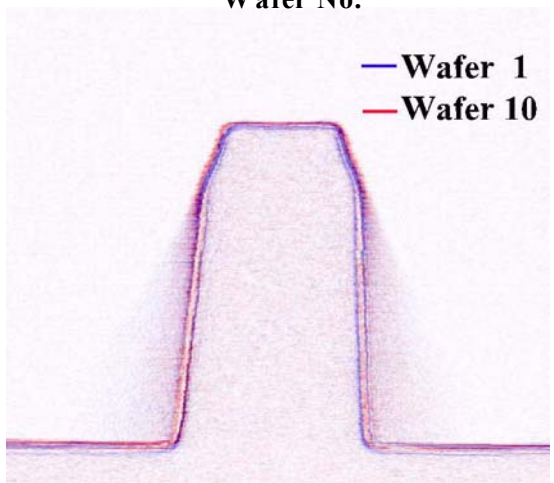
- Amount of SiF_4 in exhaust of the reactor indicates the residual Fluorine level in the chamber.
- More Fluorine is incorporated in the chamber when multiple un-optimized clean steps are run.
- Fluorine level in the chamber is not replenished to the same level by the succeeding Clean-2.
- Residual Fluorine level in the chamber decreases as more wafers are processed in the chamber and finally reaches a steady state.



Optimized WAC: No wafer to wafer drift







- Fluorine level in the chamber is replenished to the same level by the succeeding Clean-3's.
- Residual Fluorine level in the chamber is constant as more wafers are processed in the chamber.
- Deposition on the chamber wall is not changing.
- Deposition on the sidewalls of the trench is also invariant.

Chamber Condition changes due to Wet Cleans

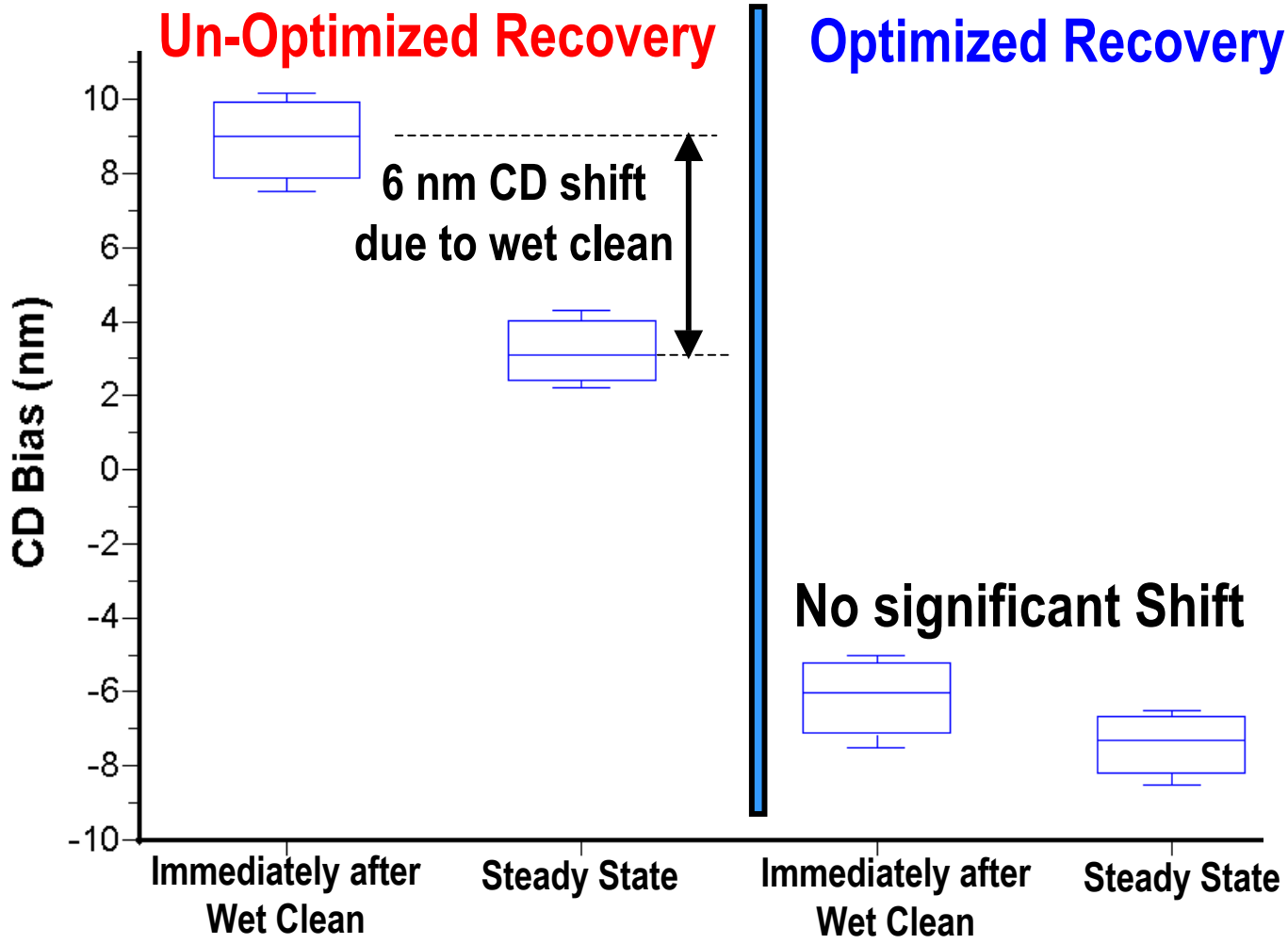
Wet Clean

- Wet clean are performed periodically on etch systems
- Wet clean can alter chamber condition due to introduction of moisture and other atmospheric species in the plasma chamber

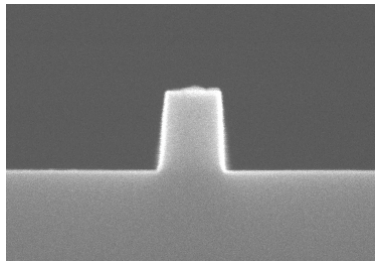
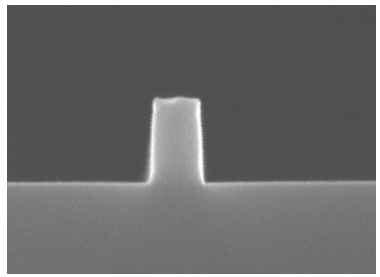
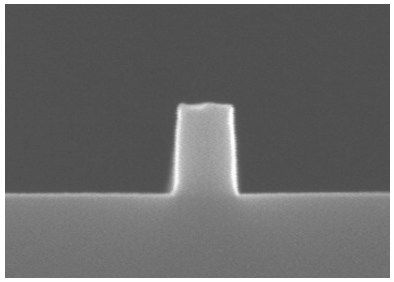
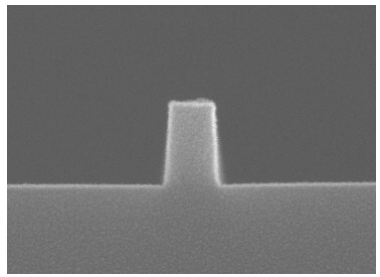
- Typically, few seasoning wafers are required to restore on-wafer performance after wet clean
  - Process dependent (usually not an issue)
  - 65nm and below technology node may require tighter control of CD after wet clean
  - WAC and recovery optimization may be required to control chamber condition after wet clean

Impact of Wet Clean and Recovery process on CD

- This particular etch process is very sensitive to chamber condition
  - Process stability?



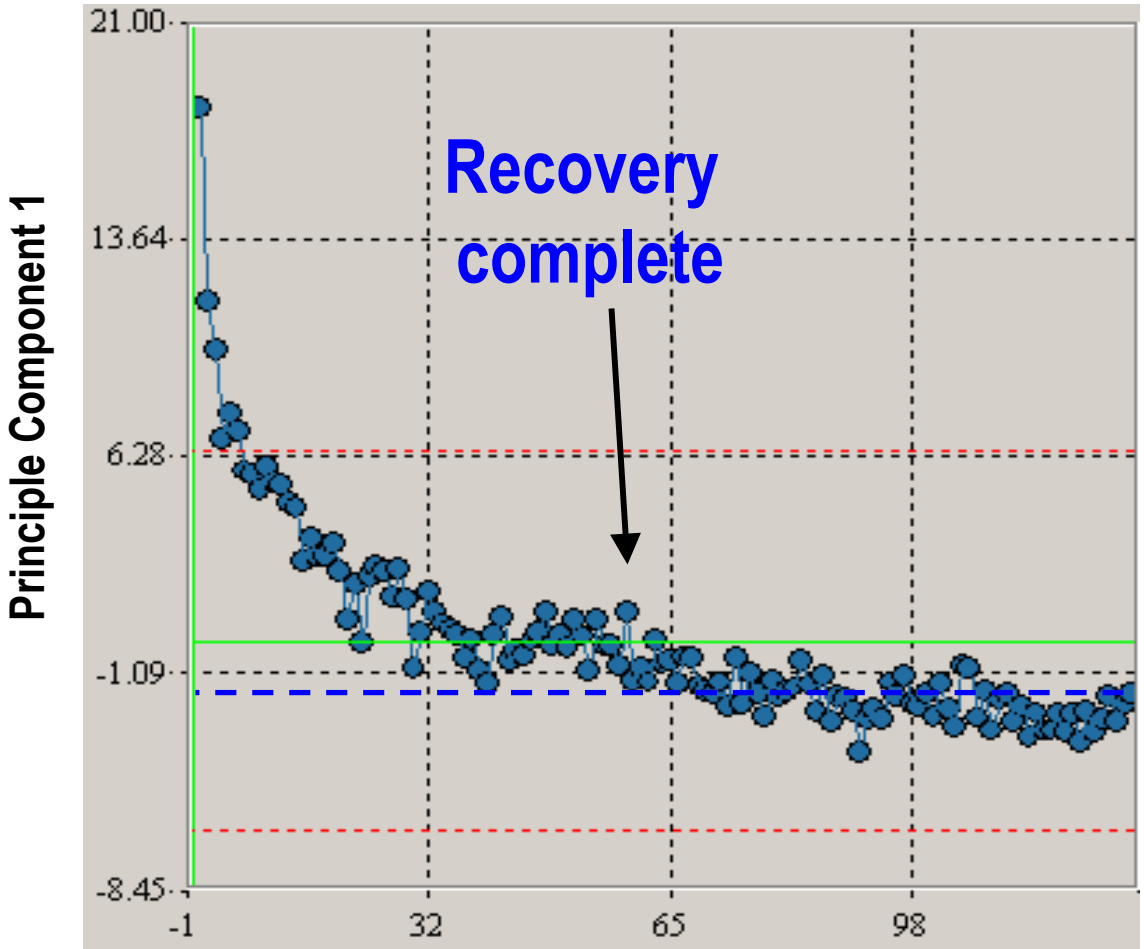
Impact of Wet Clean and Recovery process on Profile

	Un-Optimized Recovery	Optimized Recovery
Immediately after Wet Clean		
Steady State		

- Moisture may act as oxygen source

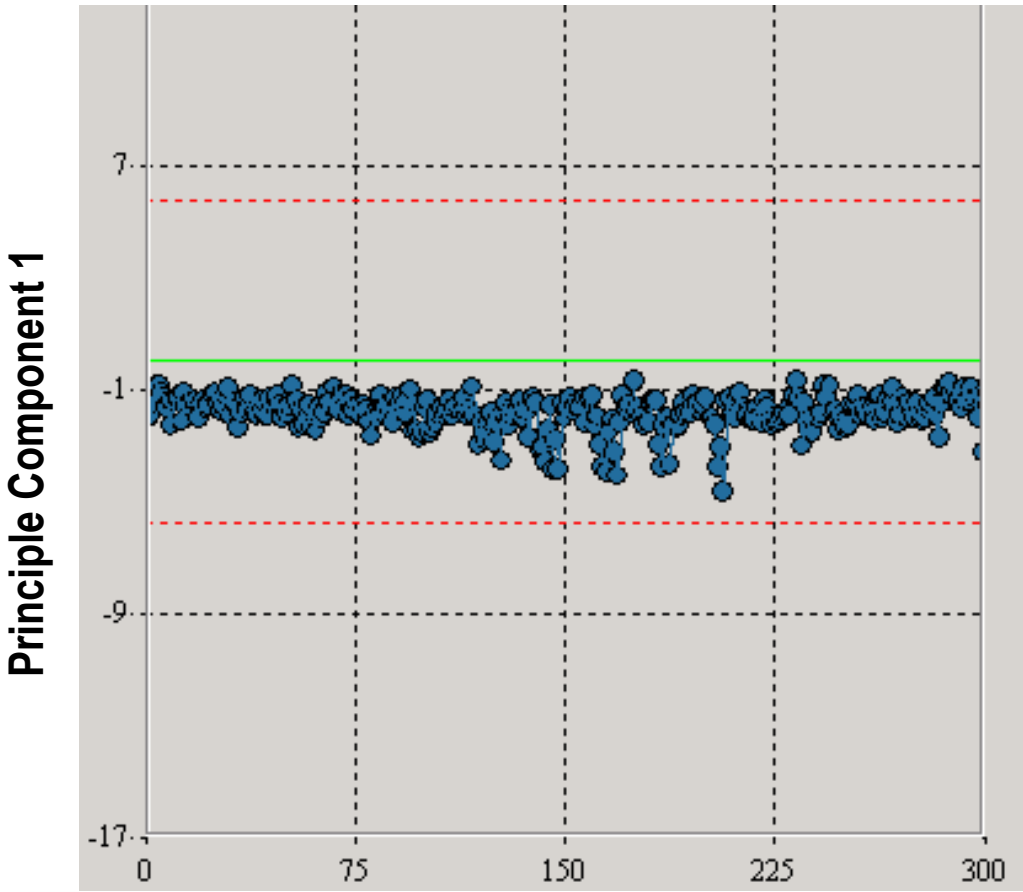
PCA shows small drift without optimized recovery after wet clean

- Drift in chamber condition not observed through other diagnostics
- Principle component analysis shows a slight drift in tool parameters over ~ 60 seasoning wafers after wet clean



No drift in tool condition with optimized recovery after wet clean

- Optimization of WAC results in no drift in tool parameters after wet clean



Summary

- Chamber condition control is critical for repeatable etch performance
  - Control of deposition on chamber walls
  - Control of reactive species on chamber walls (halogens, oxygen)

- Waferless Auto Cleans can be optimized to achieve repeatable chamber conditions
  - This will be essential as CD size continues to shrink