Plasma Etching Chamber Analysis Technique and Its Application using Full-Spectrum Optical Emission Spectroscopy
: Optimization of In-situ Cleaning & Stabilization

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Abstract

An optimization method for in-situ dry cleaning (ISD) and stabilization of etching equipment were developed. The modified principal component analysis (mPCA) was used for analyzing full-spectrum optical emission spectroscopy (OES).

OES is suitable for the monitoring of various plasma processes in mass production. The intensity of optical emission spectra from plasma depends on the composition of plasma, and it is possible to estimate the existence and amount of specific atoms. However, a few selected wavelength signals are generally analyzed, and the other signals are ignored even though the non-analyzed wavelengths–which are more than 99 % of raw data–have chemical information related to reactions in the chamber.

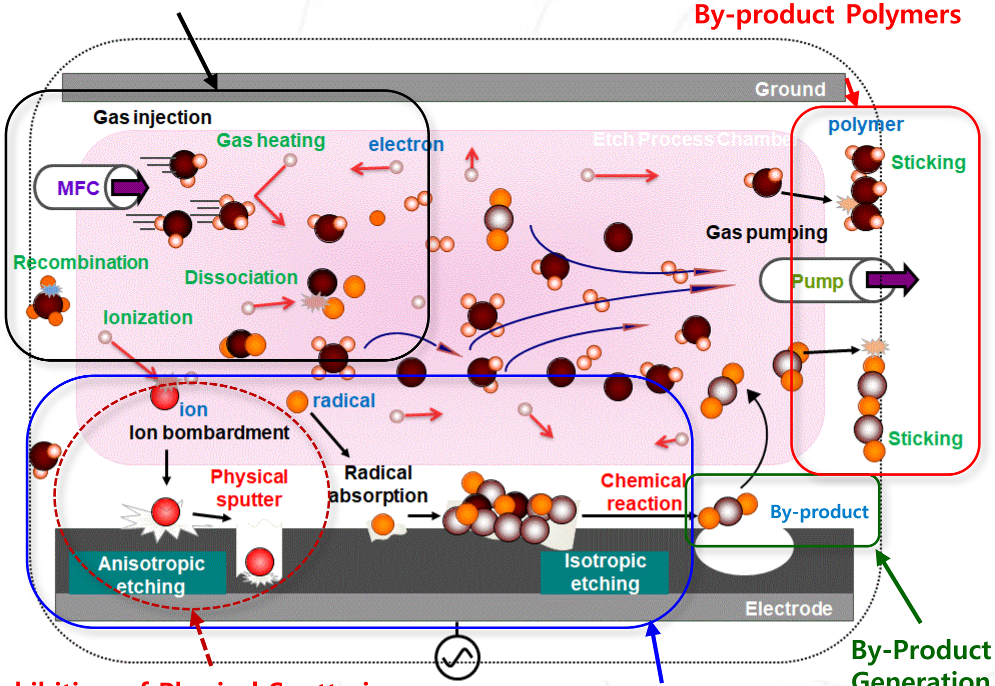
To solve this problem, mPCA is introduced for analyzing the full-wavelength optical emission spectra from ISD. The mPCA is modified from the conventional principal component analysis for the real-time process monitoring with the improving the detection limit of OES. The results show the proposed technique is successfully applied to the development of plasma etching chamber: sensitivity enhanced ISD and stabilization of etching equipment.

Introduction

◈ By-product Contamination by Etching Process

Reactions in Plasma

Wall Contamination by By-product Polymers



By-Product Generation

Inhibition of Physical Sputtering in In-Situ Dry cleaning (ISD) → Reducing ESC Damage

Wafer-Plasma Reactions
(Physical+Chemical)

『 Wall & ESC Contamination 』

Wafer-Plasma Reactions
(Physical Sputter + Chemical Reaction)
↓
By-product Generation
↓
Wall & ESC Contamination by By-product Polymers (→Particle Source)

『 Reducing Contamination 』

- **Reducing Wall & ESC Contamination to Control Particle Sources**
- **Protecting ESC from Physical Sputtering**

[Contamination Control]

Gas	Target
NF3/SF6	Si + C
O2	C

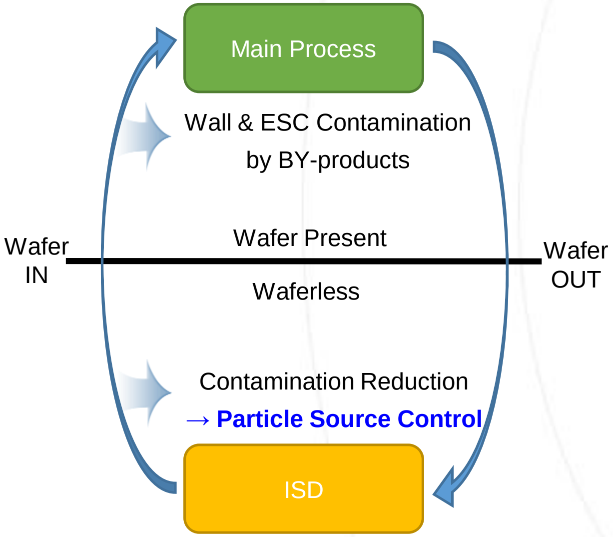
↓
Chemical Reaction
↓
Removing By-products

[ESC Damage Control]

TCP power (O)
+
Bias power (X)
↓
Inhibition of Physical Sputtering
↓
Reducing ESC Damage

Introduction

◈ In-Situ Dry cleaing (ISD)

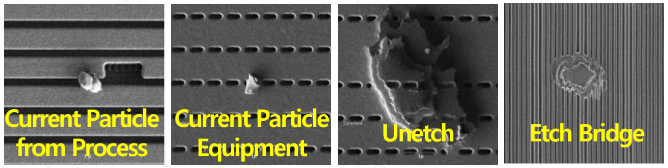


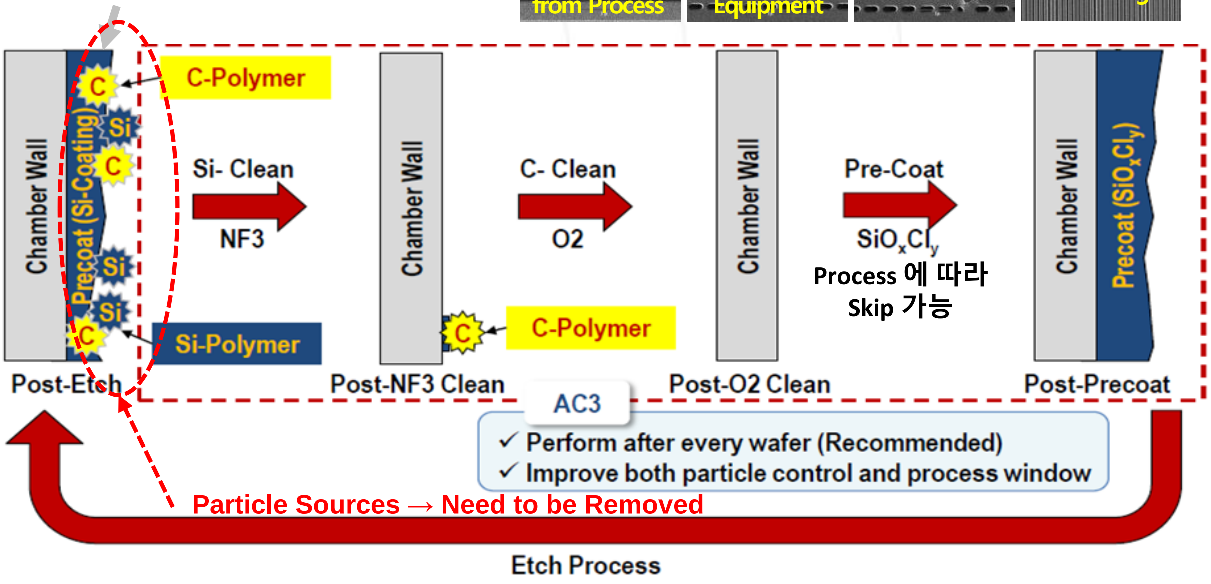
『 Chamber Maintenance for Particle Control : NF3/O2 ISD 』

Removable Defects by ISD

: Related to Chamber Wall Contamination

= Current Particle, Unetch, Etch Bridge





✓ Perform after every wafer (Recommended)
✓ Improve both particle control and process window

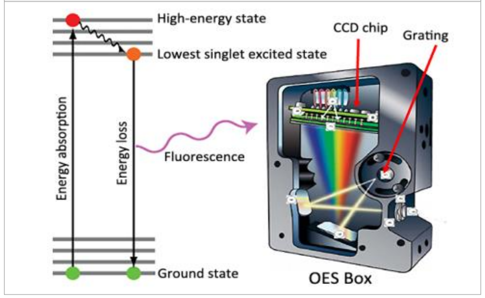
Introduction

◈ Need for Improvement of Plasma Monitoring

『 Plasma Monitoring Tool 』

▣ OES (Optical Emission Spectroscopy)

Spectroscopic Principle : OES



Quantization of Electron Energy :

Electron Excited - Ground State

↓

Correlation between

Chemicals in Plasma and

Emission Wavelength

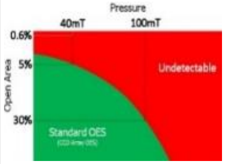
↓

Chemical Reaction Monitoring in

Plasma Chamber

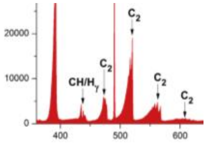
Analysis Constraints

▣ Limitation of OES



Narrow process windows

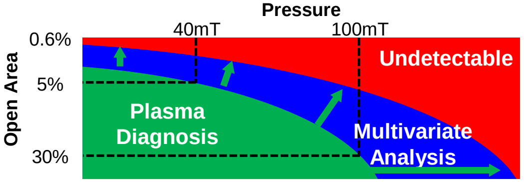
▣ Wavelength Selection



Problems dependent on the user experience

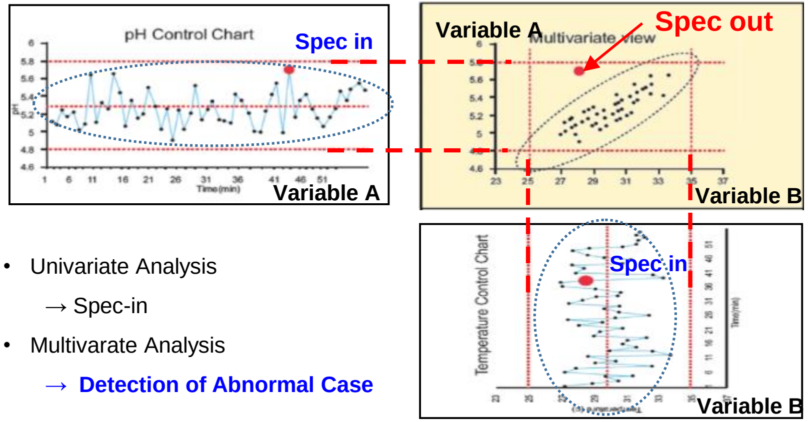
『 Multivariate Analysis 』

▣ Sensitivity Enhancement : Data-mining



Expansion of analysis area through multivariate analysis

(ex) Expectations of with Multivarate Analysis : Detecting Hidden Spec-out



- Univariate Analysis
  → Spec-in
- Multivarate Analysis
  → **Detection of Abnormal Case**

Mario Rougieri, Applied Materials, APC Conference 2018

Analytical Methodology

◈ Data-mining : mPCA (Modified Principal Component Analysis)

『PCA』

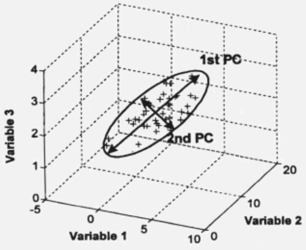
▣ Principal Component Analysis

【 PCA 】

Many variables
: Correlated

Loss of
partial information
(less than 10%)

A few variables
: Uncorrelated



Dimension Reduction
(3→2 variables)

Gathering OES data

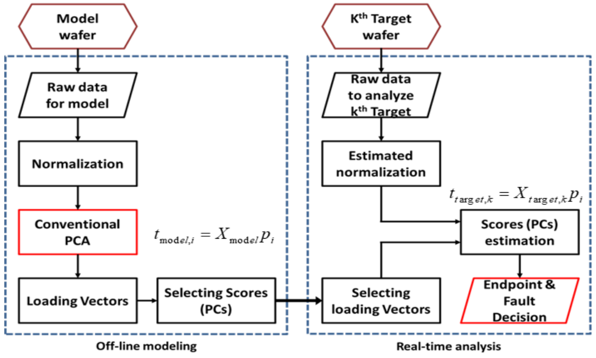
Weight calculation for each wavelength

Generating new variables t_i

Diagnosis of process vulnerabilities

『Modified PCA』

▣ OES Full-spectrum Analysis for Plasma Etcher



$$t_{model,i} = X_{model} p_i$$

$$t_{target,k} = X_{target,k} p_i$$

[Training Data Set]
OES Data

PCA

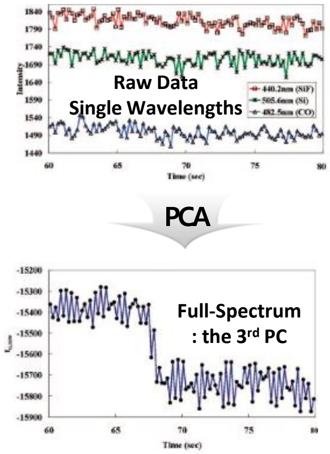
[Modeling]
Weight Determination
for each wavelength

[Target Data Set]
OES Data

[Full Spectrum Analysis]
Chamber Monitoring

Enhanced EPD Sensitivity

Open Area 0.8%



효과 → **Reducing Analysis Time** → **Quantification** → **Yield Enhancement**

Homeostasis, Stability, EPD   Process / ISD Optimization

Analytical Methodology

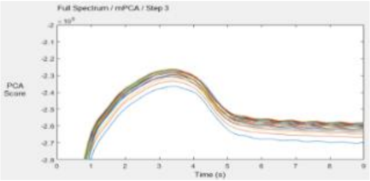
SAMSUNG

◈ Quantification of OES Signal Analysis

[Rule 1] OES Homeostatsis

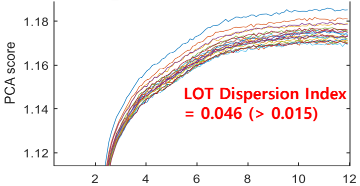
▣ LOT Dispersion Index

- Scale correction → Median of (MAX-MIN)

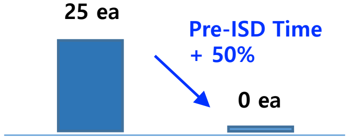


Elapsed Time on Signals

『 OES-mPCA 』



LOT Dispersion Index
= 0.046 (> 0.015)



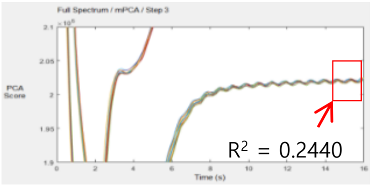
Pre-ISD Time
+ 50%

# of Round shape Particle

[Rule 2] OES Stability

▣ Signal Stability Index

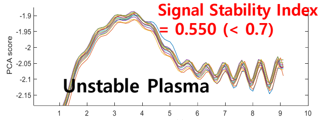
- Based on linear regression R^2



$R^2 = 0.2440$

Unstable Pressure

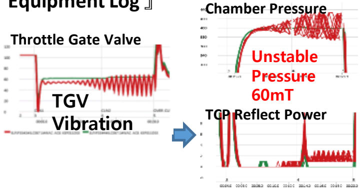
『 OES-mPCA 』



Signal Stability Index
= 0.550 (< 0.7)

Unstable Plasma

『 Equipment Log 』



TGV
Vibration

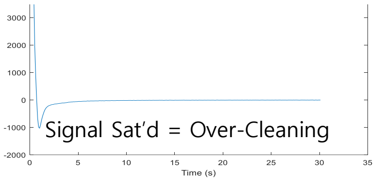
Unstable
Pressure
60mT

TGV Control (Manometer)

[Rule 3] OES EPD

▣ Endpoint Detection

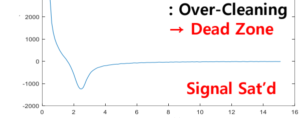
- Based on signal gradient



Signal Sat'd = Over-Cleaning

Inadequate Process Time

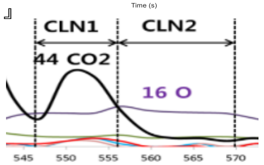
『 OES-mPCA 』



Single Step ISD
: Over-Cleaning
→ Dead Zone

Signal Sat'd

『 RGA 』

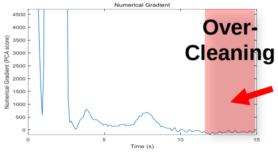


→ +5s → -5s

➡ FCC Gain 1.12

EPD at Over-CLN

▶ **Statistical Significant Difference Analysis**



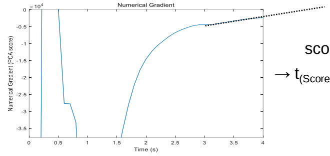
Over-
Cleaning

A record with the same characteristics with a 95% probability

- Endpoint : Gradient = 0

EPD at Under-CLN

▶ **Gradient Estimation**



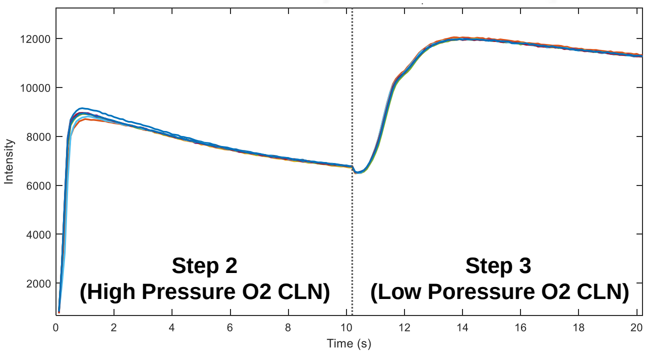
score = 2388.4t-11729
→ $t_{(Score=0)} = 4.91s$

- Linear regression : Estimating Gradient = 0

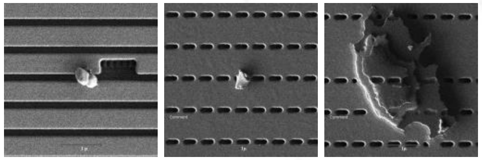
Applications: ISD

◈ ISD Optimization for Defect Control: Reference Condition

『 Full Spectrum PCA : Reference Condition 』



『 Defect of Interest 』

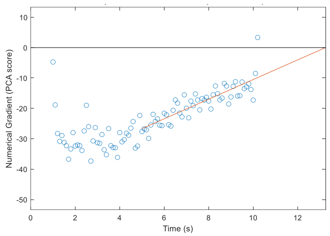
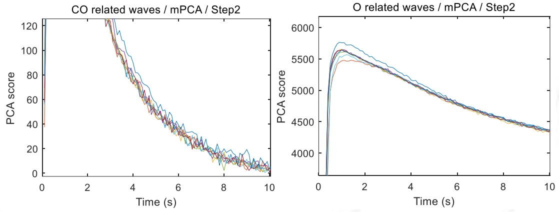
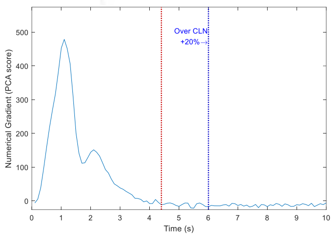
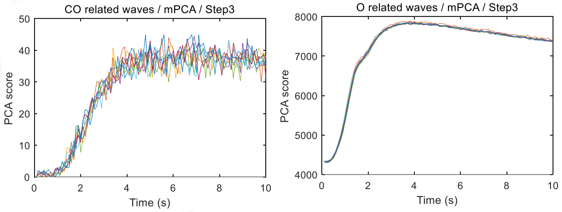


Round Shape
C, O, Al

Current Particle
C, F, Al

Unetch
C

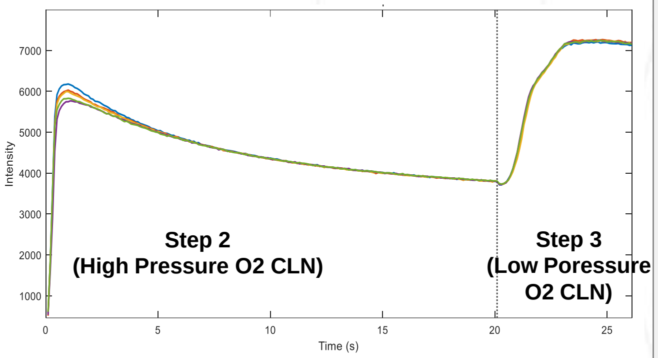
『 Estimating Endpoint + Chemical Components Related Spectrum 』

Step	STEP 2 : High pressure O2 Cleaning	STEP 3 : Low pressure O2 Cleaning
Analysis	**[1] Reaction Time Suggestion (10→20s)**  **[2] Chemical Components**  CO related waves / mPCA / Step2 O related waves / mPCA / Step2	**[1] Reaction Time Suggestion (10→6s)**  Over CLN +20% **[2] Chemical Components**  CO related waves / mPCA / Step3 O related waves / mPCA / Step3
Results	- Insufficient time: incomplete C removal - Suggested time: 10→20s	- Excessive time: Al particle source due to ESC damage - Suggested time: 10→6s
Suggestion	- **New Hybrid ISD Condition Test (Step2 20s + Step3 6s)**	

Applications: ISD

◆ ISD Optimization for Defect Control: Test Condition

『 Full Spectrum mPCA : Test Condition 』

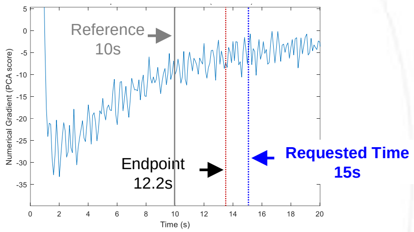
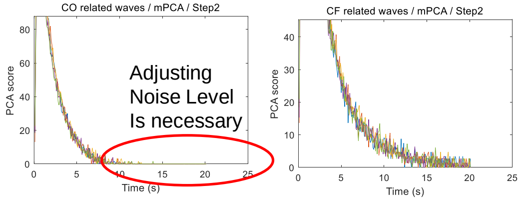
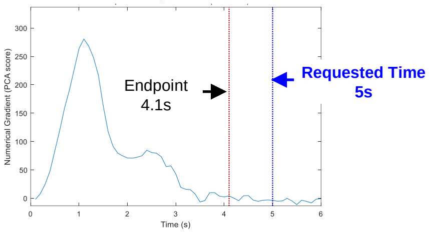
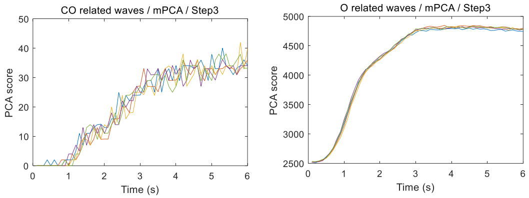


『 Improvement Effect : 15s+5s Condition 』

Defect Index	2.03 gain
EDS Index	0.13 gain

YLD	+0.40%
Suspect LOT Feedback	9→6.7 times/month (-25.5%)

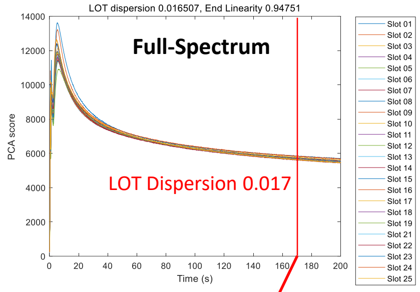
『 Estimating Endpoint + Chemical Components Related Spectrum 』

Step	STEP 2 : High pressure O2 Cleaning	STEP 3 : Low pressure O2 Cleaning
Analysis	**[1] Requested Reaction Endpoint : 15s**  **[2] Chemical Components**  	**[1] Requested Reaction Endpoint : 5s**  **[2] Chemical Components** 
Results	- Additional Reaction is detected. - Suggested time: 15s	- Test Condition is verified. - Suggested time: 5s
Suggestion	- New Hybrid ISD Condition (Step2 15s + Step3 5s)	

Applications: Stabilization of Etching Equipment

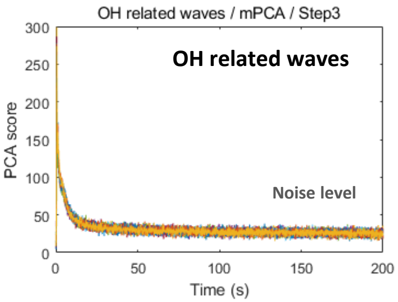
◈ Optimization of Chamber Stabilization (NPW Aging) for Defect Control

[NPW Aging Step 3 in ICP Chamber]


LOT dispersion 0.016507, End Linearity 0.94751

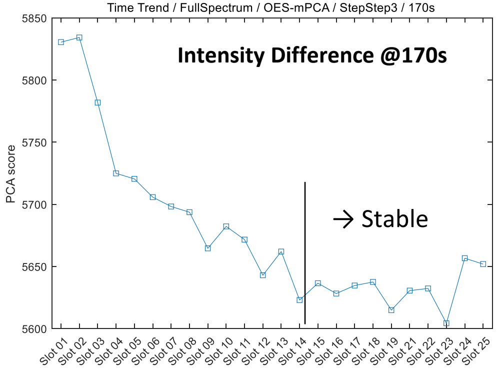
Full-Spectrum

LOT Dispersion 0.017


OH related waves / mPCA / Step3

OH related waves

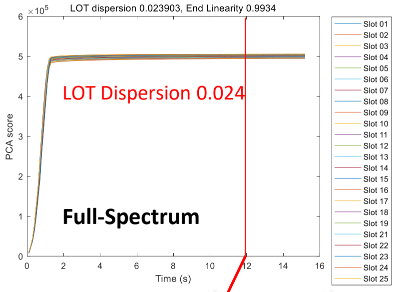
Noise level


Time Trend / FullSpectrum / OES-mPCA / StepStep3 / 170s

Intensity Difference @170s

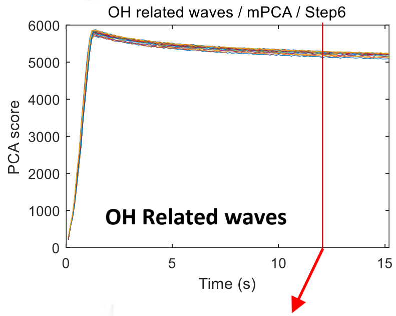
→ Stable

[NPW Aging Step 6 in ICP Chamber]

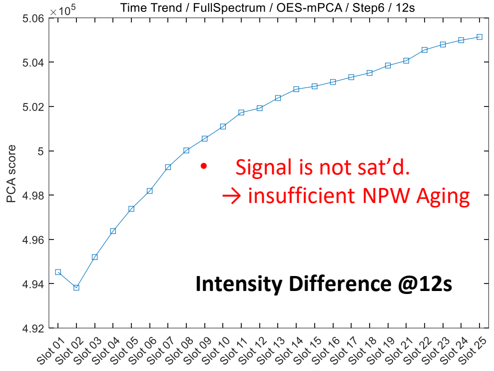

LOT dispersion 0.023903, End Linearity 0.9934

LOT Dispersion 0.024

Full-Spectrum

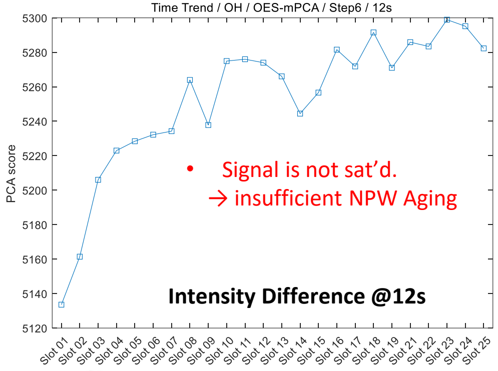

OH related waves / mPCA / Step6

OH Related waves


Time Trend / FullSpectrum / OES-mPCA / Step6 / 12s

- Signal is not sat'd.
  → insufficient NPW Aging

Intensity Difference @12s

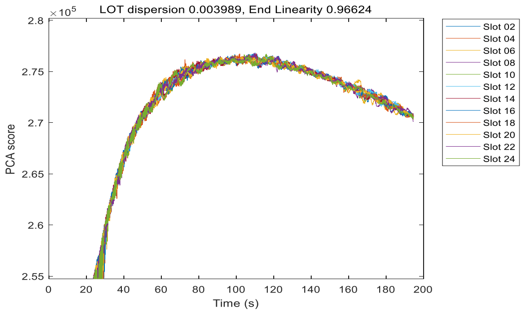
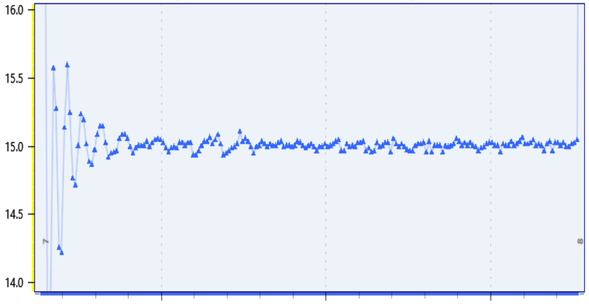
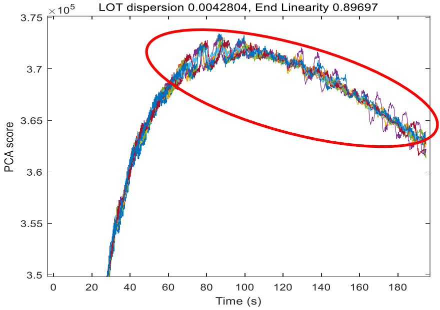
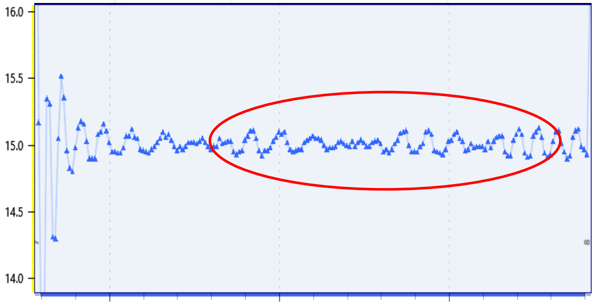

Time Trend / OH / OES-mPCA / Step6 / 12s

- Signal is not sat'd.
  → insufficient NPW Aging

Intensity Difference @12s

Applications: Main Etch Analysis

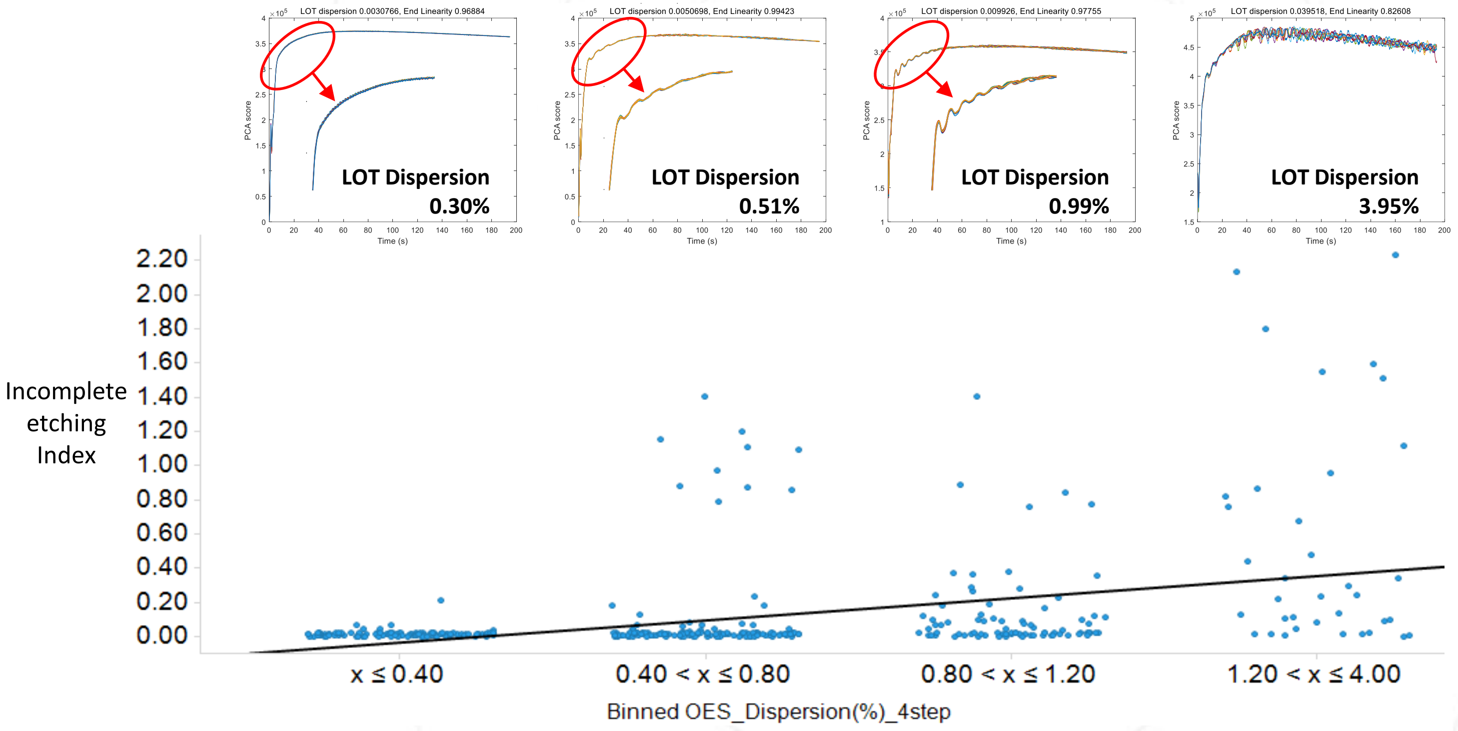
◈ Relationship between OES-mPCA Stability and Yield

LOT	OES-mPCA	Chamber Pressure (FDC)
Normal	 LOT dispersion 0.003989, End Linearity 0.96624 	
Affected by Equipment Problem	 LOT dispersion 0.0042804, End Linearity 0.89697 	
	Significant difference confirmed from OES-mPCA. - Unstable Plasma - Need to Press & RF power Check	Pressure difference detected.

Applications: Main Etch Analysis

◈ Relationship between OES Signal Stability and Yield

: Correlation between OES signal LOT Dispersion & incomplete etching



Unstable Plasma (LOT Dispersion)

⬇

Incomplete Etching ↑

⬇

Equipment Risk Detection

Conclusion

- Plasma process optimization and fault detection are possible through mPCA analysis of OES data.

- It was possible to use the following:
  - ISD Optimization
  - Chamber Stabilization by NPW Aging
  - Fault detection and yield degradation prediction in main etch processes.