Enhanced Chamber Management and Fault Detection in Plasma Etch Processes via SEERS(Self Excited Electron Resonance Spectroscopy)

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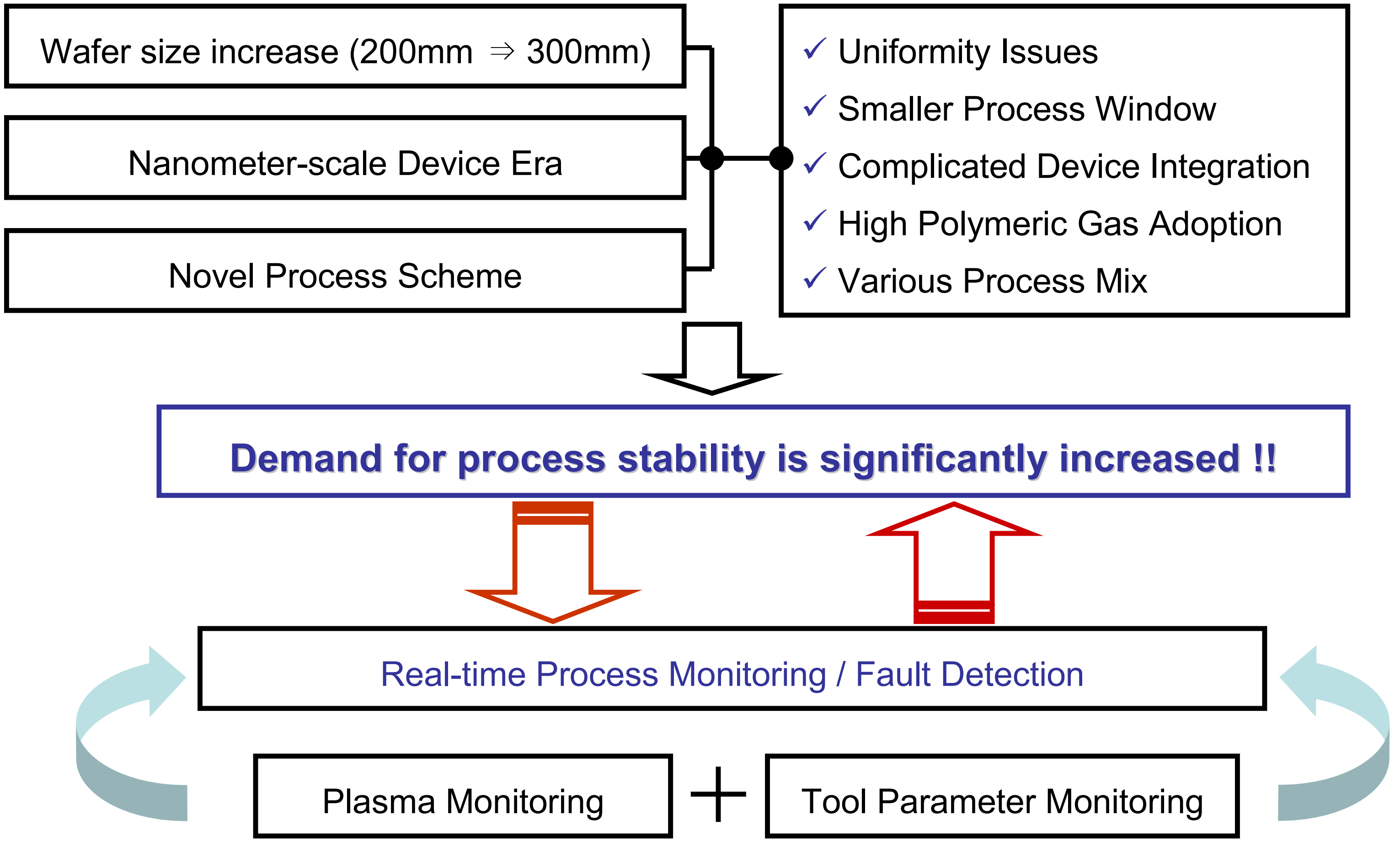
Outline

- **Background**
- **SEERS(Self Excited Electron Resonance Spectroscopy) ?**
- **Chamber and Process Monitoring through SEERS**
- **Minimization of Chamber Wall Condition Dependence**
- **Summary**

Background

- Why real-time process monitoring is necessary?



Wafer size increase (200mm ⇒ 300mm)

Nanometer-scale Device Era

Novel Process Scheme

- ✓ Uniformity Issues
- ✓ Smaller Process Window
- ✓ Complicated Device Integration
- ✓ High Polymeric Gas Adoption
- ✓ Various Process Mix

Demand for process stability is significantly increased !!

Real-time Process Monitoring / Fault Detection

Plasma Monitoring + Tool Parameter Monitoring

Why plasma monitoring is more effective than tool parameter monitoring?

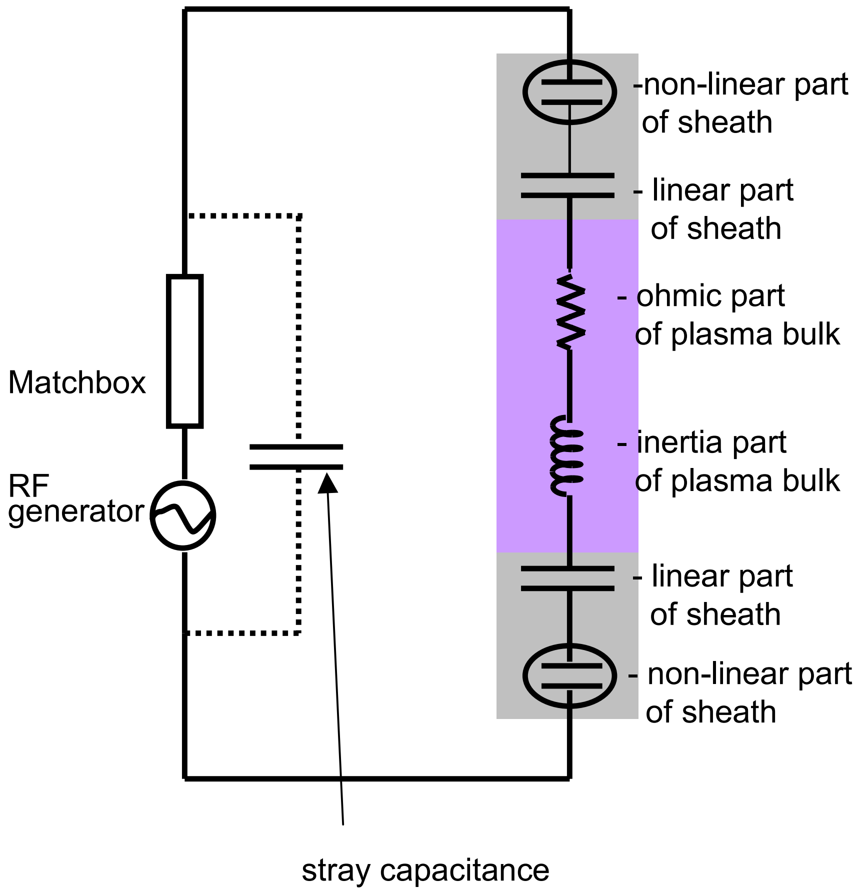
Background

- Some Plasma Monitoring Tools

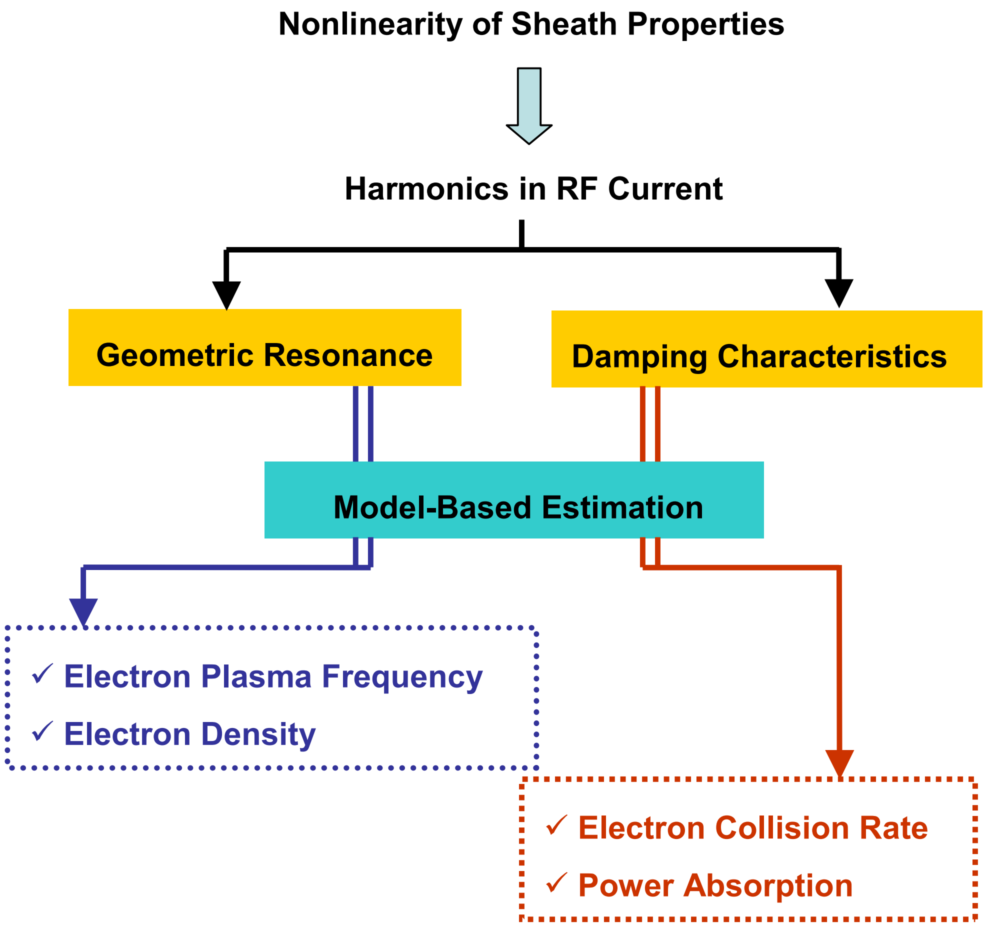
	Measurement	Main application	Advantage	Disadvantage	Comments
OES Optical Emission Spectroscopy	Relative emission intensities of excited species	Endpoint detection	Easy access via sight window Different species can be identified. Supports process development and analysis	Interpretation needs high level of knowledge Requires data compression due to large amount of data -> PCA(Principal Component Analysis) or …	Impact of chamber wall polymer Less than 10^{-4} of ground state density
SEERS Self Excited Electron Resonance Spectroscopy	RF current at chamber wall	Process monitoring	Provides real plasma parameters(electron density, collision rate…) Easy handling for process monitoring Supports process and chamber development	Needs access to chamber via passive sensor on ground potential Not available for all chamber types	No impact of chamber wall polymer Model based calculation
Impedance Monitor	RF voltage and current at matchbox	RF maintenance	Easy to understand Monitor truly transferred power to plasma Supports chamber development and analysis	Provides only fundamental or some harmonics Less relation to plasma	No impact of chamber wall polymer

SEERS(Self Excited Electron Resonance Spectroscopy)

- SEERS(Self Excited Electron Resonance Spectroscopy)?



Equivalent Electric Circuit of Plasma Reactor



Nonlinearity of Sheath Properties

Harmonics in RF Current

Geometric Resonance

Damping Characteristics

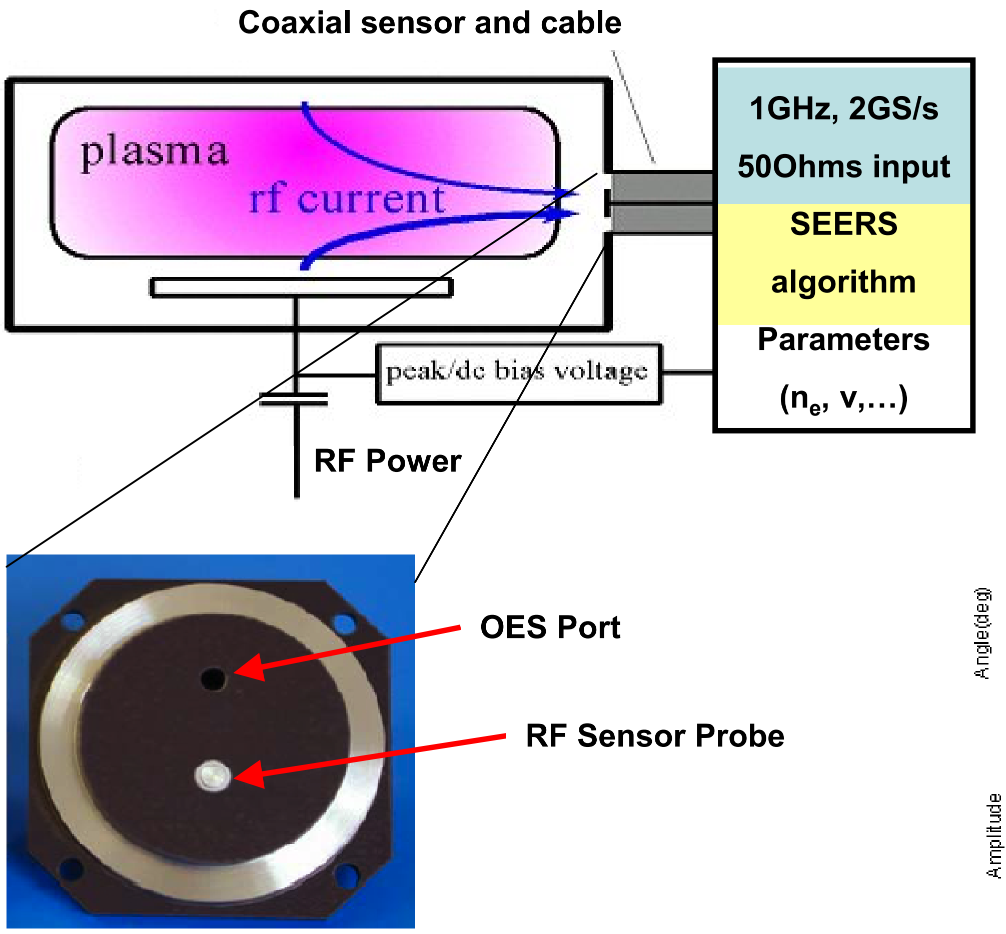
Model-Based Estimation

- ✓ **Electron Plasma Frequency**
- ✓ **Electron Density**

- ✓ **Electron Collision Rate**
- ✓ **Power Absorption**

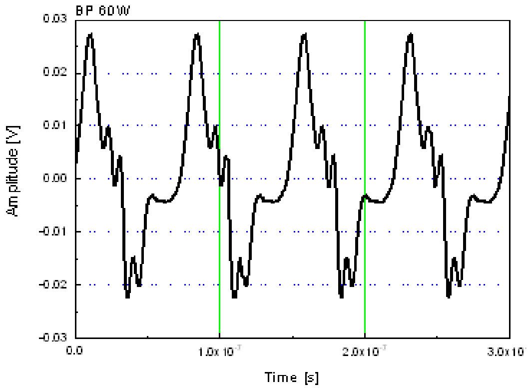
SEERS(Self Excited Electron Resonance Spectroscopy)

- Basic Set-up for SEERS

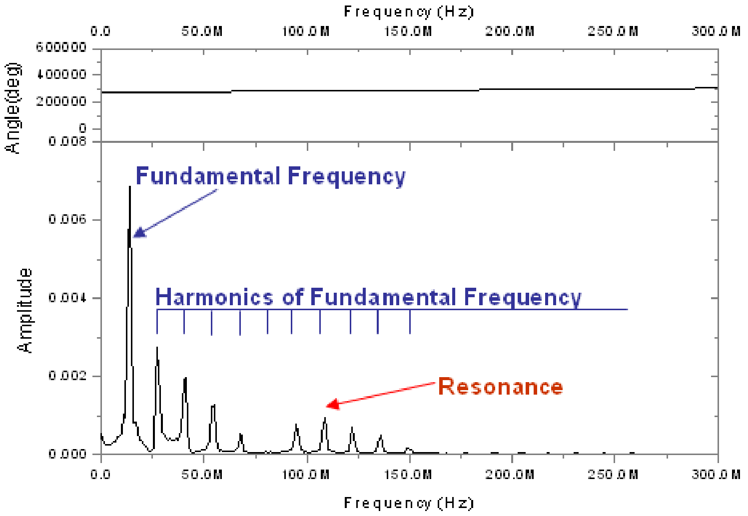


Viewport modified for SEERS

Measured RF Current

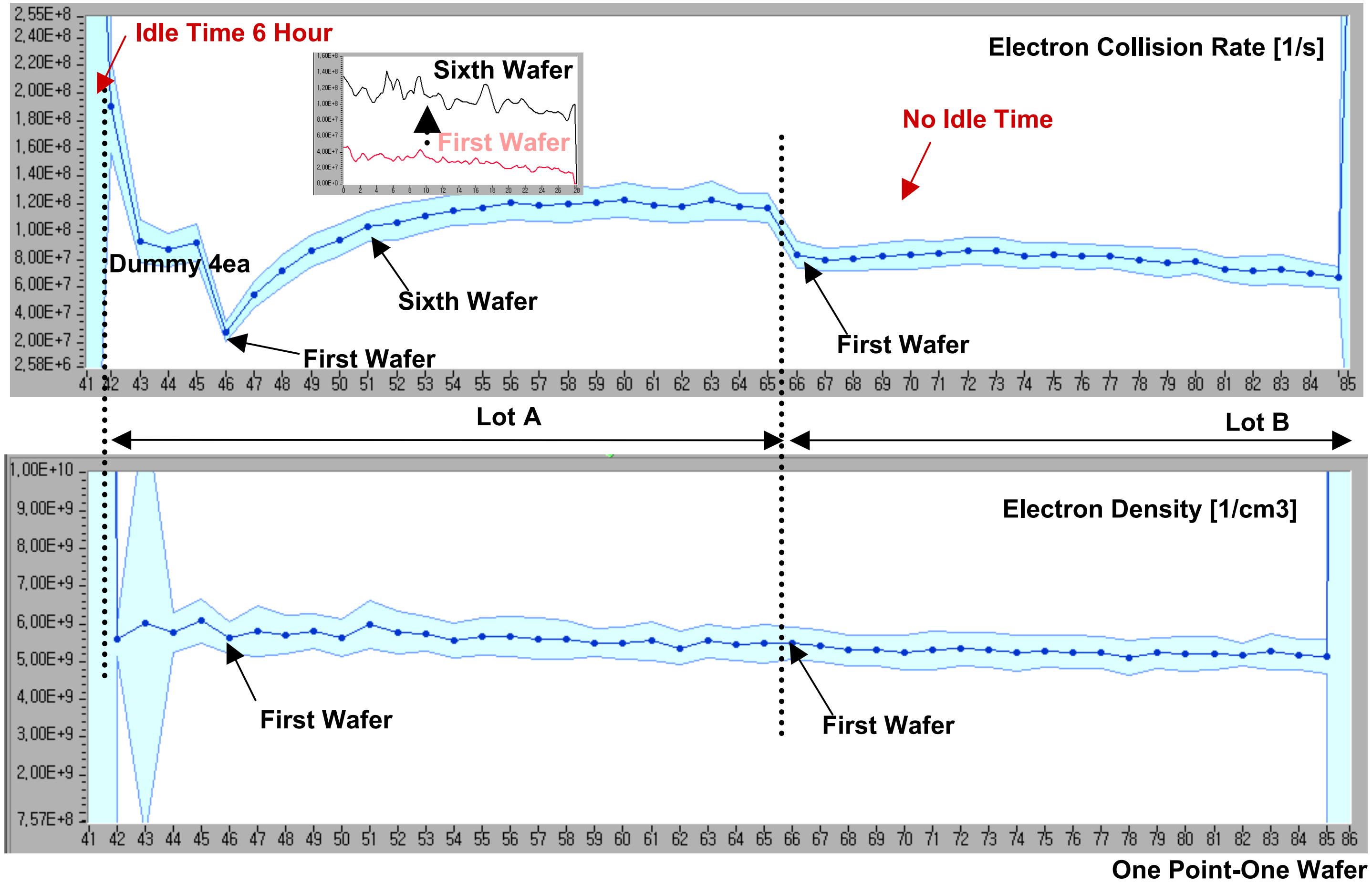


FFT



SEERS(Self Excited Electron Resonance Spectroscopy)

- Electron Collision Rate vs. Electron Density : Effects of Chamber Idle Time



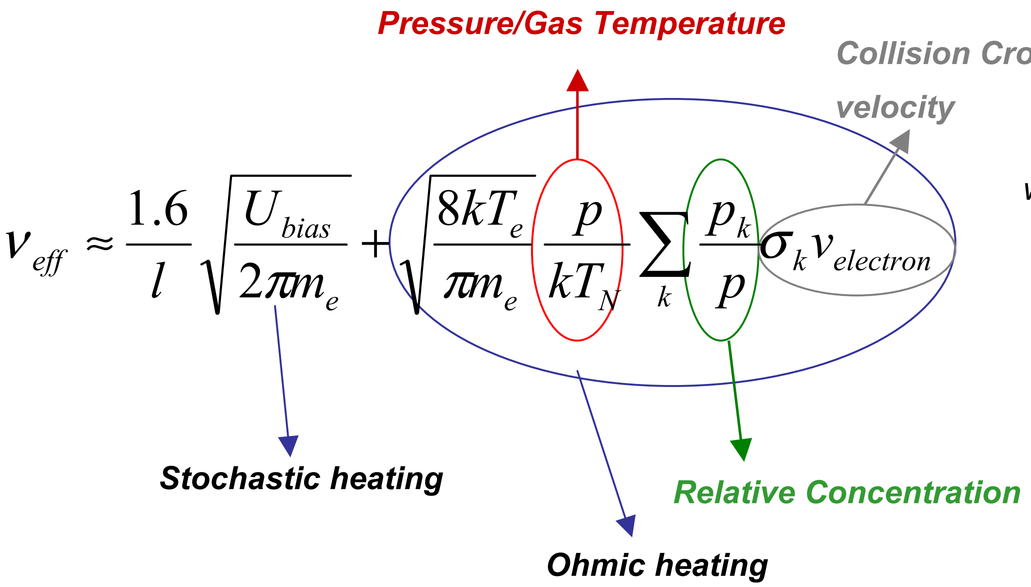
Electron collision rate is a more sensitive indicator for process drift!!

SEERS(Self Excited Electron Resonance Spectroscopy)

- Physical Backgrounds to Electron Collision Rate

Electron Collision Rate ?

- *Depends on the neutral's density.*
- *Depends on power and gas mixture.*
- *Impact of electrons on chemistry via heating.*
- *Feedback from chemistry via cross sections and relative concentration of species.*



Pressure/Gas Temperature

Collision Cross-section x Thermal velocity

$$\nu_{eff} \approx \frac{1.6}{l}\sqrt{\frac{U_{bias}}{2\pi m_e}} + \sqrt{\frac{8kT_e}{\pi m_e}}\frac{p}{kT_N}\sum_k \frac{p_k}{p}\sigma_k v_{electron}$$

Stochastic heating

Relative Concentration

Ohmic heating

with U_{bias} : DC bias, l : plasma length

p : total pressure,

p_k, σ_k : partial pressure, cross section of gas k

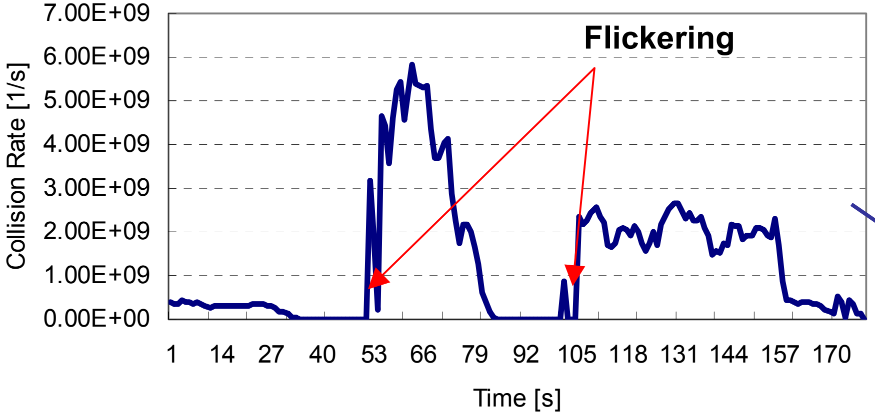
T_N : gas temperature

Electron collision rate can be an universal index of plasma process !!

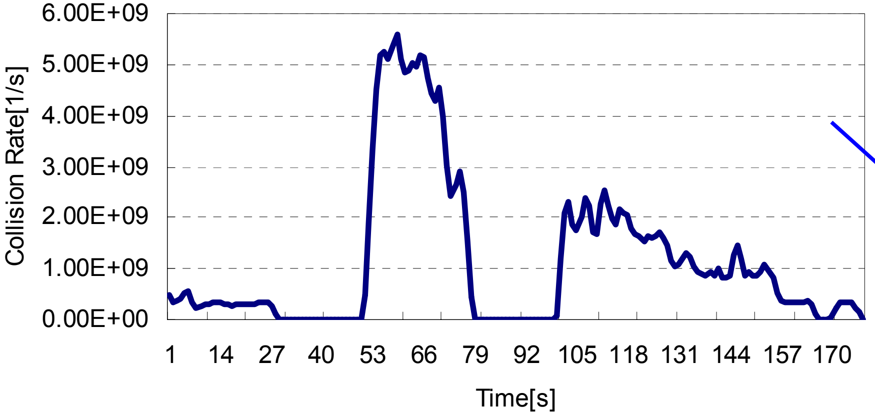
Chamber and Process Monitoring through SEERS

- Detection of Extremely Small Changes in Chamber

Lot A

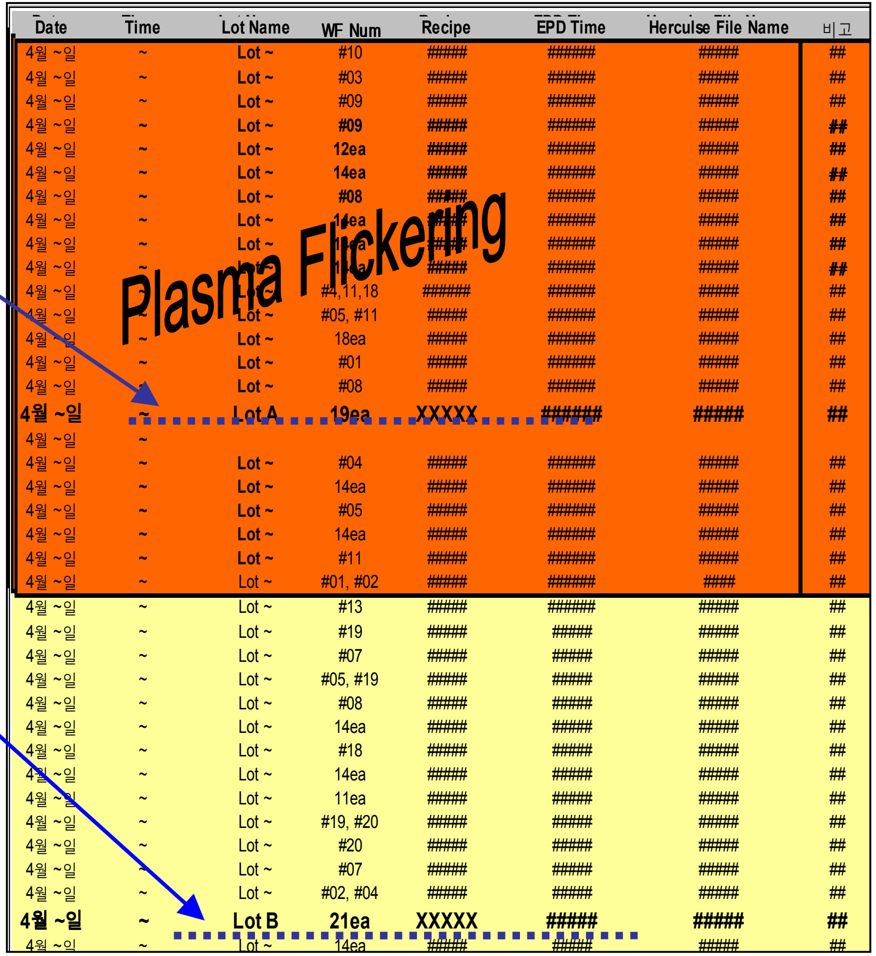


Lot B



Time-resolved collision rate data for different chamber conditions

After Wet Cleaning



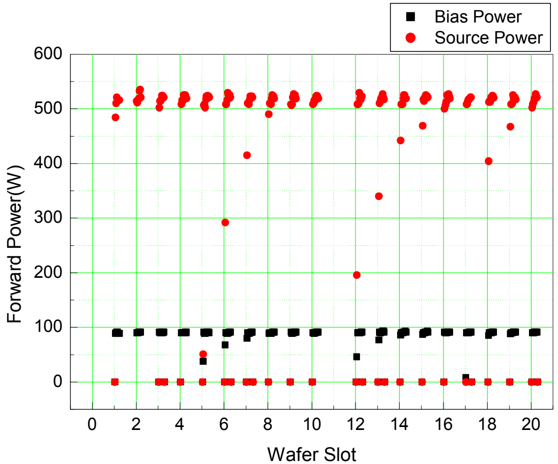
Date	Time	Lot Name	WF Num	Recipe	EPD Time	Herculse File Name	비고
4월 ~일	~	Lot ~	#10	#####	######	#####	##
4월 ~일	~	Lot ~	#03	#####	######	#####	##
4월 ~일	~	Lot ~	#09	#####	######	#####	##
4월 ~일	~	Lot ~	#09	#####	######	#####	##
4월 ~일	~	Lot ~	12ea	#####	######	#####	##
4월 ~일	~	Lot ~	14ea	#####	######	#####	##
4월 ~일	~	Lot ~	#08	#####	######	#####	##
4월 ~일	~	Lot ~	14ea	#####	######	#####	##
4월 ~일	~	Lot ~	[illegible]	#####	######	#####	##
4월 ~일	~	Lot ~	[illegible]	#####	######	#####	##
4월 ~일	~	Lot ~	#4,11,18	######	######	#####	##
4월 ~일	~	Lot ~	#05, #11	#####	######	#####	##
4월 ~일	~	Lot ~	18ea	#####	######	#####	##
4월 ~일	~	Lot ~	#01	#####	######	#####	##
4월 ~일	~	Lot ~	#08	#####	######	#####	##
4월 ~일	**~**	**Lot A**	**19ea**	**XXXXX**	**######**	**#####**	**##**
4월 ~일	~						
4월 ~일	~	Lot ~	#04	#####	######	#####	##
4월 ~일	~	Lot ~	14ea	#####	######	#####	##
4월 ~일	~	Lot ~	#05	#####	######	#####	##
4월 ~일	~	Lot ~	14ea	#####	######	#####	##
4월 ~일	~	Lot ~	#11	#####	######	#####	##
4월 ~일	~	Lot ~	#01, #02	#####	######	####	##
4월 ~일	~	Lot ~	#13	#####	######	#####	##
4월 ~일	~	Lot ~	#19	#####	#####	#####	##
4월 ~일	~	Lot ~	#07	#####	#####	#####	##
4월 ~일	~	Lot ~	#05, #19	#####	#####	#####	##
4월 ~일	~	Lot ~	#08	#####	#####	#####	##
4월 ~일	~	Lot ~	14ea	#####	#####	#####	##
4월 ~일	~	Lot ~	#18	#####	#####	#####	##
4월 ~일	~	Lot ~	14ea	#####	#####	#####	##
4월 ~일	~	Lot ~	11ea	#####	#####	#####	##
4월 ~일	~	Lot ~	#19, #20	#####	#####	#####	##
4월 ~일	~	Lot ~	#20	#####	#####	#####	##
4월 ~일	~	Lot ~	#07	#####	#####	#####	##
4월 ~일	~	Lot ~	#02, #04	#####	#####	#####	##
4월 ~일	**~**	**Lot B**	**21ea**	**XXXXX**	**#####**	**#####**	**##**
4월 ~일	~	Lot ~	14ea	#####	#####	#####	##

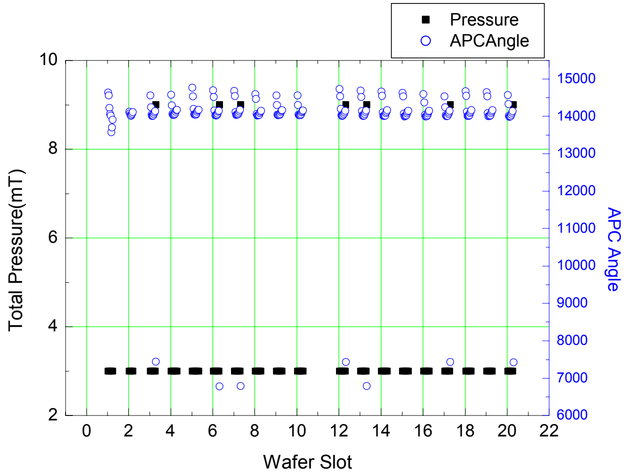
Chamber History

Chamber and Process Monitoring through SEERS

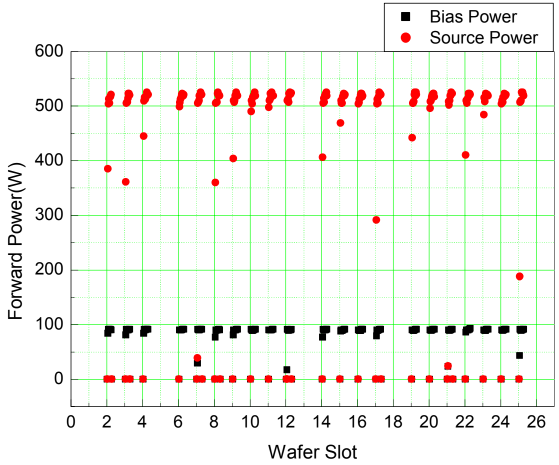
- Some Tool Parameter Data During Main Etch for Lot A and B

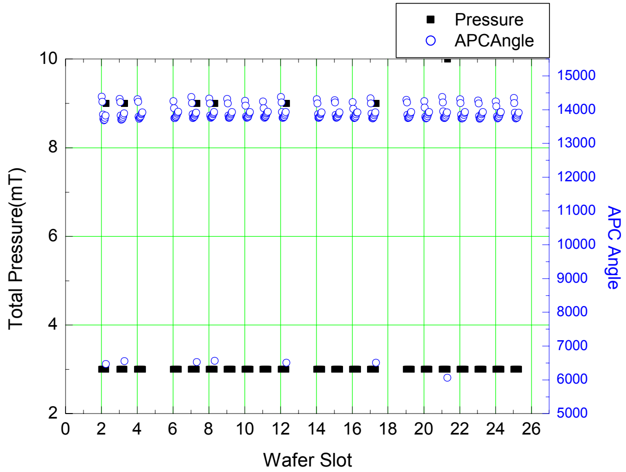
Lot A





Lot B



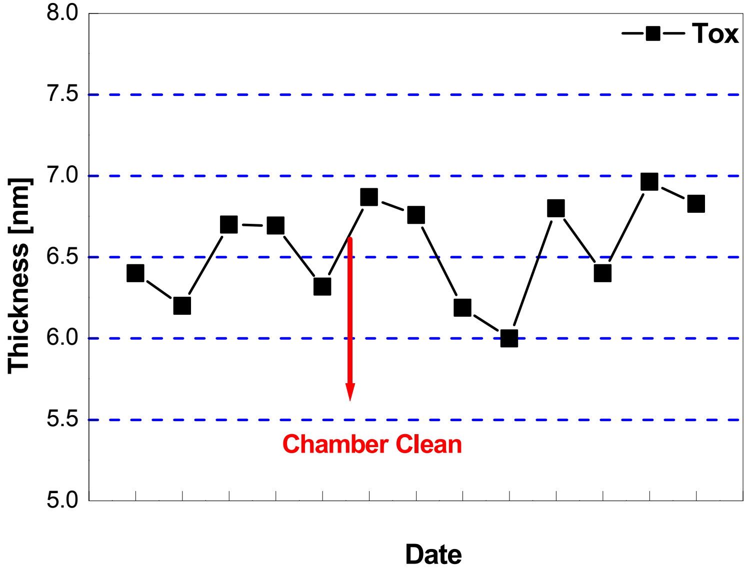


No Particular Event in Tool Parameters Except for Scattered Points!!

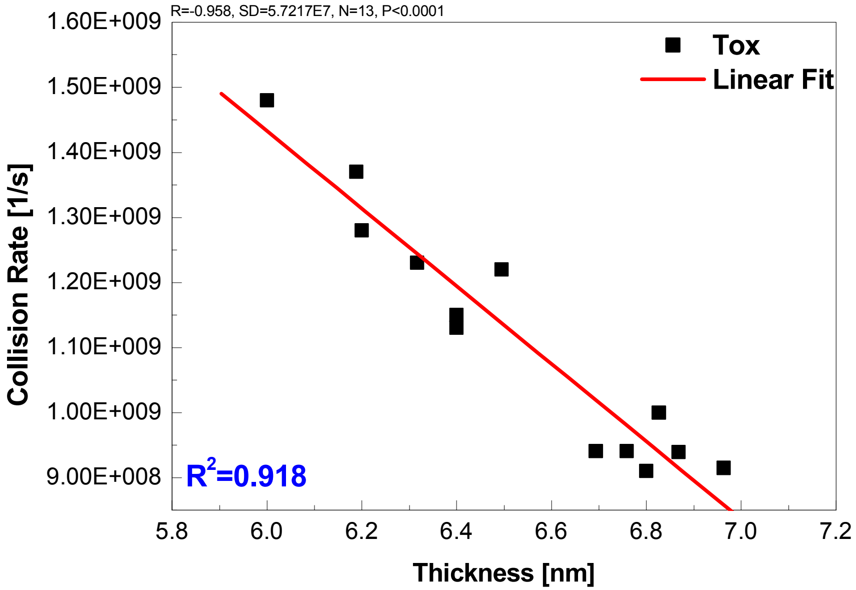
* Scattered Points : Data Acquisition Problem.

Chamber and Process Monitoring through SEERS

- Remain Oxide Thickness after Gate Etch



Thickness Variations vs. Date



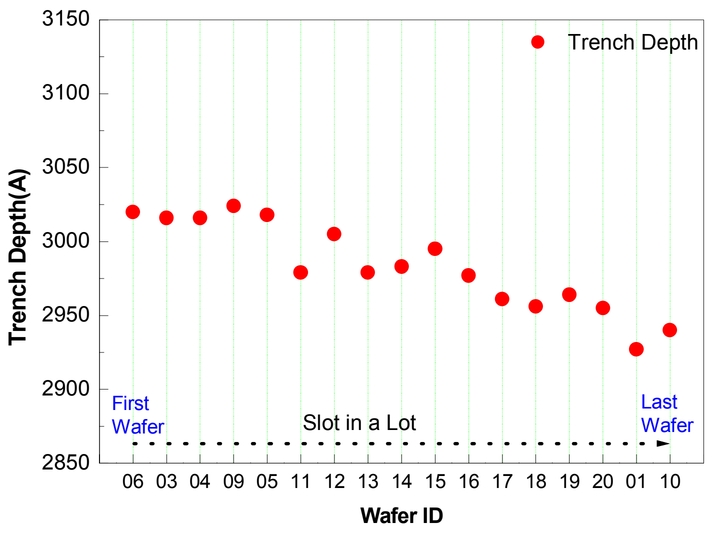
Thickness Variations vs. Collision Rate

Electron collision rate explains trends of thickness !!

⇒ Give us Two Benefits ; Thickness Data for All Wafers, Tight Process Control

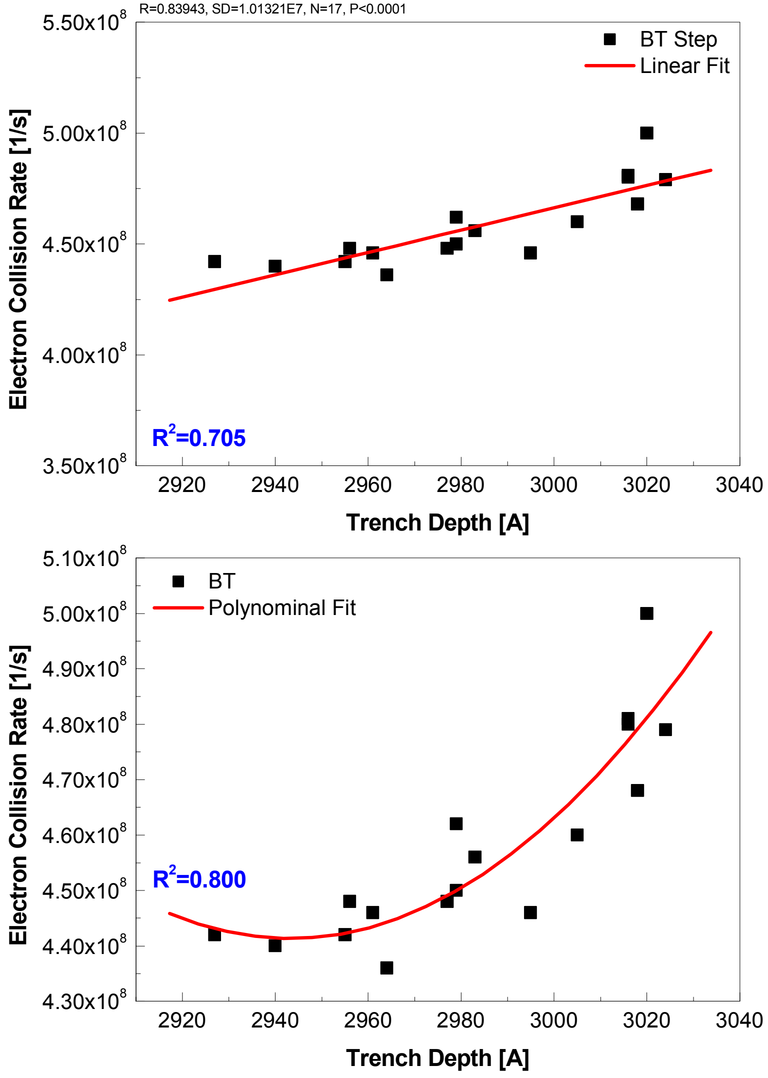
Chamber and Process Monitoring through SEERS

- Trench Depth Variation within a Lot



- Trench Depth Variation within a Lot.

A correlation between electron collision rate and trench depth is a bit high !!



- Electron Collision Rate of BT Step vs. Trench Depth

Minimization of Chamber Wall Condition Dependence

- Current Situations of Chamber A

Major Etching Gas Chemistry :

- **HBr/O2/Cl2 Chemistry :**

Total Pressure : 50mT

xHBr/yCl2/zO2 Chemistry : Higher HBr Condition

**x`HBr**/y`Cl2/z`O2 Chemistry :

**x``HBr**/y``Cl2/z``O2 Chemistry :

x```HBr/y``Cl2/z```O2 Chemistry : Lower HBr Condition

- **HBr/O2 Chemistry :**

Total Pressure : 30mT

aHBr/bO2 Chemistry : Higher HBr Condition

aHBr/b'O2 Chemistry : Higher HBr Condition

a'HBr/bO2 Chemistry : Lower HBr Condition

* CF6/Ar chemistry for breakthrough step is common!!

Chamber Maintenance :

- Manual Dry Cleaning According to RF Time.
- Before starting main lot, dummy wafers for conditioning are employed.
- In case of some devices, manual dry cleaning is also employed.
- Wet Cleaning Cycle : Around 25 Hour of RF Time
- Criteria for Starting Process after Wet Cleaning : Etch Rate, Particle Number After Chamber Conditioning.

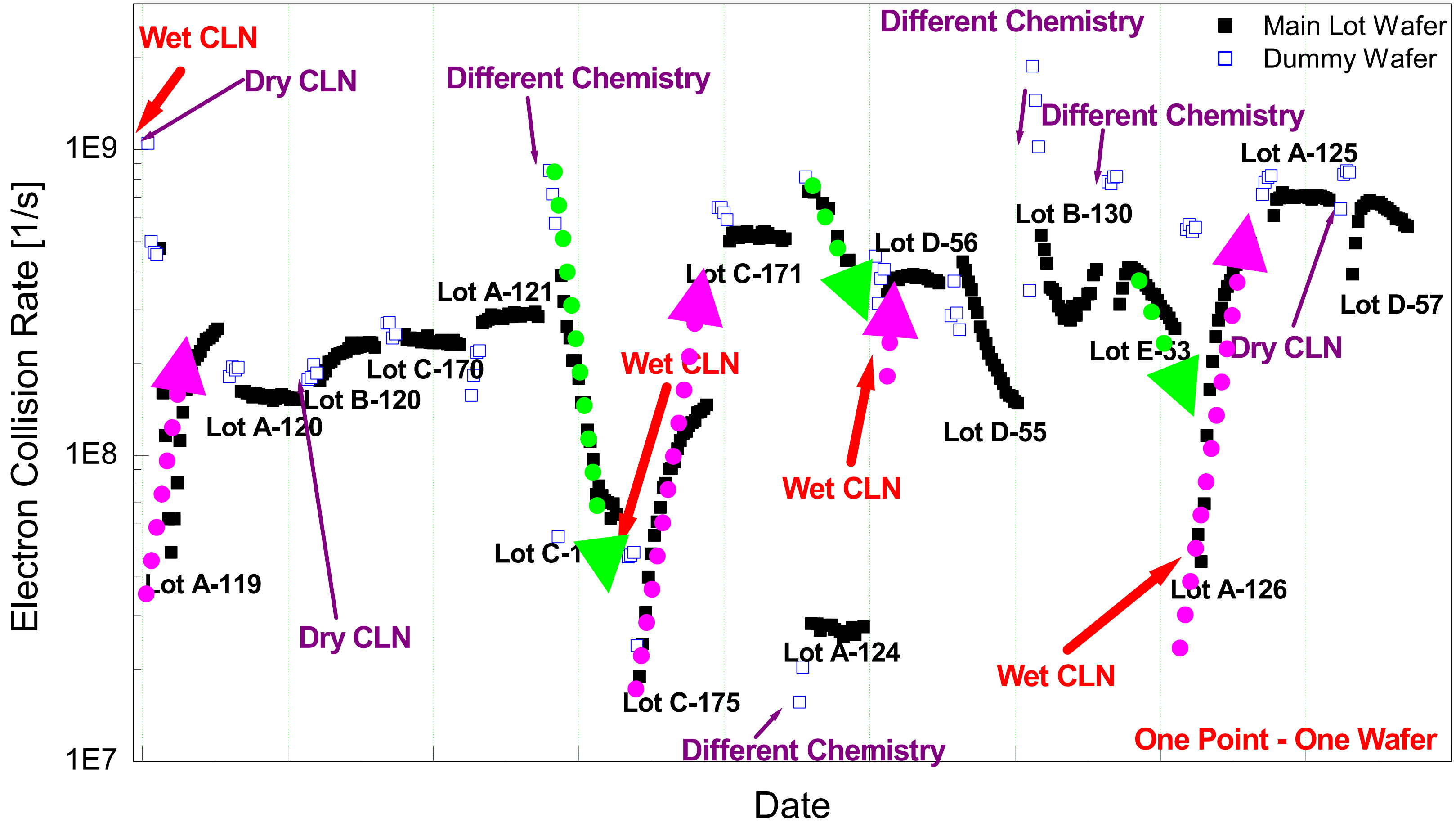
** Dry Cleaning Condition : HBr+Cl2+O2+SF6 Chemistry, Chamber Conditioning : HBr+Cl2+O2 Chemistry.*

Current Issues :

Strong Chamber Wall Condition Dependence, Heavy Polymeric Particle Issues

Minimization of Chamber Wall Condition Dependence

- Monitoring of Device A

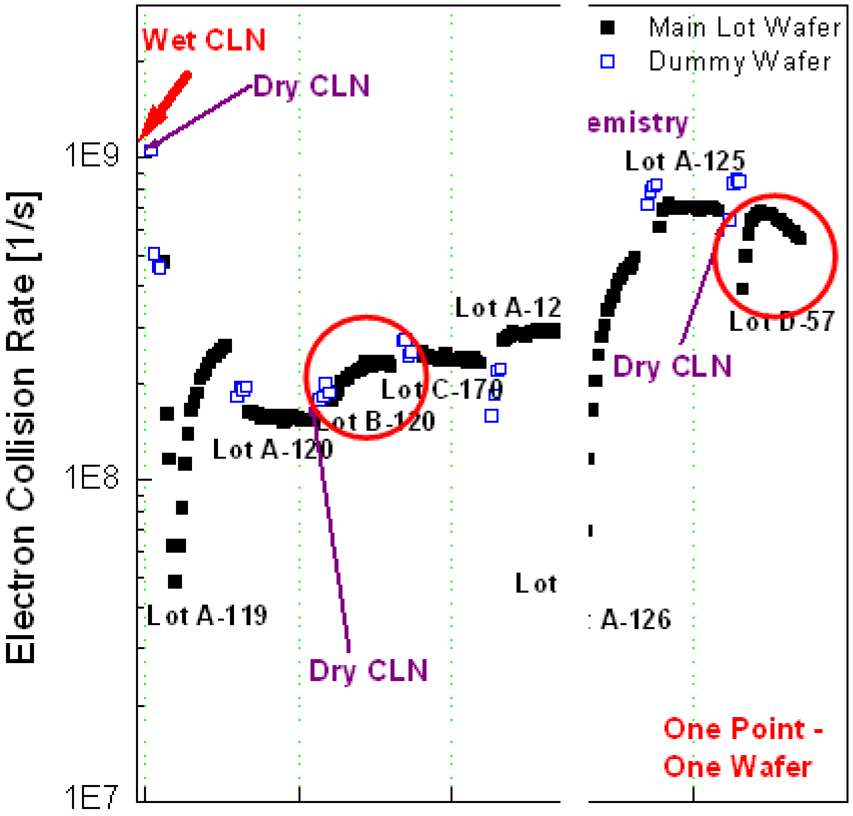


- **After wet-cleaning, collision rates of the lot are gradually going up. : Light Pink Arrows.**
- **Right before wet-cleaning, collision rates of the lot are going down. : Light Green Arrows.**

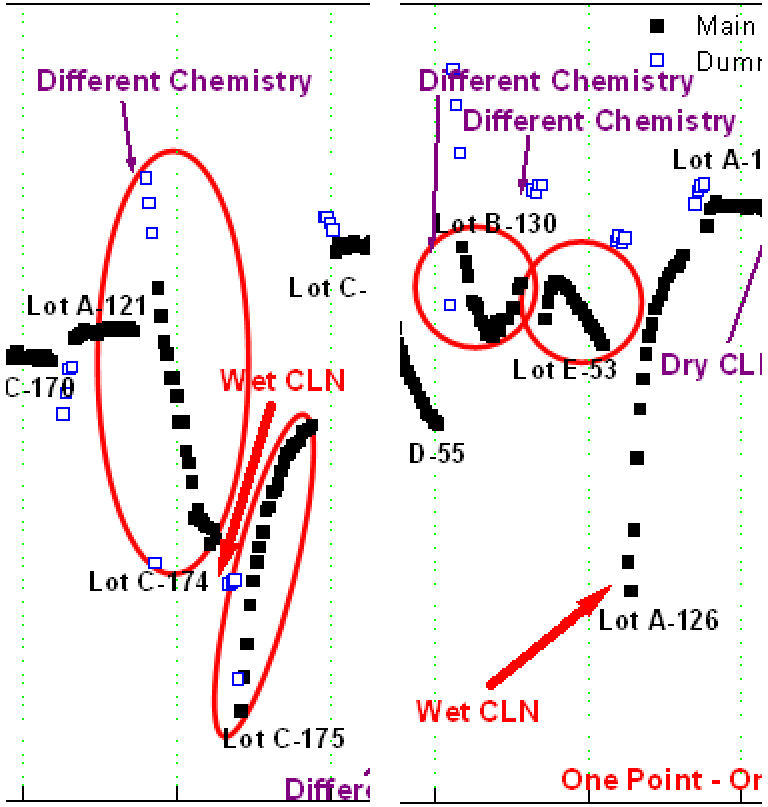
Minimization of Chamber Wall Condition Dependence

- Monitoring of Device A

Effects of Dry Cleaning Process



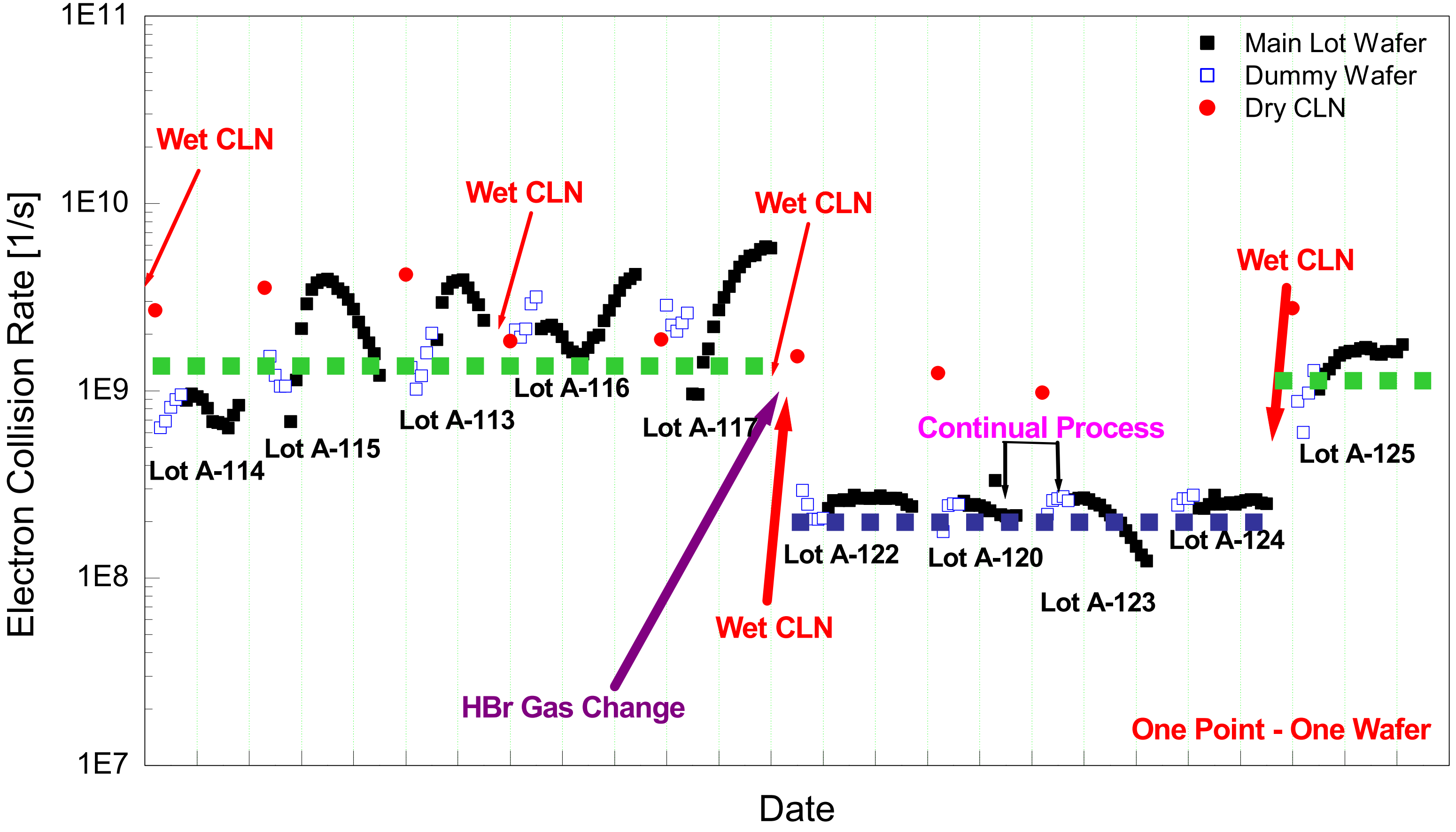
Effects of Different Chemistries



Dry cleaning or different chemistries seems to change the chamber wall conditions a lot. So, it takes several wafers to get back to normal conditions.

Minimization of Chamber Wall Condition Dependence

- Monitoring of Device B



- **Collision Rate Higher Than 1E9/sec : Unstable Period, Large Fluctuations**
- **Collision Rate lower than 4E8/sec : Stable Period, Straight Collision Rate Trends.**

What happened between these periods? Two Times Wet Cleaning, HBr Gas Change?

Minimization of Chamber Wall Condition Dependence

- Adoption of In-situ Chamber Cleaning

Situations in Chamber A

Previous Maintenance	Current Maintenance
▪ Manual Dry Cleaning According to RF Time. ▪ Dummy Wafers for conditioning. ▪ Wet Cleaning Cycle : Around 25 Hour of RF Time	▪ **In-situ Chamber Cleaning Every Wafer** ▪**Wet Cleaning Cycle : now Evaluating**

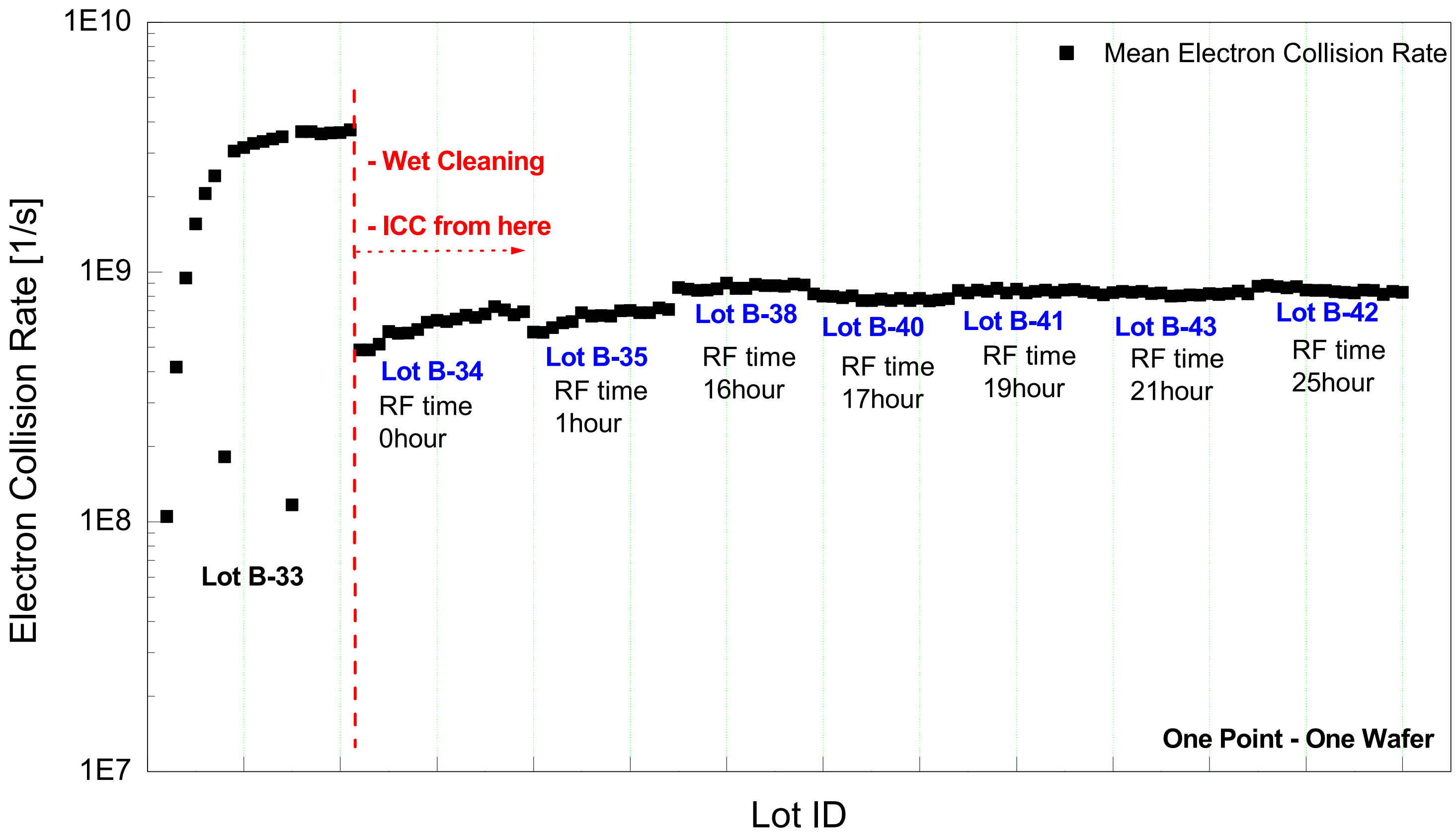
* *Dry Cleaning Condition : HBr+Cl2+O2+SF6 Chemistry, Chamber Conditioning : HBr+Cl2+O2 Chemistry.*

**** In-situ Chamber Cleaning (ICC) Condition : SF6 Chemistry***

In-situ chamber cleaning might give us benefits; Chamber can be kept clean and wafer-to-wafer(also lot-to-lot) variation can be minimized!!

Minimization of Chamber Wall Condition Dependence

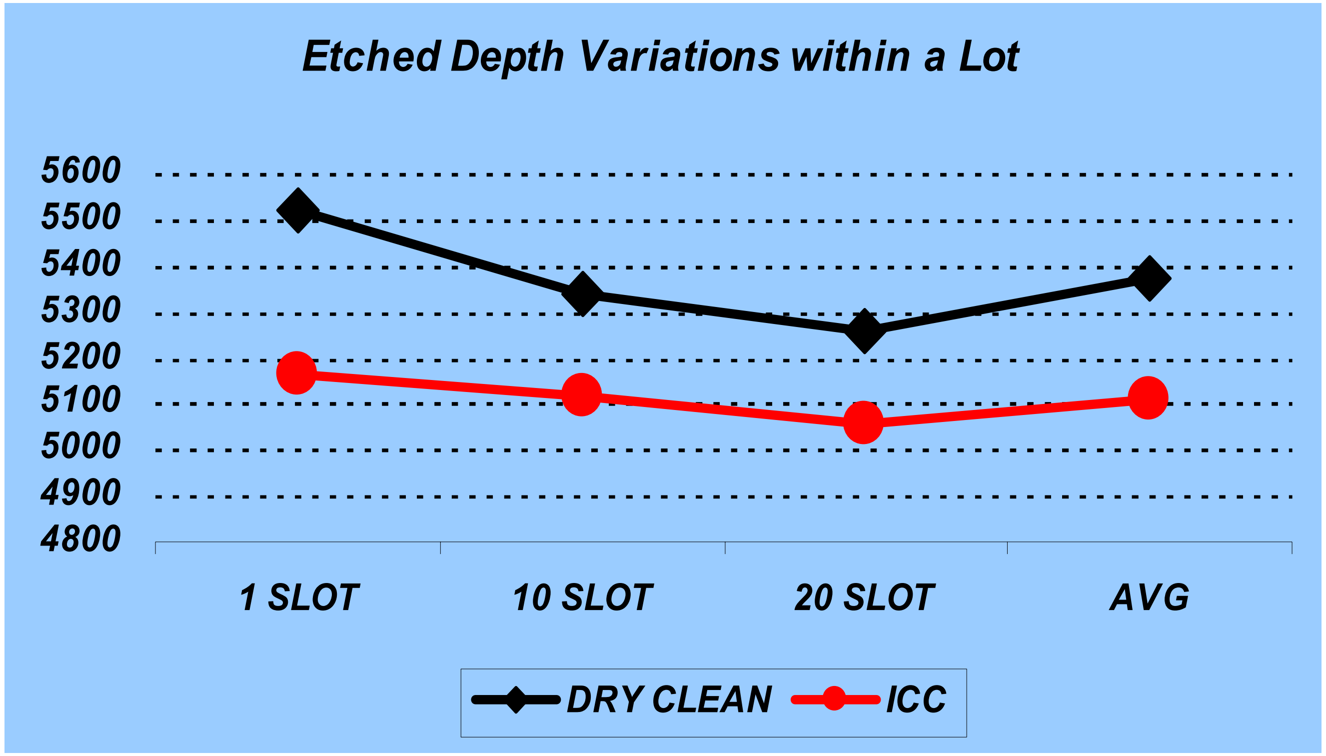
- Effects of ICC on Wafer-to-Wafer Variations



- **After adoption of ICC, wafer-to-wafer variations decrease dramatically!!**
- **Conditioning process after wet cleaning seems to be insufficient.**

Minimization of Chamber Wall Condition Dependence

- Comparison between Etched Depth Variations: Manual Dry Cleaning vs. ICC

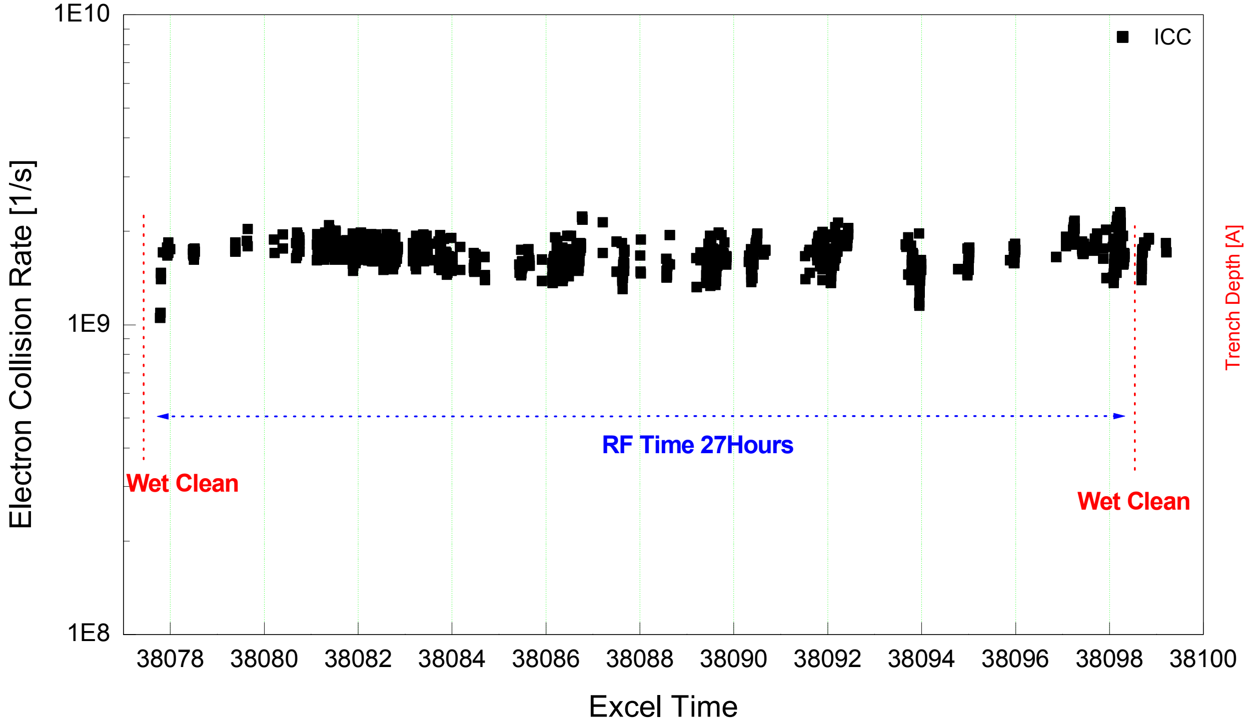


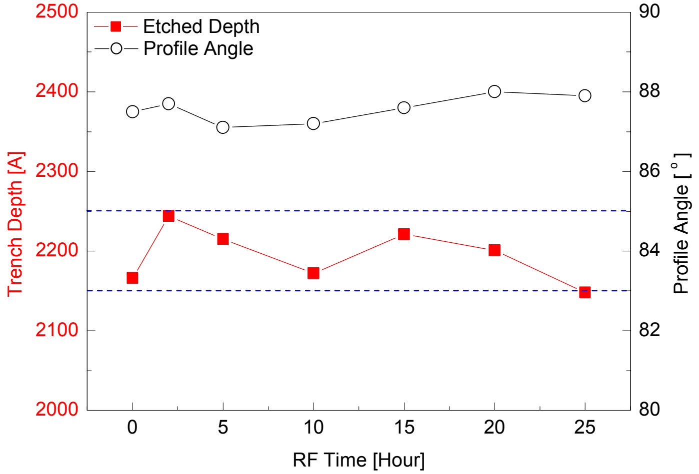
- Dry Cleaning : DEPTH AVG: 5373A/RANGE:240A
- ICC : DEPTH AVG: 5111A / RANGE:105A

Adoption of ICC reduces depth variations by nearly 50%!!

Minimization of Chamber Wall Condition Dependence

- Electron Collision Rate for RF Time 27Hours





Etched Depth and Profile as a Function of RF Time

- **Electron collision rate maintains 1E9~2E9 level for RF time 27 hours.**
- **During this period, process variations are quite small irrespective of RF time.**
- **Can electron collision rate of ICC step be a barometer of wet cleaning period?**

Minimization of Chamber Wall Condition Dependence

- Potential Problems by Adoption of ICC

✓ **Frequent Use of ICC ⇒ ESC deterioration by direct exposure to the plasma.**

ESC deterioration →

① **Rough Surface of ESC.**
② **Backside He Leak.**
③ **Non-uniform Wafer Cooling.**
④ **Aluminum Contamination Issues.**

There is a significant demand for optimum ICC conditions!!

↓

How to evaluate effectiveness of ICC ?

through a conventional method? or through in-situ plasma monitoring?

Summary

- SEERS(Self Excited Electron Resonance Spectroscopy)

  ➔ Effective way to monitor process plasma under industrial environments.

  ➔ Electron collision rate from SEERS(universal index of plasma process).

- Chamber and Process Monitoring through SEERS

  ➔ Identify extremely small changes in chamber conditions.

  ➔ Strong correlation between mean electron collision rate and etched results.

  (Remain oxide thickness in gate etch : R^2=0.918, Etched depth in trench etch : R^2=0.800)

- Minimization of Chamber Wall Condition Dependence

  ➔ Classify wafer-to-wafer(also lot-to-lot) variations by monitoring electron collision rate.

  ➔ Deploy all devices in several chambers, based on electron collision rate data.

  ➔ Efficiently confirm effects of in-situ chamber cleaning by using SEERS.