Method for Real Time Monitoring of Gas Composition with High Sensitivity Using Optical Emission Spectroscopy

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Overview

- Introduction
- Etch Process
- Method of Analysis
- Results for bare Si wafers
- Results for production wafers
- Conclusions
- Acknowledgements

Introduction

- Gate CD is a critical parameter for DRAM Etch
- O_2 flow rate has been shown to be correlated to CD skew[1]. Multi-way PCA was used.
- Goal:
  - Detect by OES the effect of O_2 flow variation in the etch process
  - Use multivariate analysis methods

[1] Yongjin Kim, Gyungjin Min , Changjin Kang, Hanku Cho, and Jootae Moon, "Real-time process monitoring by optical emission spectroscopy in DRAM gate CD control", Semiconductor Manufacturing, ISSM 2005, IEEE International Symposium. p136, 2005.

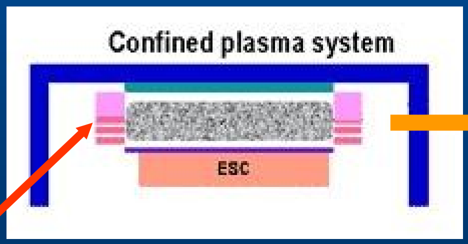
Introduction

- Observe the emission spectra from the plasma
  - Originates from the region of the etch chemistry
  - Emission spectra related to the O_2 flow
- Compensate for absorption from window clouding
  - Etch chemistry creates fluorocarbon polymers to enhance etch selectivity
  - Fluorocarbon polymers coat window increasing optical absorption
  - Window coating absorption
    - In UV-Visible, large and non-linear with wavelength
    - In Near-IR, small and linear with wavelength
- Method is inexpensive and requires no modification of the etch chamber
- Data is only spectra, i.e. no RF parameters

Process

- LAM Exelan® dielectric etch system
- Oxygen Mass Flow Controller:
  - Max 30 sccm
  - 0.01 sccm resolution
  - Does not necessarily indicate oxygen concentrataion over wafer

radiation to spectrograph



Verity Instruments
SD1024™
UV-Visible
spectrograph

confinement ring

fiber optic cable

Process

- Dry etch with RF Plasma
- Chemistry
  - Break-through Etch
    - $CF_4 + O_2 + Ar$
  - Main Etch
    - $CF_4 + CHF_3 + CH_2F_2 + O_2 + Ar$
- Increasing O_2 flow will decrease polymer formation and decrease gate CD
- No pre-cleaning or post cleaning step –causes more polymer coating of window
- Confinement ring reduces ion bombardment of window and increases polymer coating of window

Method of Analysis

- Look for simple method that has high sensitivity
- Create a predictive model for the etch processes
- PCA method
  - Versatile
  - PSI can be Q, T^2 , or PC projection
- PLS method
  - PSI is closely related in magnitude to the true flow rate.
  - Valid for small changes in the response variable
  - Selects variance that is specified by response variable
  - Adaptive PLS – correct for drift
  - Verity method of FDC (US patent 6,830,939)

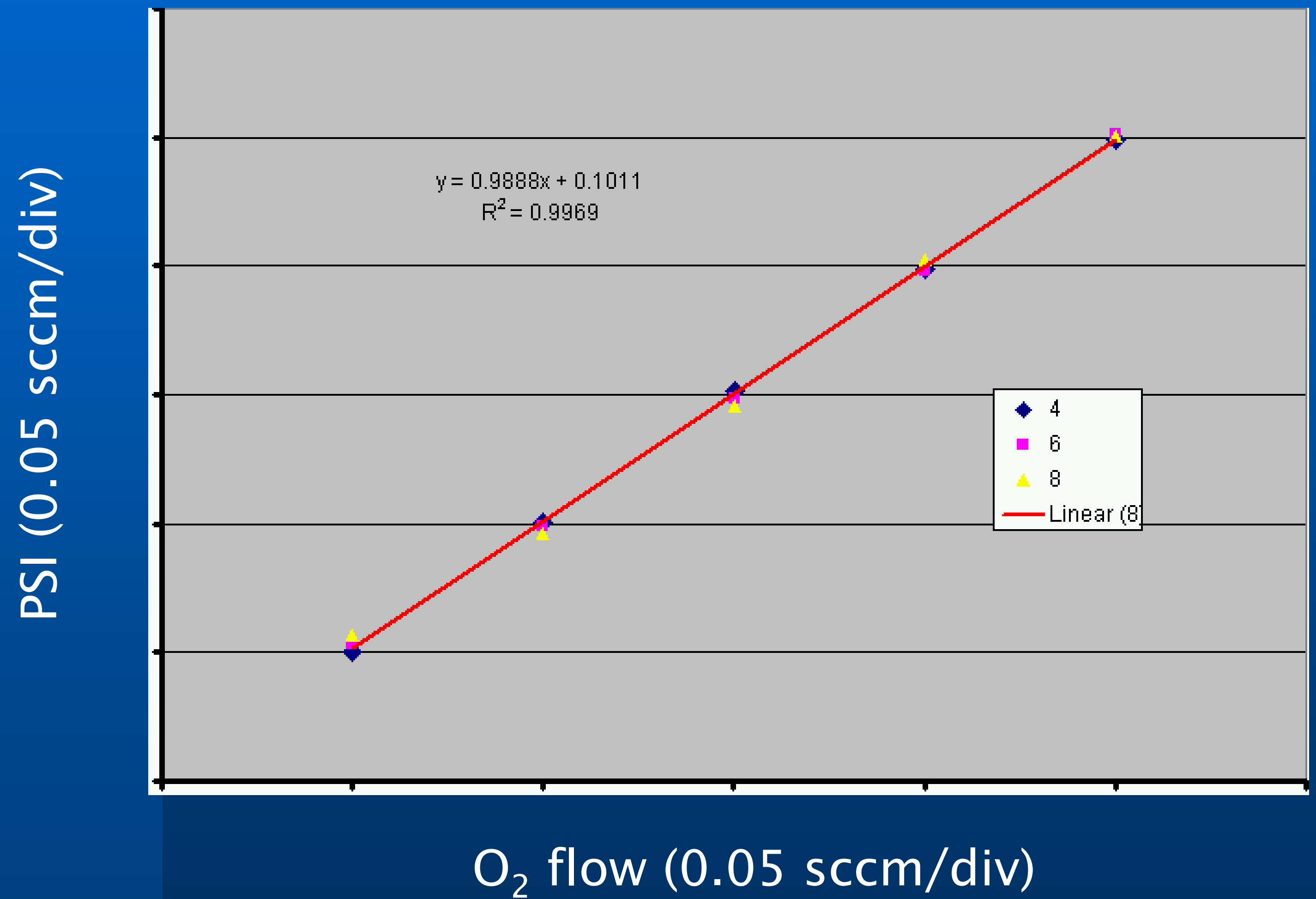
PSI = process state index

Results – Bare Si Wafers

- Demonstrate method with bare Si wafers
- Simpler spectra – no etch chemistry
- Reduces window clouding
- Perform calibration with O_2 flow rates at known values

Results – Bare Si Wafers

Break-through Etch - Validation



Method of Analysis – Figure of Merit

- Response

  $$R_S = dy_N / dr_N$$

- Repeatability

  $$R_R = 1/\sigma(y_N)$$

- Sensitivity

  $$S = R_S * R_R = (dy_N / dr_N)(1/\sigma)$$

$y_N = y/y_{nom}$, is the normalized PSI variable
$r_N = r/r_{nom}$, is the normalized flow rate
PSI = process state index

Results – Bare Si Wafers - adaptive PLS

Break-through Etch Validation

Wafers	4,6,8	10,12,14,16,18
Std Dev	0.0003	0.0002
Repeatability	3203	4259
Response	1.06	0.976
Sensitivity	3389	4155

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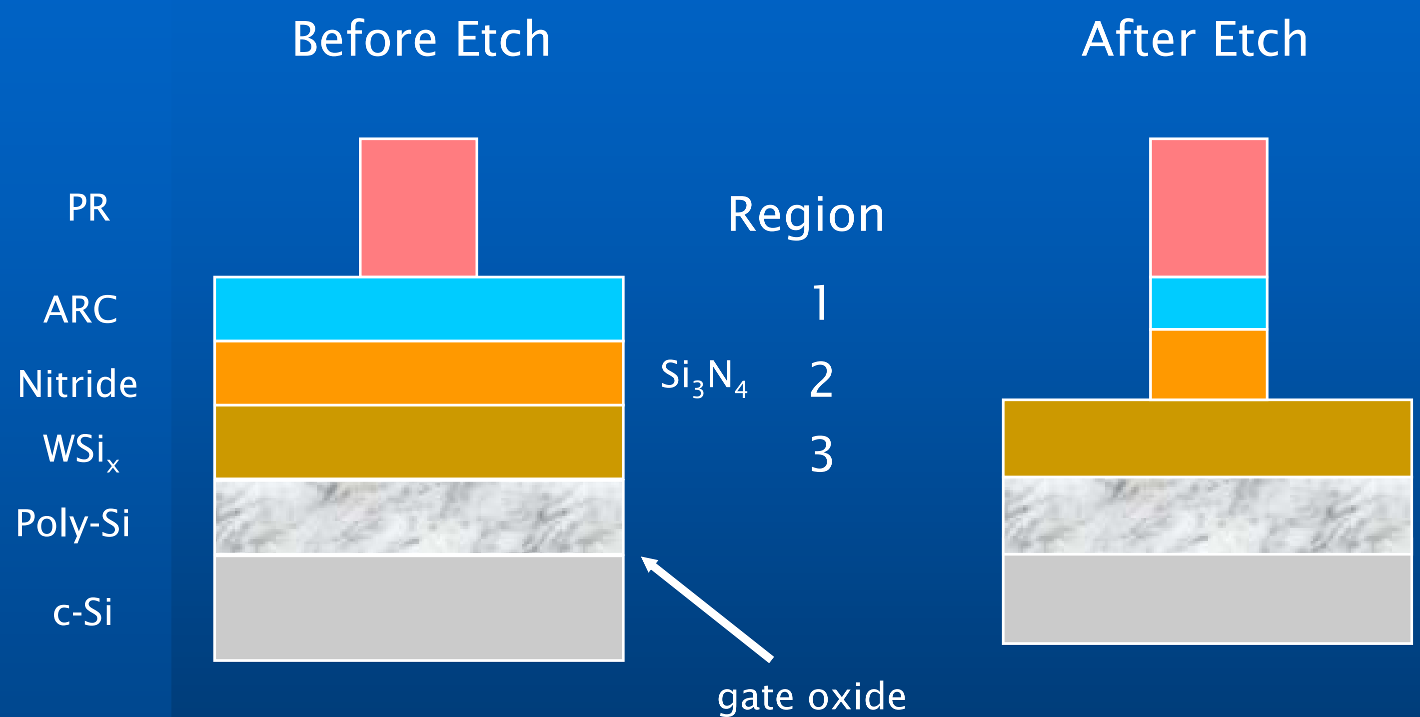
Results – Product Wafers

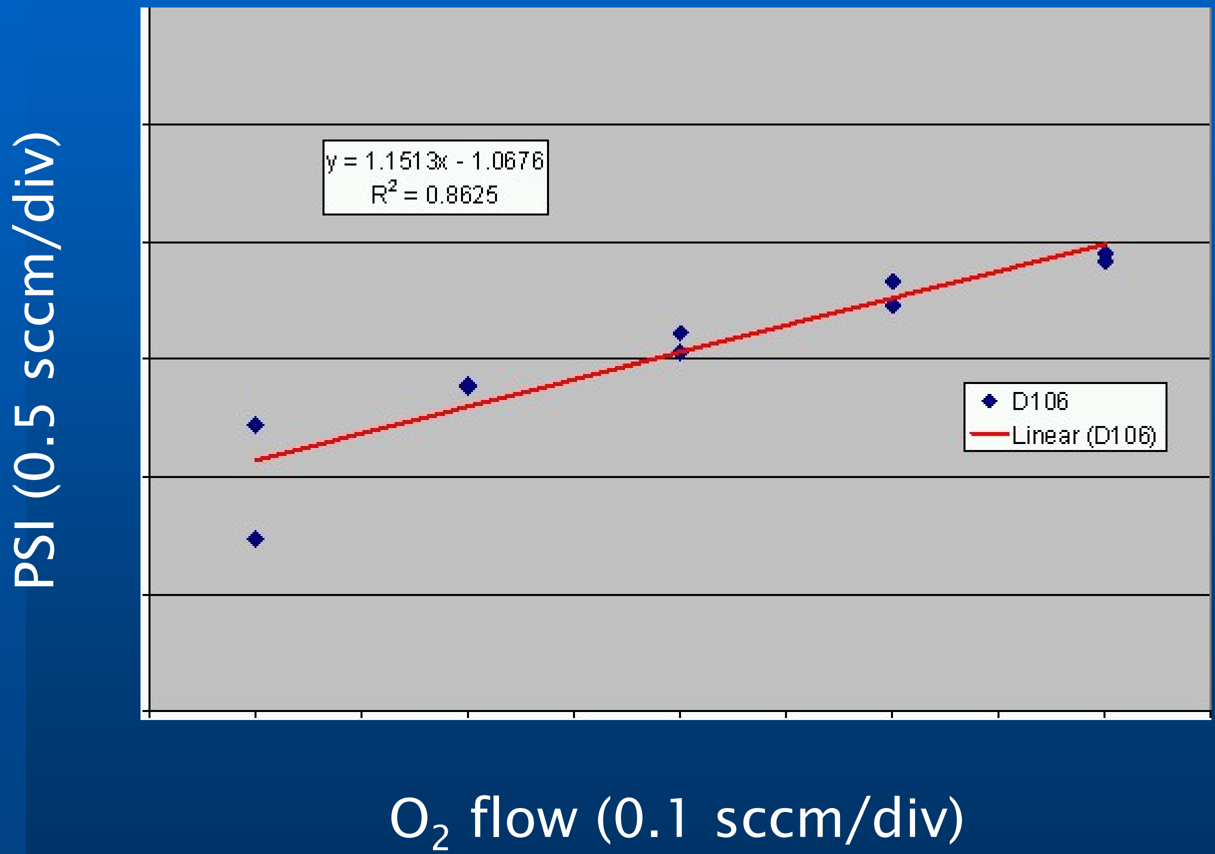
- Demonstrate method with product wafers
- Test result of calibration on production wafers over two week period
- More complex spectra – etch chemistry and etch products
- Increased window clouding
- Perform calibration, as before, with O_2 flow rates at known values

Process – Hard Mask Etch

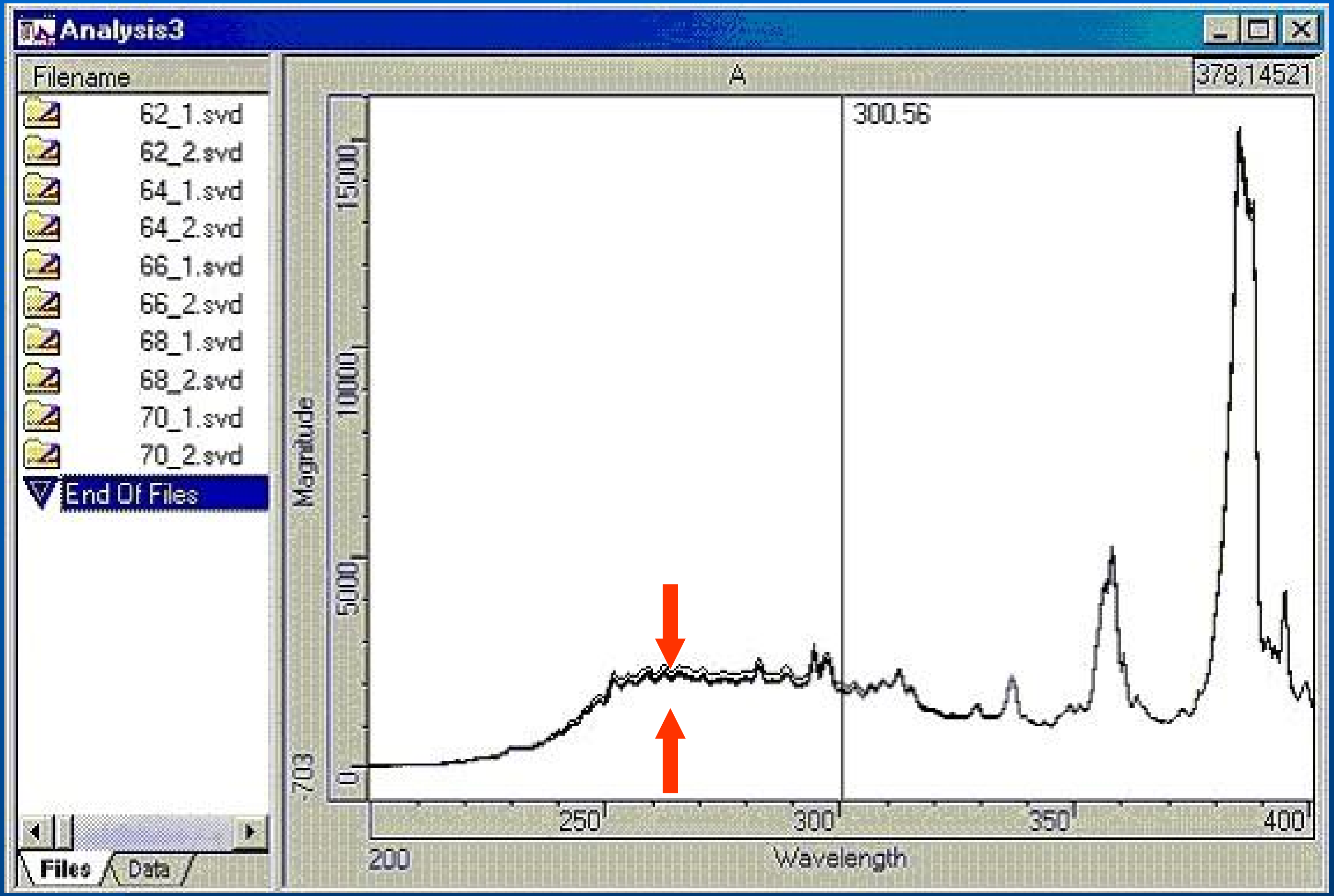


Results – Product Wafers - Calibration

Calibration/ Validation – UV-visible spectra

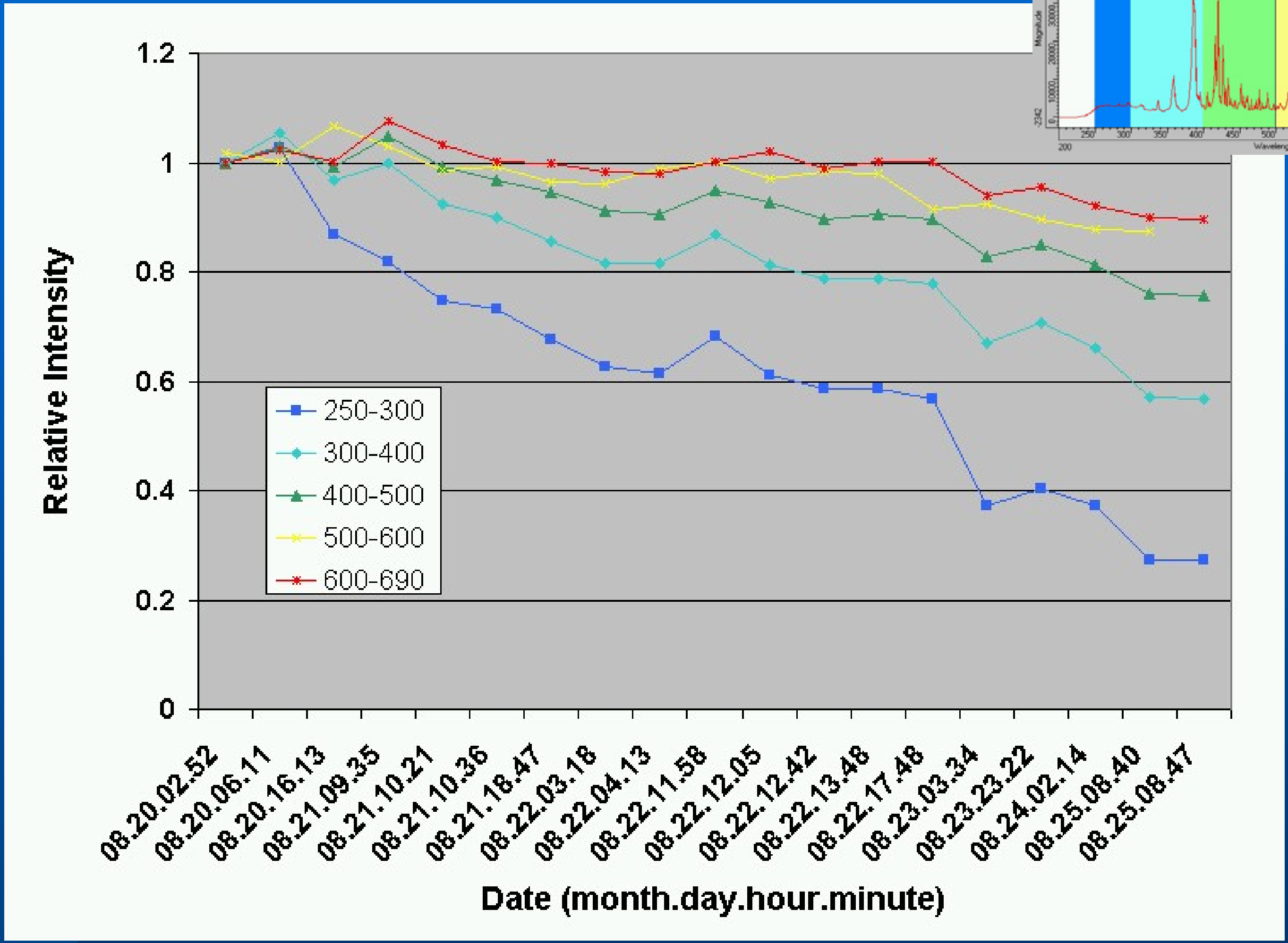


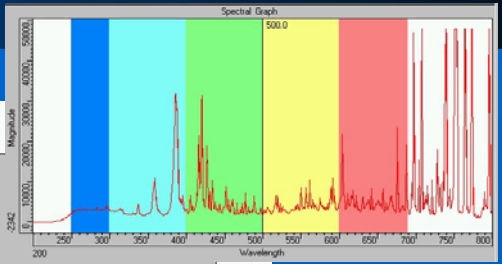
Results - Product Wafers - Calibration



Calibration with UV-visible spectra is degraded by window clouding, which causes small changes that are greatest in UV and least in red.

Results – Product Wafers





The intensity of the UV-visible spectra decreases in time more in the UV spectral region and less in the red region.

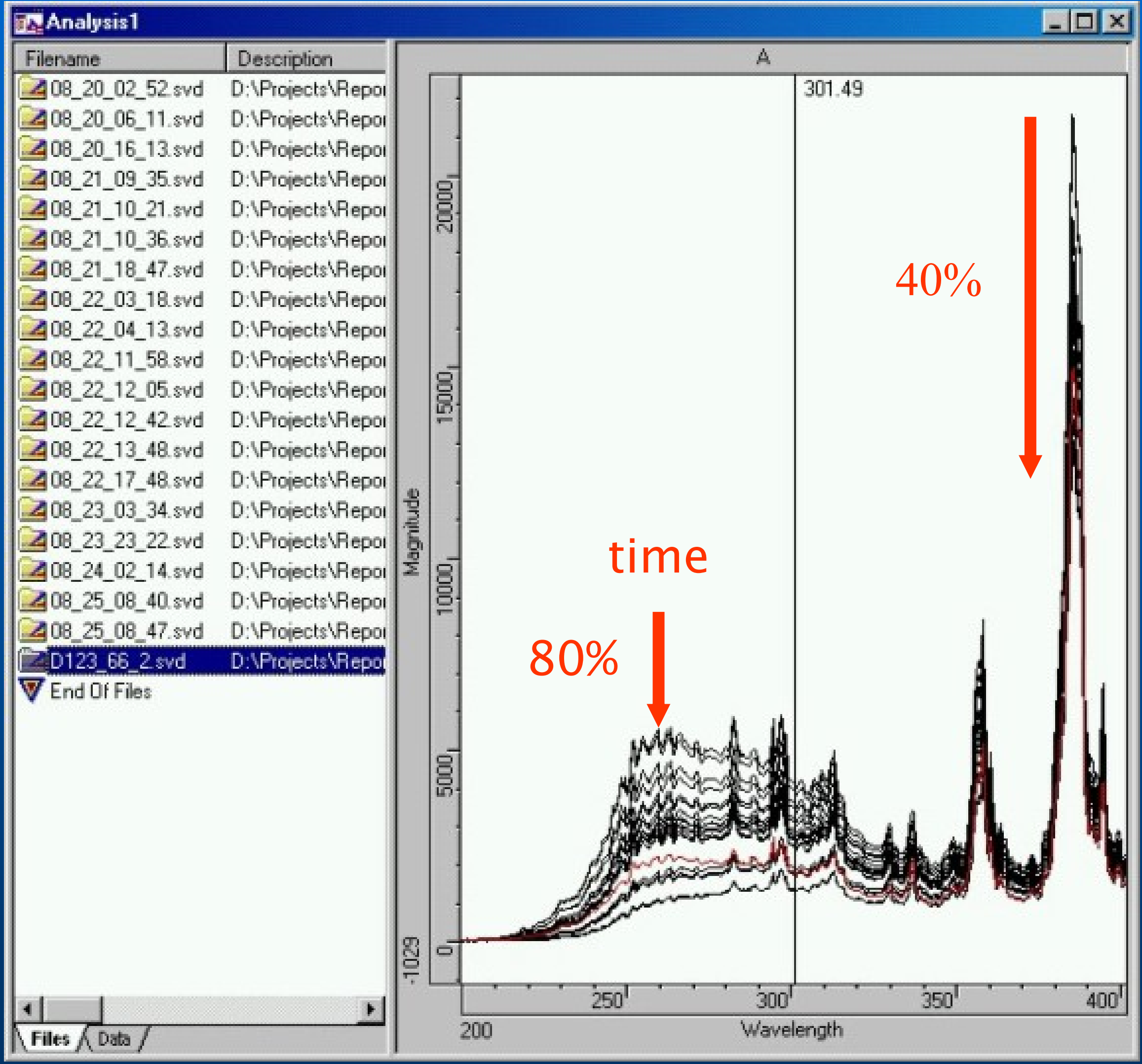
Results – Product Wafers

UV-visible spectra collected over two-week period

Window clouding causes greater intensity decrease in UV region of spectra.

Calibration data is red trace

Therefore window transmission may be high in Near-IR spectral region.



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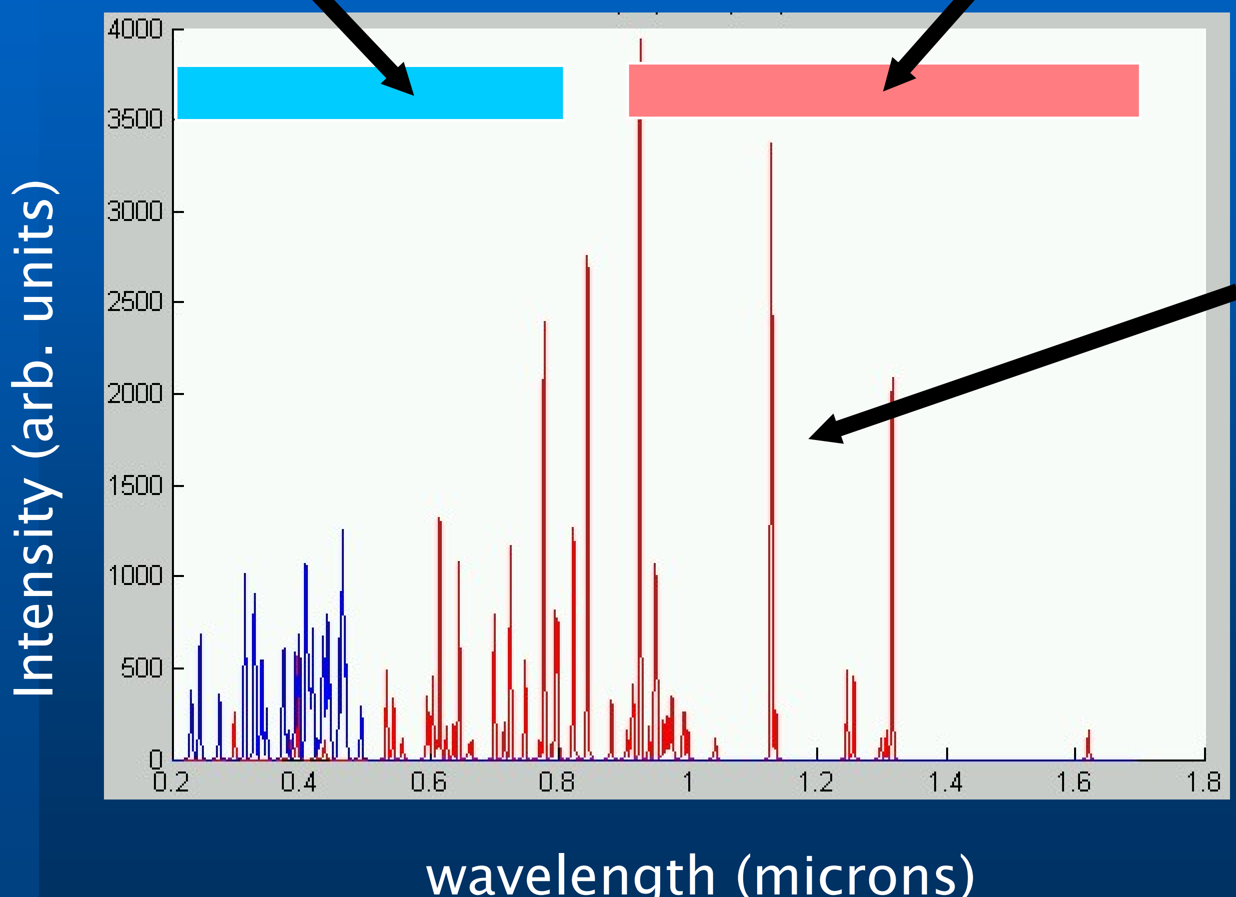
Detectors

UV-Visible - Si CCD
200 - 800 nm
1250.0 - 50,000.0 cm^{-1}

Oxygen (O, O+)
NIST Tables

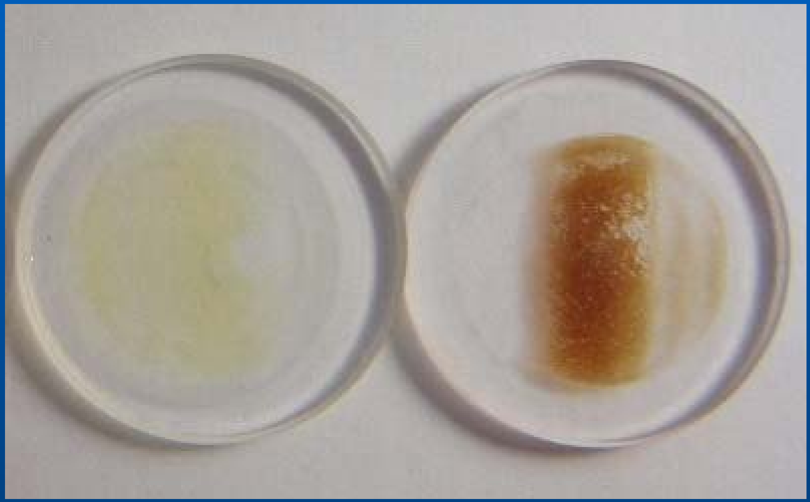
NIR - InGaAs CCD
0.9 - 1.7 um
5,900 - 11,100 cm^{-1}



useful spectra in NIR

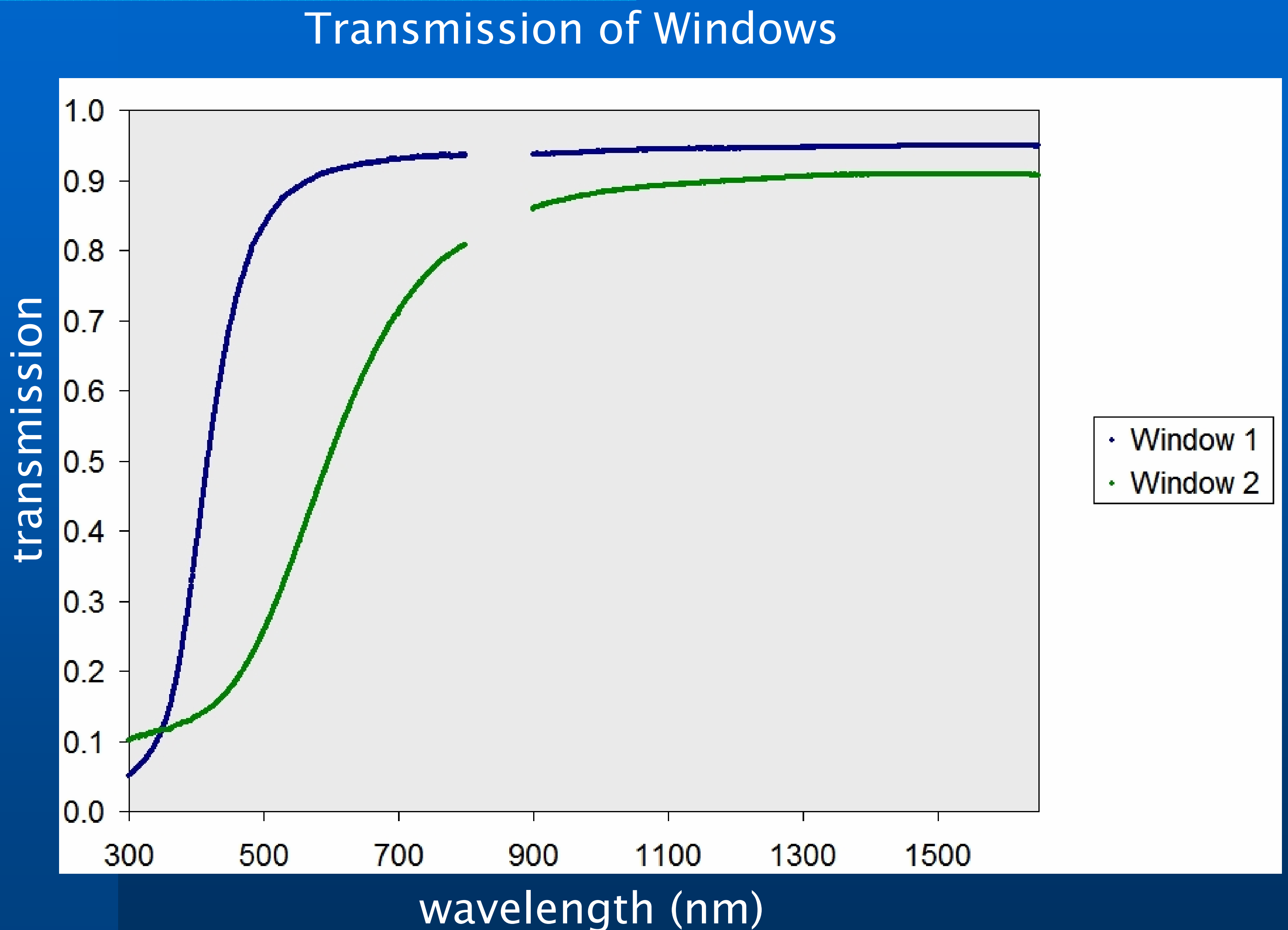
Results - Windows

Windows with progressive exposure to plasma.



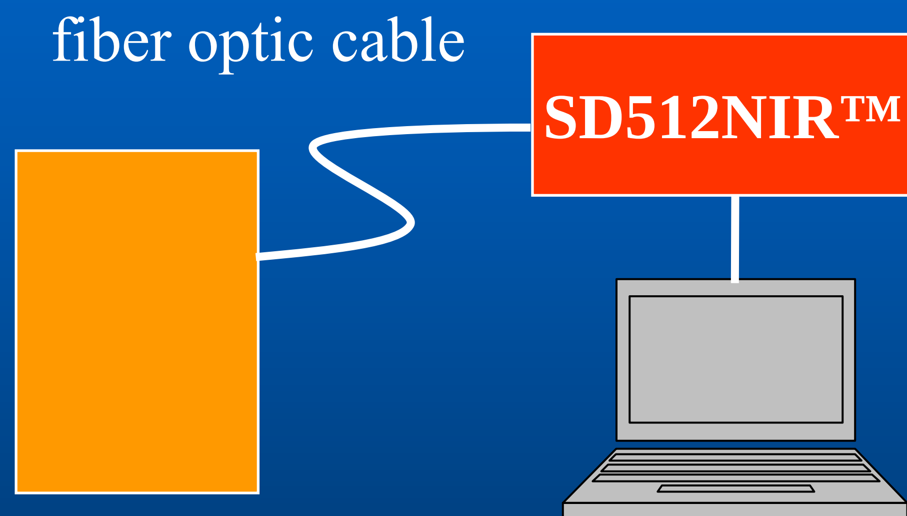
Window 1 Window 2

Results - Windows



Detectors

Verity Instruments SD512NIR™ Series spectrograph

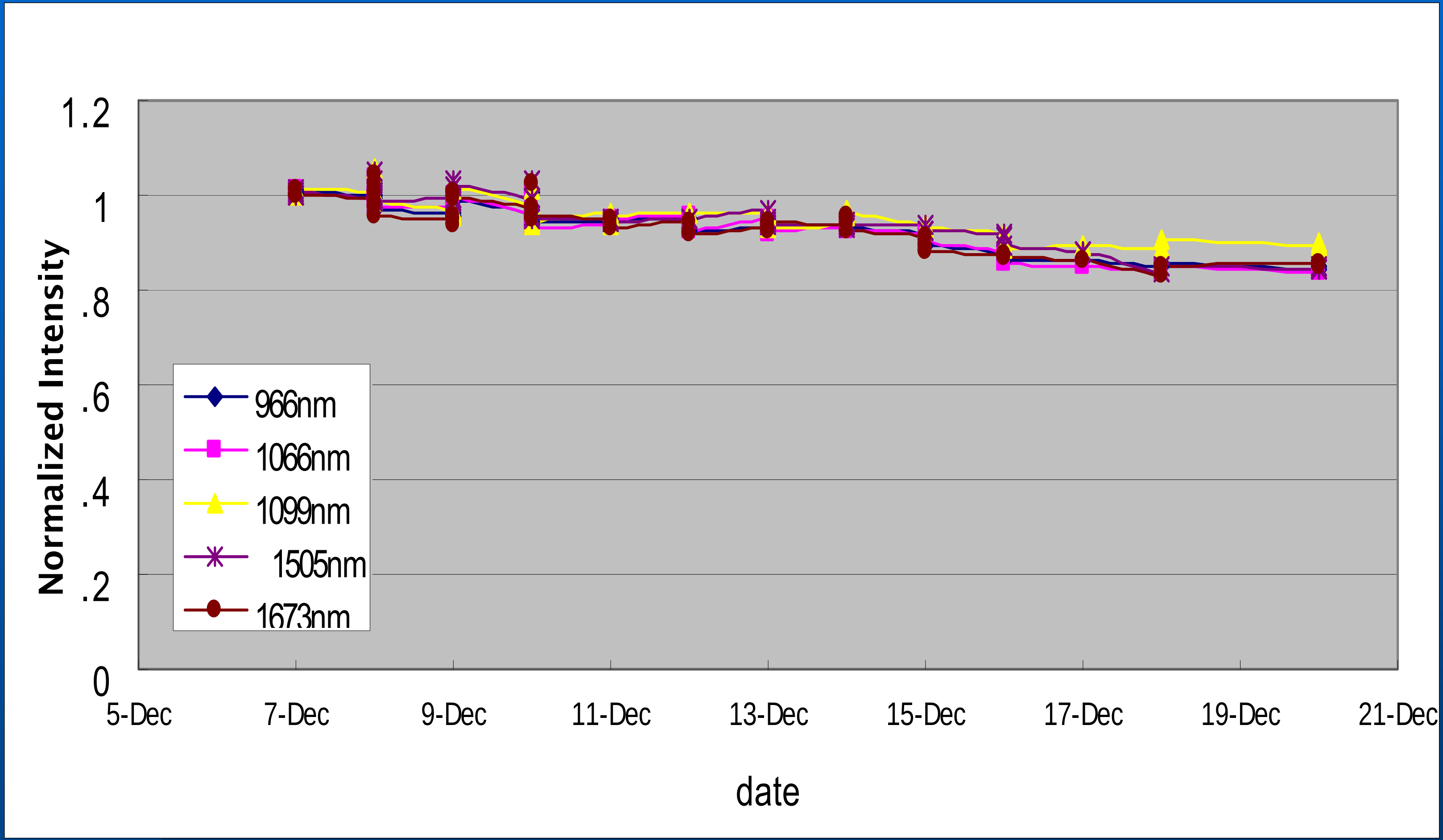


NIR - InGaAs CCD
0.9-1.7um
5,900 - 11,100 cm^{-1}

Process Chamber

Application computer with SpectraView™ software

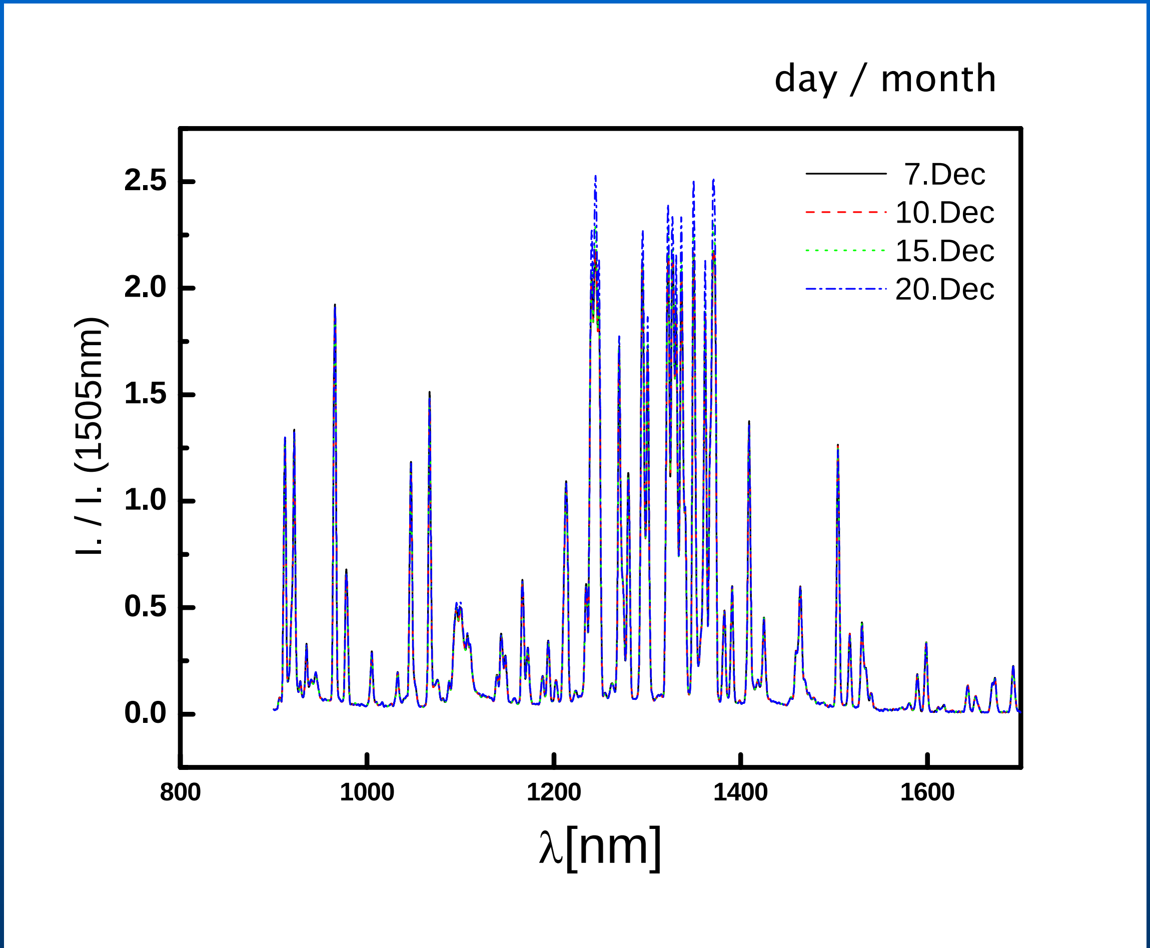
Results – Product Wafers



Verified that window transmission is greater in Near-IR and spectral intensity decreases in time less than in UV-Visible region.

Results – Product Wafers

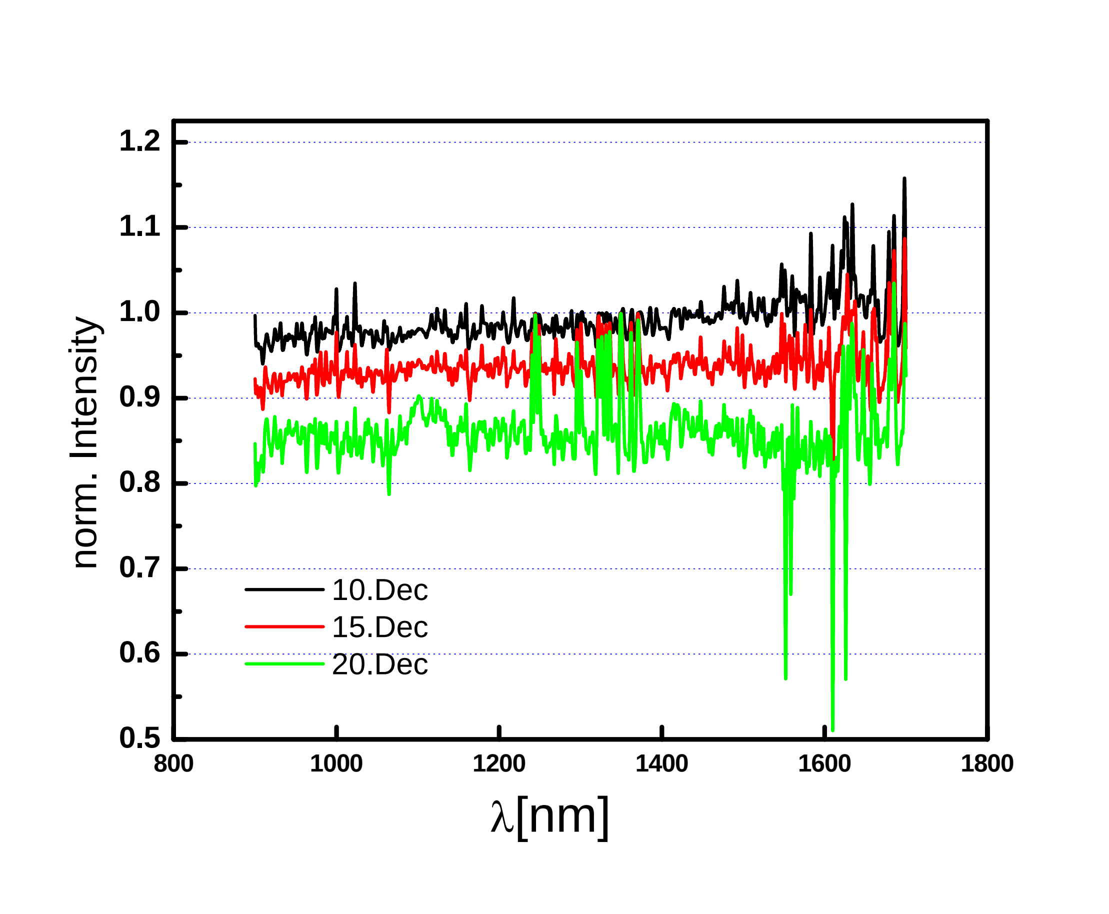
Useful in FDC analysis to compensate for small window clouding effects



- NIR spectra intensity normalized to intensity at 1505 nm
- Normalized intensity shows almost same profile over time

Results – Product Wafers

FDC is possible in Near-IR with normalized intensity

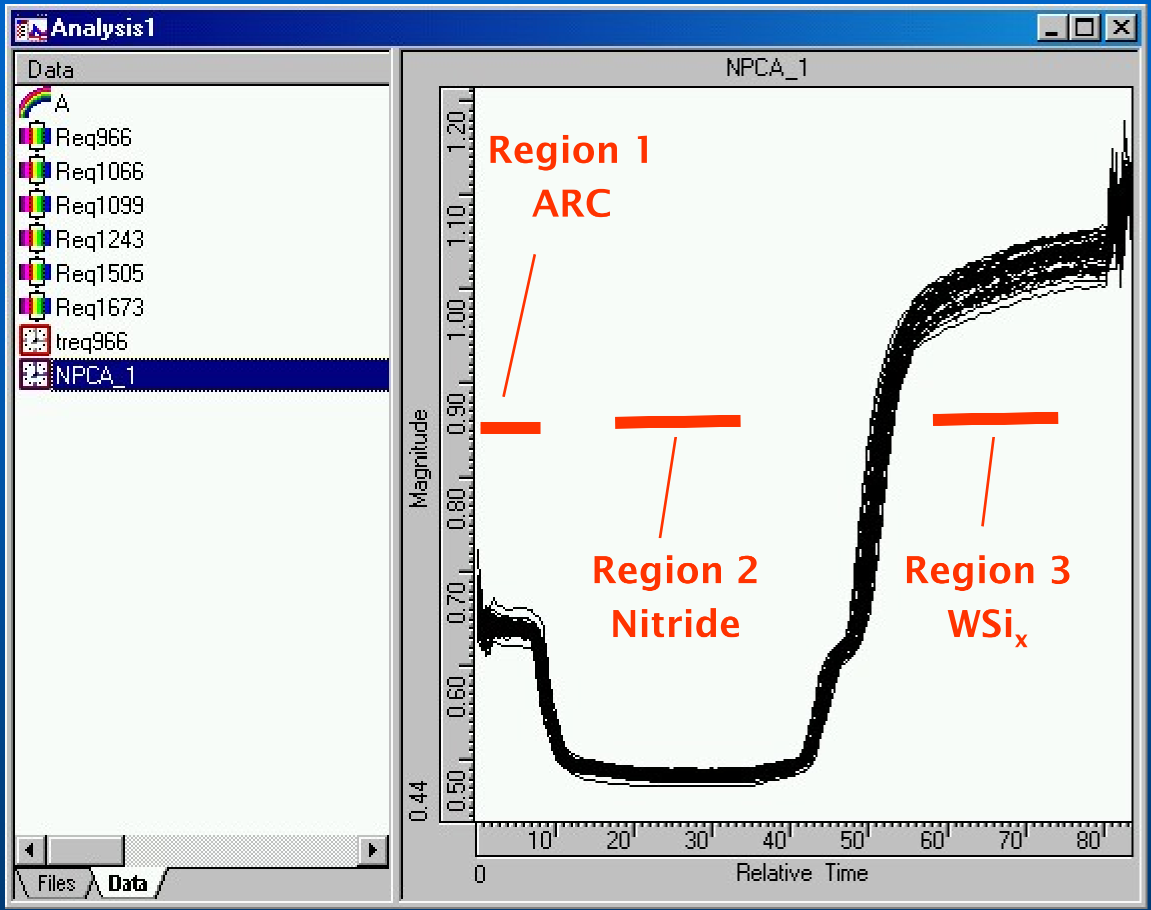


- Near-IR spectra normalized to intensity of spectra on 12/07
- Intensity decrease is nearly constant for all wavelengths

Results – Product Wafers

Near-IR spectra

NIR endpoint is stable with window clouding

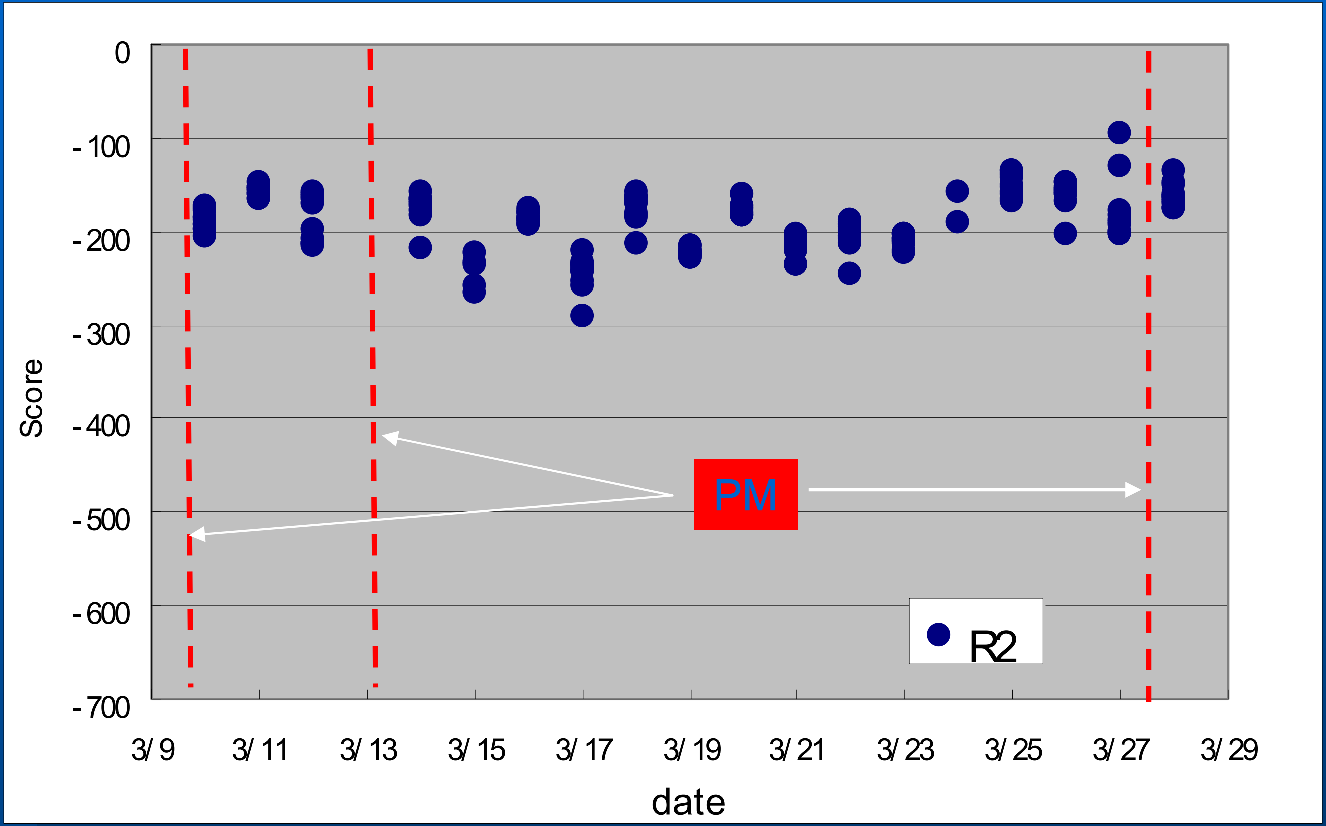


Endpoint trend with Neural-PCA™ data collected over two week period

Results – Product Wafers

NIR PCA Model: Region 2

PSI



- No monotonic increase or decrease between Periodic Maintenance (PM)
- Random variation is small compared to that of UV-visible PCA

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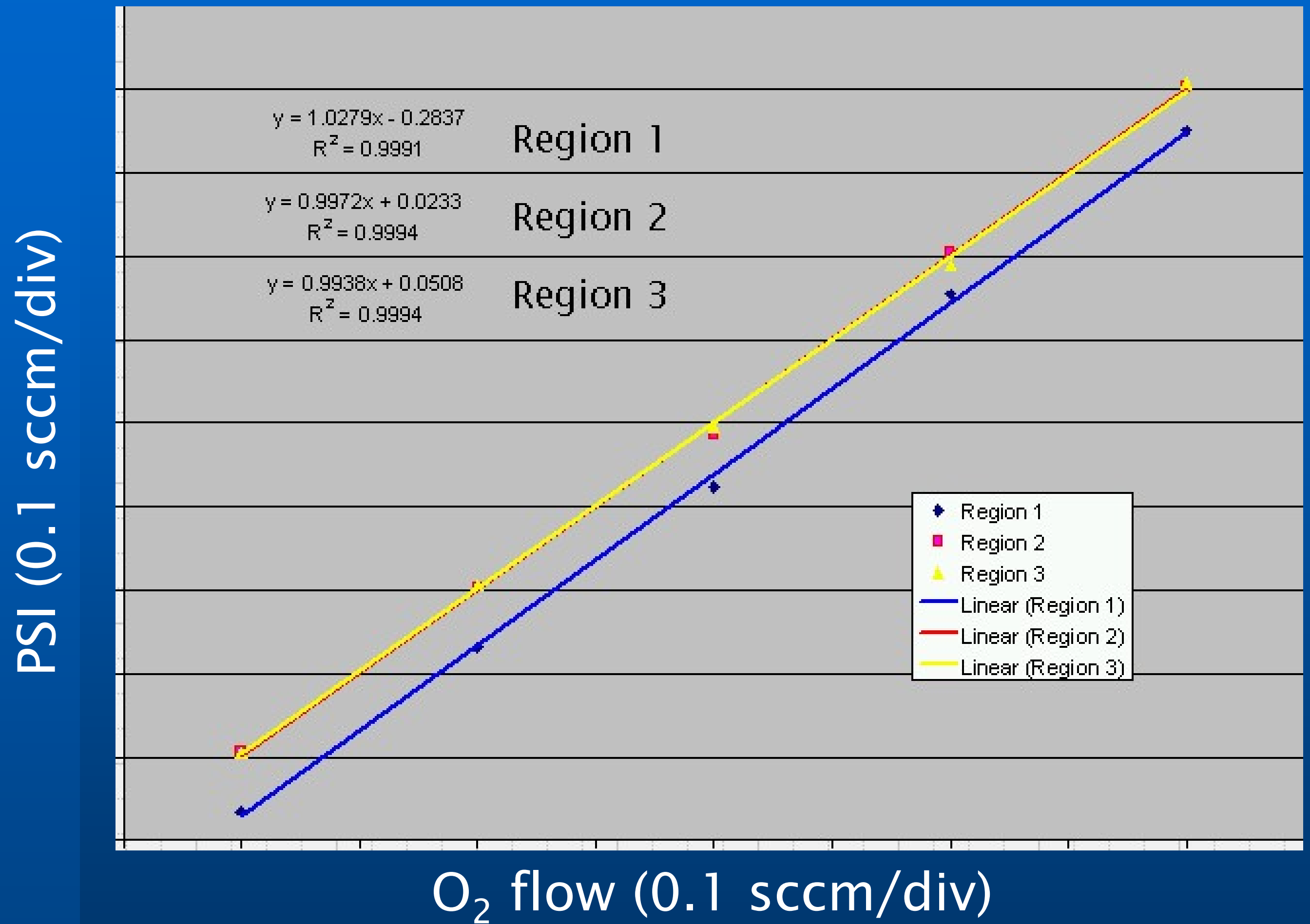
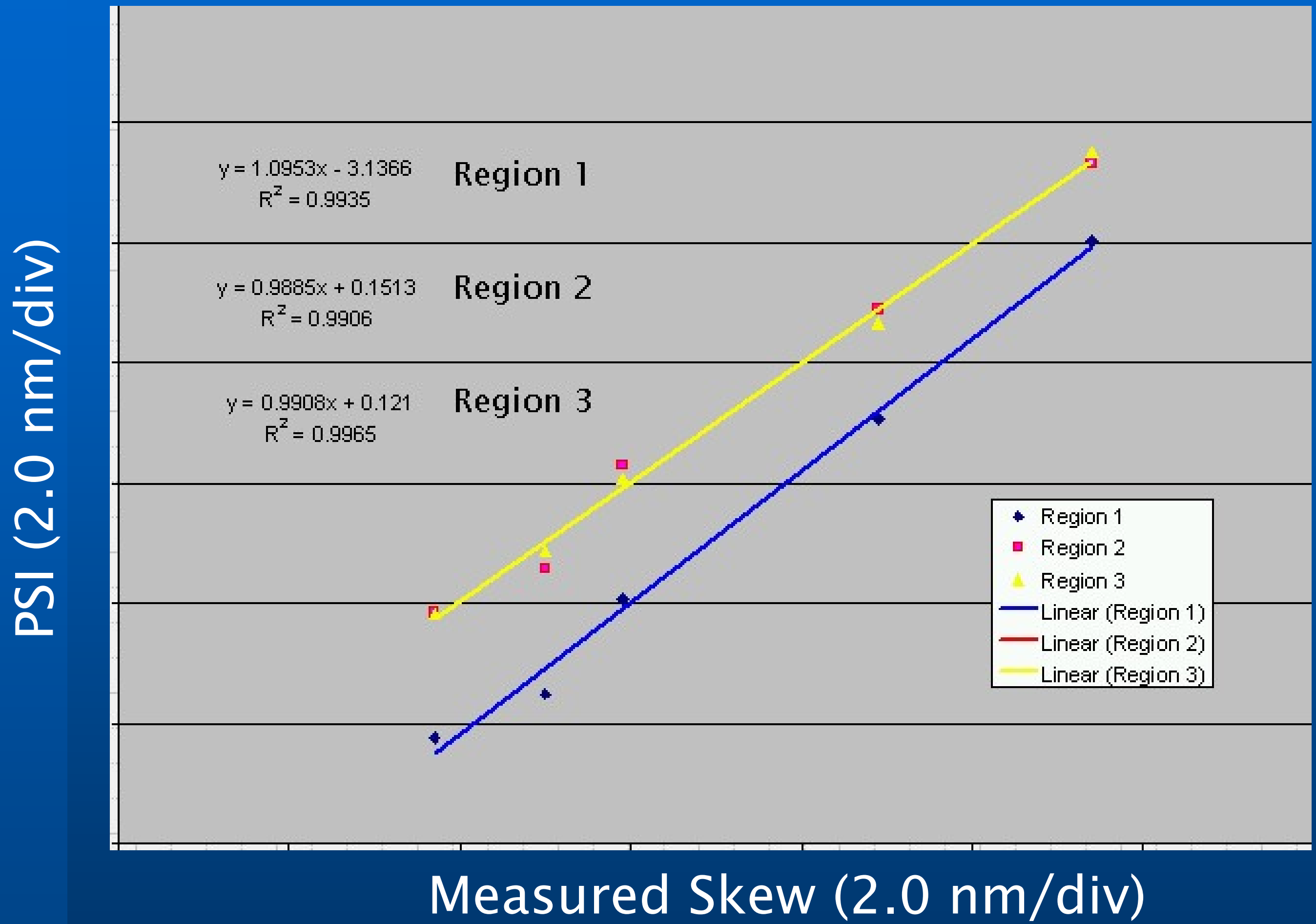
Results – Product Wafers



PLS Calibration with NIR spectra and the measured oxygen flow of the etched wafers

Results – Product Wafers



PLS Calibration with NIR spectra and the measured skew of the etched wafers

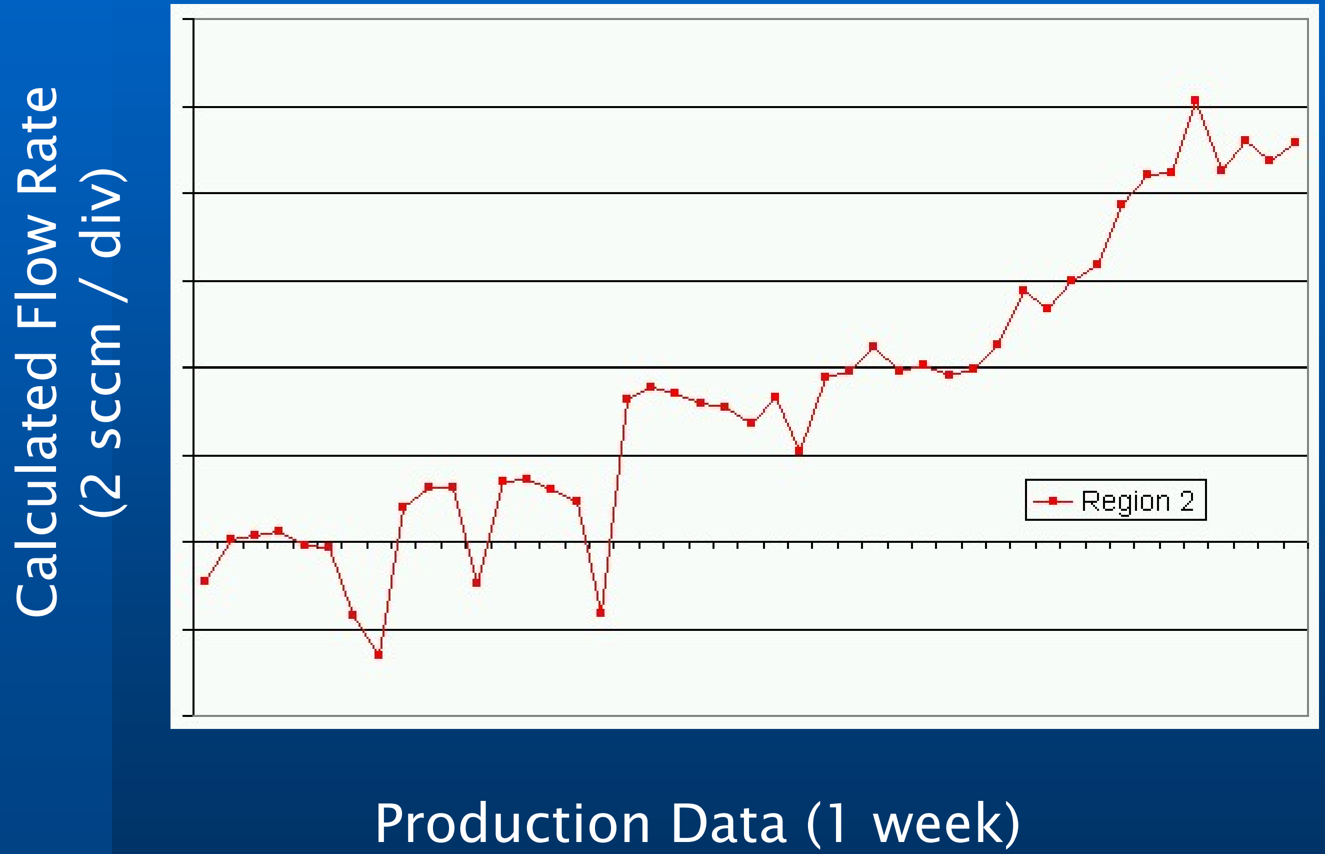
Results – Product Wafers

PLS Calibration - Region 2 – NIR spectra

Method	flow	skew
Std Dev	0.0003	0.012
Repeatability	3007	84.9
Response	0.995	12.2
Sensitivity	2991	1034

Results – Product Wafers

NIR PLS Calculation of O_2 Flow Rate



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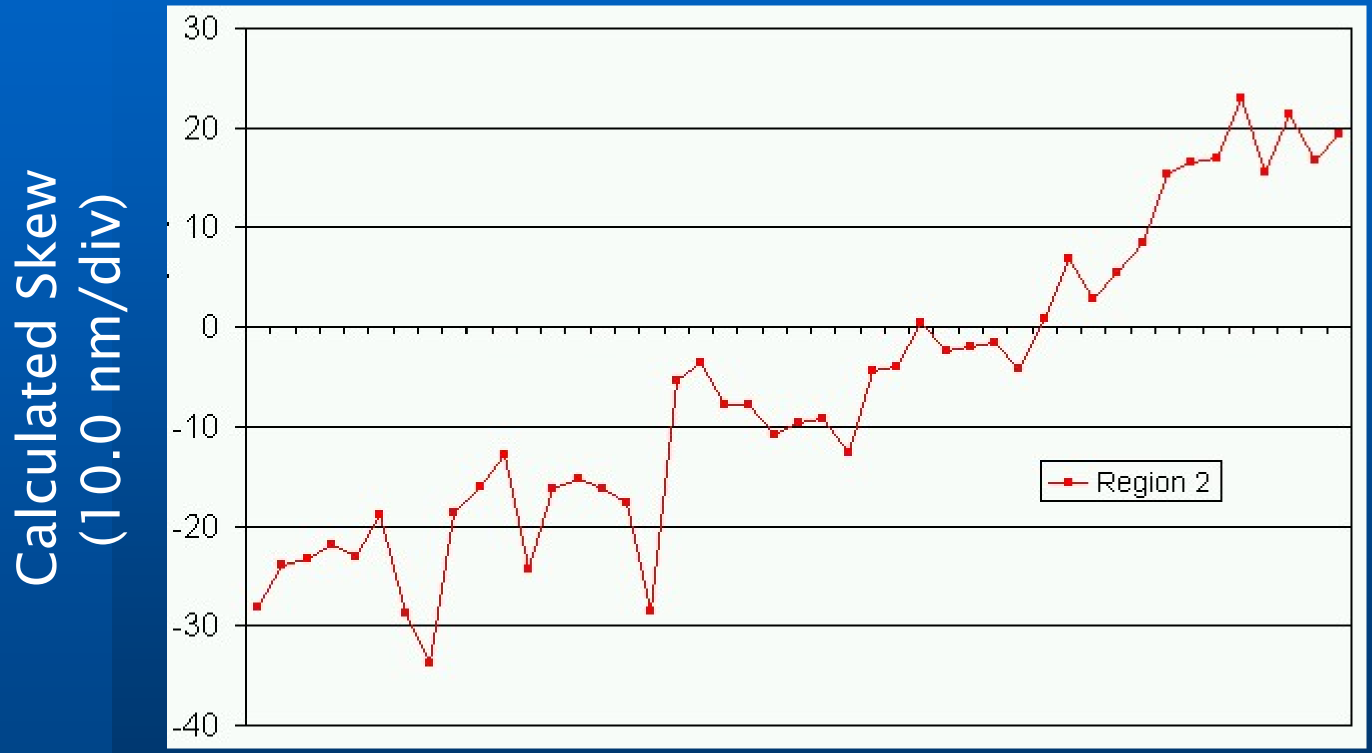
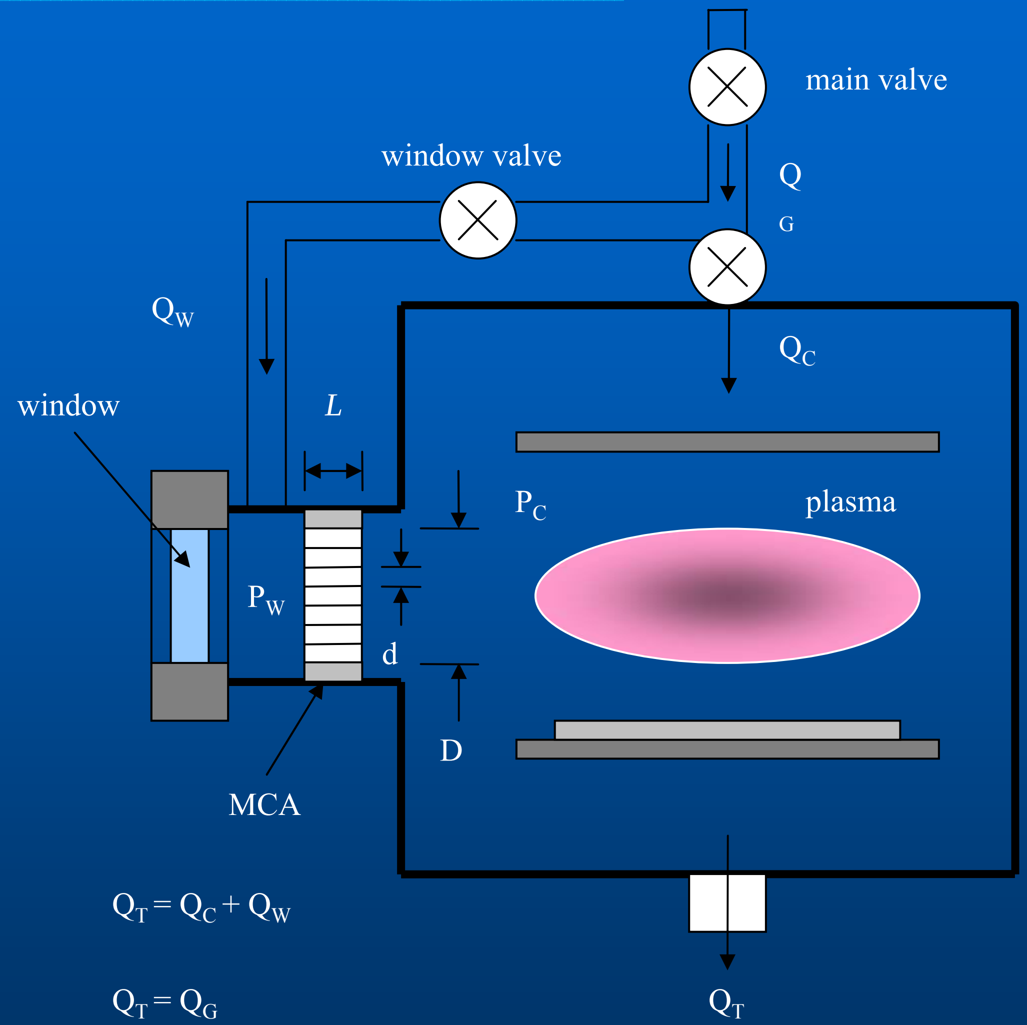
Results - Product Wafers

NIR PLS Calculation of Skew



Production Data (1 week)

Future Work: New Robust Window Design



$Q_T = Q_C + Q_W$

$Q_T = Q_G$

New method for window protection (patent pending)

Conclusions

- This method produces an effective PSI for fault detection of O_2 flow.
- Windows with clouding have greater transmission in the near-IR spectral region.
- Multi-channel arrays and heated windows will decrease clouding and improve transmission.
- Endpoint and multivariate techniques are facilitated in the NIR.
- NIR detection will have application with related chemistries, such as C_4F_6, C_4F_8, etc., which may produce fluorocarbon deposits on windows.

Optical Endpoint & Semiconductor Process Control since 1981

Acknowledgements

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